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Programm Photovoltaik Ausgabe 2011
Überblicksbericht, Liste der Projekte
Jahresberichte der Beauftragten 2010

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Titelbild:

Eine Vision wird Realität: Die Photovoltaik hebt ab ...

Im Jahr 2010 konnte das Forschungsprogramm Photovoltaik auf 25 Jahre Pioniergeist und Innovation in Forschung, Entwicklung und Umsetzung zurückblicken. Im Jubiläumsjahr wurde ein symbolhafter Meilenstein erreicht: Im Juli 2010 führte das Solarflugzeug Solar Impulse von Bertrand Piccard einen ersten Tag- und Nachtflug durch und blieb insgesamt 26 Stunden in der Luft. Modernste Technologien der Materialien, der Konstruktion, der Photovoltaik, des effizienten Energieeinsatzes, der Energiespeicherung und des Energiemanagements erlaubten diesen wichtigen Erfolg. Initiative, Pioniergeist, Risikobereitschaft und der feste Glaube an ein Ziel sind die menschlichen Attribute, welche die Grundlage dazu bilden. Das Beispiel zeigt stellvertretend für die gesamte Entwicklung der letzten 25 Jahre, wie Erfolge erzielt werden können (Quelle: www.solarimpulse.com).

BFE Forschungsprogramm Photovoltaik
Überblicksbericht 2010

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Einleitung

Die Photovoltaik ist sowohl wissenschaftlich-technisch wie industriell und marktbezogen eine viel diskutierte und sehr dynamische Technologie. Vor dem Hintergrund einer rasch wachsenden, global orientierten Industrie findet weltweit eine intensive Forschung statt, welche als Hauptziel die Kostenreduktion und die rasche Industrialisierung der Photovoltaik verfolgt. Dabei geht es einerseits um die anhaltende Weiterentwicklung der bestehenden Photovoltaik-Technologien sowie die Erforschung neuer Materialoptionen und Konzepte. Nebst dem Kerngebiet der verschiedenen Solarzellen-Technologien beinhaltet die Photovoltaikforschung auch technologiespezifische Themen auf der Systemebene, z. B. der Gebäudeintegration, der elektrischen Systemtechnik oder der Umweltindikatoren und des Recyclings. Immer häufiger bilden auch systemübergreifende Aspekte wie die Netzintegration, die Speicherung oder energetische Konzepte im Gebäude Themen der Forschung. Aufgrund des anhaltenden Marktwachstums werden neue Erkenntnisse und Resultate aus der Forschung möglichst rasch in die Industrie übergeführt.

Die Photovoltaik als möglicher wesentlicher Pfeiler einer nachhaltigen Stromversorgung hat in relevanten Szenarien weiter an Bedeutung gewonnen: Die im Jahr 2010 publizierte Photovoltaik-Roadmap der IEA [1] spricht bis 2050 von einem möglichen Beitrag von mehr als 10 % zur weltweiten Stromversorgung, ein Wert der von vielen Akteuren aus der Photovoltaik als untere Grenze angesehen wird. Nicht überall hat sich diese Meinung allerdings durchgesetzt, so dass die Photovoltaik und ihre Aussichten weiterhin Gegenstand der öffentlichen Diskussion sind.

Die Photovoltaikforschung in der Schweiz konnte im Jahr 2010 auf ihr 25-jähriges Bestehen als themenspezifische Forschung zurückblicken. In diesen 25 Jahren hat sich eine starke Schweizer Position in verschiedenen Gebieten der Photovoltaikforschung herausgebildet: Im Vordergrund stehen die Entwicklungen und Ergebnisse von mehreren Dünnschicht-Technologien, welche schon immer den Schwerpunkt der Schweizer Photovoltaikforschung bildeten. Ausgehend von Arbeiten an neuen Solarzellen-Konzepten wurden diese sukzessiv in die industrielle Umsetzung übergeführt. Heute findet nebst der Forschung an Instituten und Hochschulen auch seitens der Industrie eine intensive Technologieentwicklung statt, welche mittlerweile zu einer entlang der ganzen Wertschöpfung der Photovoltaik bedeutenden Schweizer Industrie geführt hat.

Laufende Aktivitäten in Forschung und Entwicklung sowie Projekte im Bereich von Pilot- und Demonstrationsanlagen umfassen im Berichtsjahr 2010 rund 70 Projekte, wobei alle der Programmleitung bekannten Projekte mit einer Förderung der öffentlichen Hand berücksichtigt sind. Nebst den durch das Bundesamt für Energie (BFE) geförderten Projekten und den Schwerpunkten einzelner Hochschulen und Forschungsinstitute spielen KTI- und EU-Projekte im Forschungsprogramm Photovoltaik eine tragende Rolle.

Das Schweizer Forschungsprogramm verfolgt in der Periode 2008–2011 die folgenden Ziele [2,3]:

- Senkung der Kosten der Solarzellen und -module;
- Steigerung des Wirkungsgrades (Solarzellen);
- Senkung des Material- und Energieeinsatzes;
- Vereinfachung und Standardisierung der elektrischen Systemtechnik; Steigerung der Lebensdauer und Zuverlässigkeit von Wechselrichtern;
- Erhöhung der Verfügbarkeit und der Vielfalt industrieller Produkte.

IEA-Klassifikation: 3.1.2 Photovoltaics

Schweizer Klassifikation: 2.1.2 Photovoltaik

Programmschwerpunkte

Das Forschungsprogramm Photovoltaik ist in folgende fünf Bereiche aufgeteilt (die in Klammern angegebene Klassifizierung bezieht sich auf die Liste der Projekte, Seite 11 ff.):

(1a-e) Solarzellen

Verschiedene materialspezifische Ansätze zu Dünnschichtsolarzellen stellen hier den wichtigsten Schwerpunkt dar (Silizium, Verbindungshalbleiter, Organische Materialien). Verstärkt werden Heteroübergänge zwischen Dünnschicht- und kristallinen Schichten untersucht. Organische und Polymersolarzellen als mögliche langfristige Technologieoptionen gewinnen an Bedeutung. Neu findet Grundlagenforschung auch an elektrochemisch abgeschiedenen Schichten statt.

(2a-e) Module und Gebäudeintegration

Das Gebiet der Solarmodule ist im Forschungsprogramm Photovoltaik eng mit der Anwendung der Gebäudeintegration verbunden. Im Vordergrund stehen Modultechnologien, welche mit den in der Schweiz entwickelten Solarzellen einhergehen.

(3) Elektrische Systemtechnik

Bei der elektrischen Systemtechnik, insbesondere bei Wechselrichtern, steht die Qualitätssicherung im Vordergrund, einschliesslich entsprechender Normen. Ein in Zukunft wichtiger werdendes Thema ist die Wechselwirkung mit dem elektrischen Netz und die Integration der Photovoltaik ins Netz.

(4) Begleitende Themen

Zum einen geht es hier um relevante technische und nicht technische Themen zur Marktentwicklung (z. B. Hilfsinstrumente, Monitoring, Umweltaspekte). Andererseits sind hier auch auf andere Energiethemen übergreifende Projekte (z. B. Gebäude, Mobilität, Speicherung) angesiedelt.

(5) Institutionelle internationale Zusammenarbeit

Sie erfolgt einerseits projektbezogen auf allen Gebieten und andererseits im Rahmen des Implementing Agreements Photovoltaic Power System Programme (PVPS) der Internationalen Energieagentur (IEA), der Europäischen Photovoltaik-Technologieplattform, der europäischen PV-ERA-Net-Kooperation (ERA: European Research Area), der neuen Solar Europe Industry Initiative (SEII) im Rahmen des SET-Plans und der Normen festlegenden Internationalen Elektrotechnischen Kommission (IEC).

Das Forschungsprogramm Photovoltaik setzt sich weiter zum Ziel, zu den einzelnen Teilbereichen Kompetenzzentren mit nationaler und internationaler Ausstrahlung zu fördern. Im Jahr 2010 sind dies das Photovoltaik-Labor (PV-Lab) an der Eidgenössische Technischen Hochschule Lausanne (EPFL) (Silizium-Dünnschicht-Solarzellen), das Institut of chemical sciences and engineering (ISIC) an der EPFL (Farbstoff-Solarzellen), die Empa (Verbindungshalbleiter- und organische Solarzellen), die Scuola universitaria professionale della Svizzera italiana (SUPSI, Solarmodule) und die Berner Fachhochschule HTI Burgdorf (elektrische Systemtechnik).

Rückblick und Bewertung 2010

Gemessen an der Anzahl laufender Projekte mit öffentlicher Finanzierung und der gesamthaft gemeldeten Forschungsprojekte [4] kann eine Verstärkung der Photovoltaik-Forschungsaktivitäten beobachtet werden. Allerdings ist diese Erhöhung in erster Linie auf Erfolge mit KTI- und EU-Projekten zurückzuführen und damit das Resultat früherer Forschungserfolge. Die zur spezifischen Förderung der Photovoltaik verfügbaren Mittel des BFE sind nach dem relativ guten Jahr 2009 im Jahr 2010 deutlich zurückgegangen. Diese Entwicklung ist insofern besorgniserregend, als die BFE-Mittel primär zur Wahrung des Kompetenzvorsprungs der beteiligten Institute auf ihren Spezialgebieten eingesetzt werden; diese vorlaufende Forschungsexzellenz ist massgebend für weitere Forschungsaktivitäten und -erfolge im Rahmen von KTI- und EU-Projekten.

Betrachtet man die Forschungsresultate insgesamt, so konnten zu verschiedenen Forschungsthemen auf den Gebieten der Dünnschicht-Solarzellen und der Module namhafte Fortschritte erzielt werden. Diese sind häufig auch Grundlage weitergehender Projekte in Zusammenarbeit mit der Industrie. Nebst der öffentlich geförderten Photovoltaikforschung haben die privaten Forschungsaufwendungen der Industrie deutlich zugenommen.

Ausblick 2011

Die Dekade 2011–2020 dürfte für die Photovoltaik weltweit eine kritische Zeit werden, welche massgebend über den mittelfristigen Erfolg dieser jungen Energietechnologie bestimmen wird. In diesem Jahrzehnt gilt es einerseits, die Kosten der Photovoltaik weiterhin soweit zu senken, dass eine aussichtsreiche Wettbewerbsfähigkeit mit anderen Energieträgern erreicht werden, und andererseits die Produktionskapazitäten weltweit soweit zu erhöhen, dass die Photovoltaik mittelfristig auch quantitativ die ihr vorhergesagte Rolle spielen kann. Die Schweiz befindet sich mit ihrer ausgezeichneten Forschung und ihrer massgebenden Industrie in der Photovoltaik in einer derzeit noch guten Ausgangslage.

Aus Schweizer Sicht gilt es deshalb, diesen Zeitraum optimal zu nutzen, um die Photovoltaikforschung als innovative Kompetenz-Grundlage der Schweizer Photovoltaikindustrie zu positionieren und in dieser Hinsicht weiter zu verstärken. Optimal wird dies mittels einer Stärkung der Forschung und der institutionellen Kapazitäten zur raschen Umsetzung von Forschung in die Industrie erreicht. Dahingehende Initiativen sollten so rasch wie möglich konkretisiert und auf eine mittelfristig feste Grundlage gestellt werden.

Highlights 2010

Forschung und Entwicklung auf dem Gebiet der kristallinen Solarzellen ist in der Schweiz weitgehend Sache der Industrie. Ein Grossteil der öffentlichen Photovoltaikforschung befasst sich mit neuen Solarzellen auf der Grundlage von Dünnschicht-Technologien. Die wesentlichen Technologieansätze betreffen Dünnschicht-Silizium (zur Hauptsache am PV-Lab der EPFL) und Dünnschicht-Verbindungshalbleiter CIGS und CdTe (Empa). Wachsende Tätigkeiten finden zudem auf dem Gebiet der organischen Solarzellen (Empa, ZHAW) statt. Auf der exploratorischen Ebene werden neue Solarzellen auf der Grundlage von sehr dünnen Absorberschichten erforscht.

Nebst aktuellen Resultaten aus den bedeutenden Arbeiten zu Dünnschichtsolarzellen auf der Grundlage von Silizium und der Verbindungshalbleiter CIGS werden im Folgenden neue Ergebnisse aus der Qualitätssicherung von Solarmodulen und Wechselrichtern eingehender dargestellt. Damit wird eine Übersicht der Fortschritte bei den wichtigsten Schweizer Photovoltaik-Kompetenzzentren angestrebt.

Figur 1: Neue PECVD Cluster-Depositionsanlage OCTOPUS am PV-Lab der EPFL (Bild PV-Lab).

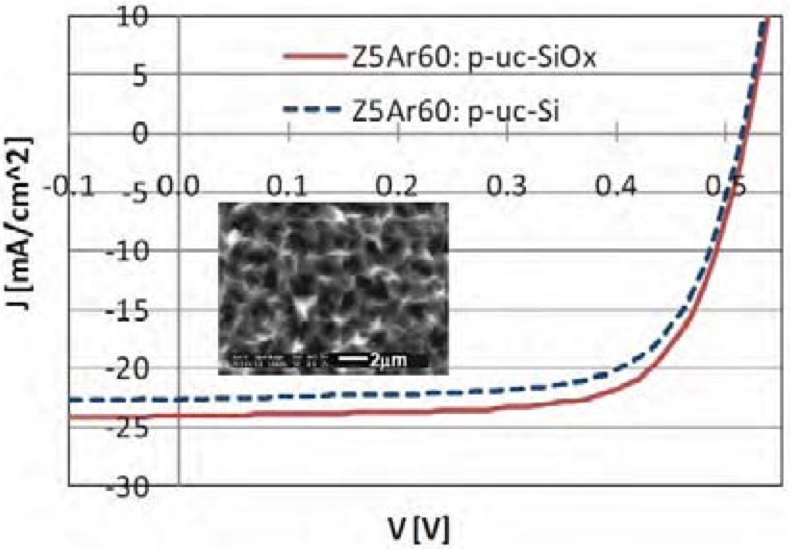
Dünnschicht Silizium – Spitzenresultate und Entwicklungen auf breiter Front

Auf dem Gebiet des Dünnschicht-Siliziums hat sich am PV-Lab der EPFL in Neuchâtel im Verlauf der Zeit ein Cluster von Projekten herausgebildet, welcher verschiedenste Materialvarianten und Prozessschritte beinhaltet: Zur Optimierung der Dünnschicht-Siliziumsolarzellen in ihren verschiedenen Ausprägungen stehen zahlreiche Parameter zur Verfügung. Nebst Art, Anzahl und Umfang der aktiven Schichten, welche zur Hauptsache aus amorphem und mikrokristallinem Silizium bestehen, spielen Dotierung, Fenster- und Zwischenschichten, Art der Deposition, usw. wichtige Rollen. Ziel der laufenden Optimierung und neuen Ansätze ist es letztlich, den Wirkungsgrad der Solarzellen zu erhöhen, also möglichst viel einfallendes Licht in der Solarzelle zu absorbieren und damit möglichst vollständig und für genügend lange Zeiträume nutzbare Ladungsträger zu erzeugen. Eine wachsende Rolle auf diesem Optimierungspfad spielen kontrollierte Strukturen und Schichten im Nanometerbereich. Entsprechend komplex ist der Weg zu verbesserten Solarzelleneigenschaften, welche auch noch den Anforderungen an grossflächige industrielle Prozesse gerecht werden müssen.

Am PV-Lab der EPFL finden eng verwandte Forschungsprojekte zu verschiedenen Fragestellungen rund um die Dünnschicht-Siliziumsolarzellen auf den Substraten Glas und Kunststoff sowie in Kombination zu kristallinen Siliziumsolarzellen (Heteroübergänge) statt. Die zu beantwortenden Forschungsfragen beinhalten das grundlegende Verständnis einzelner Prozesse und Schichten ebenso wie den Aufbau ganzer Solarzellen und neuerdings auch Kleinmodule. Die Übertragbarkeit der Forschungsergebnisse auf den industriellen Massstab bildet eine zentrale Aufgabe, bei welcher eine zunehmende Anzahl von Industrieunternehmen mit dem PV-Lab zusammenarbeitet. Damit wachsen auch die Anforderungen an eine leistungsfähige Labor-Infrastruktur, welche in der Lage sein muss, rasch reproduzierbare Resultate zu liefern.

Wichtige Arbeiten im Sinn der Kernkompetenz am PV-Lab finden im BFE-Projekt Silizium-Dünnschichtsolarzellen und -module zur weiteren Verbesserung der mikromorphen Solarzelle (Kombination aus amorphem und mikrokristallinem Silizium) statt. Fortschritte wurden im Berichtsjahr besonders mit verschiedenen Zwischen- und Fensterschichten erzielt. Dabei weisen nanokristalline Siliziumoxid-Zwischenschichten aufgrund ihrer tiefen Absorption, ihres tiefen Brechungsindexes und ihres einstellbaren Widerstandes Vorteile auf. p- und n-dotierte nanokristalline Siliziumoxid-Zwischenschichten konnten in Einfach-, Tandem- und Tripelzellen eingebaut werden, woraus eine verbesserte Lichtabsorption resultierte. Solarzellen mit diesen Zwischenschichten wurden mit optimierten Zinkoxid-Fensterschichten, stabileren Schichten aus amorphem Silizium, sowie verbesserten Schichten aus mikrokristallinem Silizium kombiniert. Damit konnten neue Rekordwerte des Wirkungsgrades von mikromorphen Solarzellen erzielt werden: 13,7 % Anfangswirkungsgrad und 11,5 % stabilisierter Wirkungsgrad. Strukturveränderungen in der Nanometer-Skala auf der Substratebene können für weitere Verbesserungen der Solarzelleneigenschaften verwendet werden. So konnte gezeigt werden, dass durch Ultraviolett-nanoimprint-Lithografie (UV-NIL) eine gute Lichteinkopplung erzeugt werden kann. Die Fortschritte auf dem Gebiet der mikromorphen Solarzellen auf Glassubstraten sind insbesondere für die Zusammenarbeit mit Oerlikon Solar relevant. Oerlikon Solar selbst hat ebenfalls einen neuen Wirkungsgrad-Rekord von 11,9 % publiziert.

Die nachgewiesenen Optimierungsmöglichkeiten durch die Erzeugung



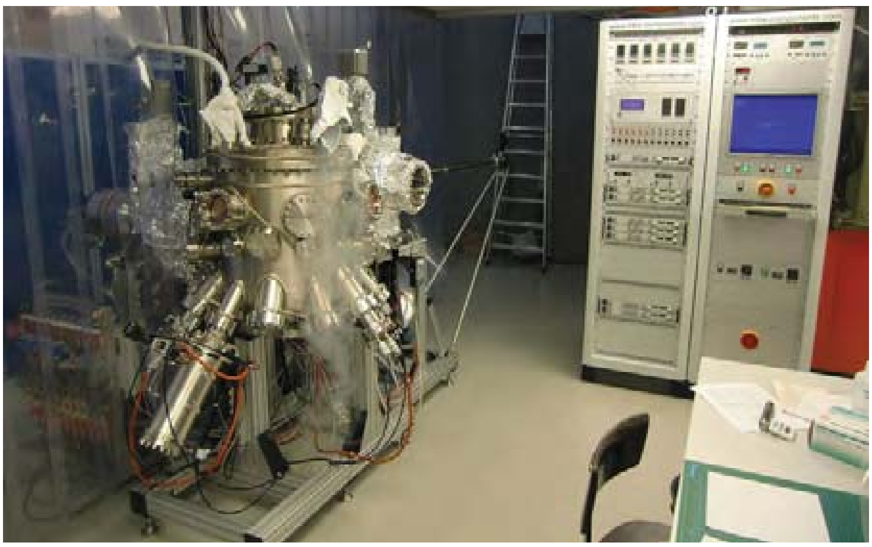
Figur 2: Vergleich der Strom-/Spannungskennlinien einer mikrokristallinen Solarzelle mit üblichem p-Typ µc-Si (blau) und der neuen p-Typ SiO_x-Schicht (rot). Die Rasterelektronenmikroskop-Aufnahme zeigt das Substrat mit einer geglätteten ZnO-Frontelektrode (Figur PV-Lab).

von Strukturen im Nanometerbereich stellen nicht triviale Anforderungen für deren Umsetzung im industriellen Massstab. Das EU-Projekt N2P (Nano to Production) befasst sich mit dieser Fragestellung und untersucht insbesondere die Möglichkeiten von Plasmaprozessen bei Atmosphärendruck. Im Vordergrund steht für das PV-Lab das Wachstum von strukturierten Zinnoxid-Schichten als leitende Oxidschicht (TCO).

Dünnschicht-Siliziumsolarzellen auf Kunststoffsubstraten bilden weiterhin ein Thema am PV-Lab der EPFL. Auch hier sind Materialeigenschaften und Lichteinfang die zentralen Fragestellungen, welche im neuen EU-Projekt Si-LIGHT untersucht werden. Nebst Fensterschichten auf der Grundlage von ITO (Indiumzinnoxid) wurden mikromorphe Tandemsolarzellen mit fast 10 % stabilisiertem Wirkungsgrad hergestellt. Diese Resultate sind auch für die Zusammenarbeit mit dem Schweizer Projektpartner VHF-Technologies relevant.

Als weitere Stossrichtung der Solarzellenforschung am PV-Lab kommt das bekannte Konzept eines Heteroübergangs zwischen verschiedenen Schichten aus kristallinem und amorphem bzw. mikrokristallinem Silizium zur Anwendung (HIT-Zelle). Mit diesem Ansatz lassen sich hoch effiziente Solarzellen herstellen. Zusammen mit dem Forschungspartner Roth & Rau wurde im Berichtsjahr in einer industriekompatiblen Anlage auf texturierten Wafern ein Wirkungsgrad von 20,7 % realisiert.

Die aufgeführten Beispiele zeigen deutlich auf, dass die Schweizer Forschung auf dem Gebiet der Dünnschicht-Siliziumsolarzellen international führende Ansätze verfolgt und entsprechende Ergebnisse erzielt. Aufgrund der bisher erreichten Position nimmt die Zusammenarbeit des PV-Lab mit weiteren Industriepartnern laufend zu und es kann eine Häufung von Photovoltaikunternehmen in der Westschweiz beobachtet werden.

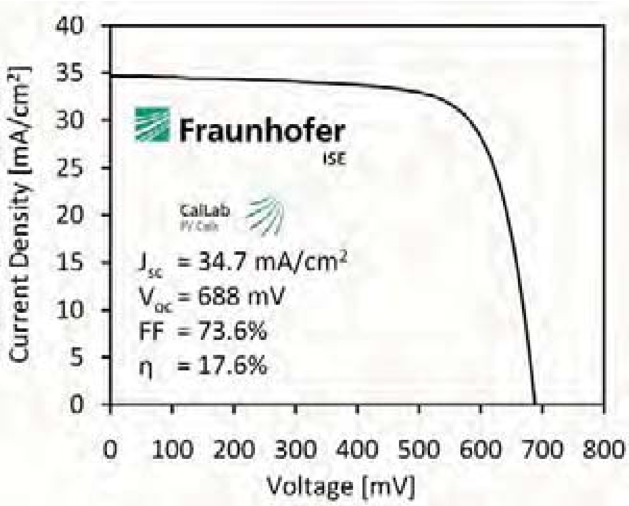


Figur 3: Neue Molekularstrahlepitaxie-Anlage zur Abscheidung von CIGS-Absorberschichten. Es können CIGS-Schichten in mehrstufigen Prozessen auf Substraten bis 10x10 cm^2 deponiert werden (Bild Empa).

Verbindungshalbleiter Solarzellen – Rekord Wirkungsgrade

Die wichtigsten Vertreter der Verbindungshalbleiter-Solarzellen sind CIGS und CdTe. Die letztgenannte Technologie hat sich in den vergangenen Jahren als weltweit führende Dünnschichttechnologie etabliert mit einer Produktion im GW-Massstab (First Solar) und als Referenzwert für die Wettbewerbsfähigkeit von Dünnschicht-Solarzellen. CIGS-Solarzellen werden erst in kleinerem Umfang produziert, bergen aber ein grosses Effizienzpotenzial. Nebst diesen Hauptvertretern der Verbindungshalbleiter-Solarzellen werden weltweit weitere Materialvarianten erforscht.

Mit dem Umzug von der ETHZ an die Empa hat sich das Labor für Dünne Schichten und Photovoltaik als leistungsfähige Forschungseinheit etabliert. Im Berichtsjahr wurde die Laborinfrastruktur deutlich ausgebaut, um den Anforderungen angewandter Fragestellungen besser gerecht werden zu können. Das Labor arbeitet im Rahmen von BFE-, EU-, KTI- und weiteren Projekten an unterschiedlichen Fragestellungen zu CIGS-Solarzellen. Dabei interessieren auch bei dieser Technologie die Materialeigenschaften und Depositionsprozesse (sowohl unter Vakuum als auch bei Atmosphärendruck), die notwendigen Pufferschichten und die Substratwahl. Von speziellem Interesse



Figur 4: Strom-/Spannungskennlinie und photovoltaische Parameter der CIGS-Solarzelle auf Polyimid mit dem Rekordwirkungsgrad von 17,6 %, unabhängig gemessen durch das Fraunhofer Institut für Solare Energiesysteme (ISE) in Freiburg, Deutschland (Figur Empa).

Figur 5: Zwei der drei am PV-Modultestzentrum des ISAAC in Lamone installierte Klimakammern für Klimatests von Solarmodulen. Die Abwärme der Klimakammern wird im Gebäude energetisch genutzt (Bild ISAAC).

sind flexible Solarzellen auf Kunststoffsubstraten. Hier erfolgt eine intensive Zusammenarbeit mit dem Spin-off-Unternehmen FLISOM.

So werden im BFE-Projekt FEBULAS mit dem Ziel Cd-freier Solarzellen die Möglichkeiten von und die Solarzelleneigenschaften mit alternativen Pufferschichten zu CdS untersucht. Mit einer Pufferschicht auf der Grundlage von In_2S_3 wurde ein Wirkungsgrad von 12,6 % erreicht. Demgegenüber wurde als Bestandteil des EU-Projektes HIPO-CIGS mit CdS ein neuer Rekordwirkungsgrad für flexible Solarzellen von 17,6 % (Solarzelle) und 12,1 % (Kleinmodul) erzielt. Damit konnte gezeigt werden, dass auch für flexible Solarzellen hohe Wirkungsgrade möglich sind.

Als kostentreibender Faktor gelten die bei CIGS Solarzellen notwendigen Ausgangsmaterialien und deren Depositionsprozesse (z. B. Verdampfen, Molekularstrahlepitaxie MBE). Im BFE-Projekt IMPUCIS wird in Zusammenarbeit mit dem belgischen Industriepartner Umicore der Einfluss von unterschiedlichen Materialreinheiten untersucht. Im Berichtsjahr wurde eine neue leistungsfähige Molekularstrahlepitaxie-Anlage aufgebaut. Es konnte gezeigt werden, dass auch mit Ausgangsmaterialien geringerer Reinheit auf Glas CIGS-Wirkungsgrade von 16 % erreicht werden können, was in der Grössenordnung von CIGS-Solarzellen mit reinerem Ausgangsmaterial liegt.

Als Alternative zu den aufwändigen Verfahren zur Herstellung von CIGS Solarzellen mittels Hochvakuumprozessen werden die Möglichkeiten von vakuumfreien Prozessen untersucht. Grundlegende Arbeiten zu diesem Ansatz erfolgten in früheren KTI- und BFE-Projekten und werden derzeit im EU-Projekt NOVA-CI(G)S weiterverfolgt. Dies ist ein weiteres Beispiel dafür, wie Forschungsarbeiten mit Unterstützung des BFE zu grösseren Folgeprojekten im internationalen Umfeld führen können. Die ersten Projektergebnisse betreffen die reproduzierbare Deposition und Aktivierung der einzelnen Schichten.

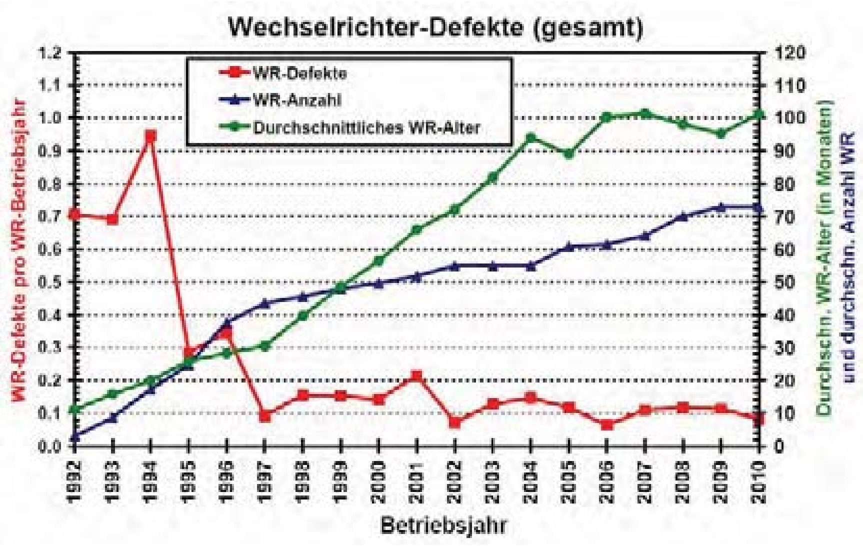
Weitere Projekte befassen sich mit der Kontaktierung von Dünnschicht-Solarzellen sowie mit CdTe-Solarzellen. Insgesamt zeigen die aufgeführten Projekte und Ergebnisse, dass das Labor für Dünne Schichten und Photovoltaik an der Empa auf seinem Gebiet zu den führenden Forschungsgruppen in Europa zählt. Dies ist nebst dem wissenschaftlichen Erfolg auch wichtig in Bezug auf die weitere industrielle Entwicklung der Verbindungshalbleiter-Solarzellen. Während CdTe-Solarzellen bereits im grossen Massstab hergestellt werden, steht die industrielle Entfaltung der CIGS-Solarzellen erst am Anfang. Aufgrund der bei dieser Technologie möglichen hohen Wirkungsgrade kann dies für die Zukunft ebenfalls eine viel versprechende Option werden.

Qualitätssicherung von Solarmodulen und Wechselrichtern

Möglichst gute Eigenschaften von Solarzellen und -modulen, insbesondere was den Wirkungsgrad anbetrifft, sind ein wichtiges Ziel der gesamten Photovoltaikforschung. Erst das vollständige System und dessen über viele Jahre zuverlässiger Betrieb entscheiden aber letztlich darüber, ob eine Technologie insgesamt als erfolgreich eingestuft werden kann. Deshalb kommt der Qualitätssicherung in der Produktion der Komponenten und beim Betrieb der Anlagen eine Schlüsselrolle zu, die zuweilen zu Unrecht etwas vergessen geht. In der Schweiz hat die Qualitätssicherung seit vielen Jahren ihren festen Stellenwert in der Forschungslandschaft, mit dem Ziel, gute Voraussetzungen für die Zuverlässigkeit und Lebensdauer der Komponenten und Anlagen zu schaffen.

Die Prüfung von Solarmodulen und deren Verhalten bei unterschiedlichen Betriebsbedingungen ist die Kernkompetenz des ISAAC an der SUPSI. Komplementär dazu wird an der Fachhochschule in Burgdorf das Verhalten von Wechselrichtern und Systemen untersucht. Beide Institute betreiben Prüflabors, in welchen Solarmodule oder Wechselrichter gemäss gängigen Normen geprüft werden können.

Das ISAAC betreibt seit vielen Jahren an kommerziell verfügbaren So-



Figur 6: Wechselrichterdefekte pro Wechselrichter-Betriebsjahr und durchschnittliche Anzahl von der Berner Fachhochschule in Burgdorf überwachter Wechselrichter in den Jahren 1992–2010 (Figur BFH).

larmodulen Messungen unter realen Betriebsbedingungen. Das Verhalten der Solarmodule wird jeweils über längere Zeit verfolgt. Im Jahr 2001 erfolgte eine erste Akkreditierung gemäss ISO 17025 für STC-Messungen der Strom-/Spannungskennlinien von kristallinen Solarmodulen. Später kam die Bestimmung des Temperaturkoeffizienten dazu. Seit 2009 wurde die Laborinfrastruktur aufgrund der wachsenden Nachfrage für zertifizierte Modulmessungen bedeutend erweitert und im Berichtsjahr 2010 konnte das neue Modultestzentrum eingeweiht werden. Dieses Prüflabor ist akkreditiert, um 25 verschiedene Tests gemäss den IEC Normen IEC 12615, IEC 61646 und IEC 61730 durchzuführen. Diese Akkreditierung gilt sowohl für kristalline Solarmodule als auch für Dünnschicht-Module mit einem Übergang (single-junction).

Nebst den Anlagen für die standardisierten Messungen gemäss IEC-Normen betreibt das ISAAC verschiedene weitere Messapparaturen, insbesondere in Hinsicht auf die Bestimmung des Energieertrags von Solarmodulen (energy rating). Diese Messungen erfolgen mit verschiedenen Strahlungssimulatoren. Zur Bestimmung der spektralen Strahlung sind spektral aufgelöste Messungen notwendig, was am ISAAC mittels drei verschiedenen Spektroradiometern geschieht. Mit einem speziellen Messaufbau kann weiter die Gleichmässigkeit der Einstrahlung in der Fläche gemessen werden.

Im Berichtsjahr wurde der 11. Messzyklus an 15 verschiedenen Solarmodulen abgeschlossen. Dabei wurden 13 verschiedene Modultypen aus mono- und multikristallinem Silizium, amorphem und mikromorphem Silizium sowie CIS und CIGS untersucht und verglichen. Die kristallinen Module zeigen bezüglich dem Energieertrag in kWh/W_p im Allgemeinen enge Toleranzen auf. Dagegen zeigen Dünnschicht-Module eine grössere Verteilung der Resultate. Diese Schwierigkeit, Dünnschicht-Solarmodule reproduzierbar zu messen ist aus früheren Projekten bekannt, kann aber zum Teil auch durch Effekte aus der Produktion hervorgerufen sein. Im Sommer 2010 wurde ein weiterer Messzyklus mit Schwerpunkt auf Dünnschicht-Solarmodulen begonnen.

Der Aufbau und die Akkreditierung des neuen Modultestzentrums konnte im engen Zeitrahmen von rund acht Monaten abgeschlossen werden. Seither wurden im ersten Betriebsjahr 32 zertifizierte Messungen durchgeführt. Pro Jahr sollten in Zukunft 40 Zertifizierungen durchgeführt werden können. Da das Prüfzentrum nicht nur einen Dienstleistungsbetrieb anstrebt, sind bis zu 20 % der Kapazität für Forschungszwecke reserviert.

Das Photovoltaik-Labor an der Fachhochschule in Burgdorf führt unter Benutzung der selbst gebauten PV-Simulatoren Tests an Wechselrichtern bis 100 kW gemäss prEN50530 durch. Im Berichtsjahr wurde ein Resonanzkreis entwickelt, welcher bei grösseren Wechselrichtern bis 100 kW neu Inselbetriebstests nach VDE 126-1-1 und IEC 62116 ermöglicht.

Aufgrund von Langzeitmessungen an 73 Photovoltaik-Anlagen, welche teilweise bis auf das Jahr 1992 zurückgehen, konnten die Langzeit-Erfahrungen mit diesen Anlagen fortgesetzt werden. Dabei konnte die Wechselrichter-Ausfallstatistik um ein weiteres Jahr verlängert und stetige Verbesserungen mit den neueren Modellen festgestellt werden. Es hat sich ein Wert von 0,1 Wechselrichterdefekten pro Betriebsjahr eingependelt.

Im Sommer 2010 erschienen vermehrt Berichte über die mögliche Gefährdung der Feuerwehr durch Photovoltaik-Anlagen bei Brandfällen. Es wurde gar behauptet, dass bei solchen Anlagen bereits durch nächtliches Restlicht (z. B. bei Vollmond) lebensgefährliche Spannungen aufträten. Dies ist übertrieben und basiert auf mangelnder Kenntnis der Eigenschaften von Photovoltaik-Anlagen und der Gefährdung des Menschen durch die darin auftretenden Gleichströme. Durch Markierung der Gebäude mit Photovoltaik-Anlagen und Ausbildung der Feuerwehrkader sollte im Brandfall vor Ort eine sinnvolle Beurteilung der Gefahr möglich sein, so dass ein Rettungs- und Löscheinsatz durchführbar ist. Aufgrund dieser Ausgangslage wurde das Problem näher untersucht und erste Messungen durchgeführt. Insbesondere wurden unter Mitwirkung der Feuerwehr Burgdorf nächtliche Kennlinienmessungen an Teilgeneratoren von 5 kW und 21 kW der PV-Testanlage in Burgdorf durchgeführt.

Die hier beschriebenen Erfahrungen in Bezug auf die Messung relevanter Parameter von Solarmodulen, Wechselrichtern und ganzer Photovoltaik-Anlagen belegen die hohen und praxisnahen Kompetenzen, welche an den Forschungslabors der Fachhochschulen vorhanden sind und dadurch einen sicheren, zuverlässigen und langlebigen Betrieb von Photovoltaik-Anlagen begünstigen. Ausserdem tragen diese Fachhochschulen eine wichtige Verantwortung in der Ausbildung von Fachleuten.

Nationale Zusammenarbeit

Im Berichtsjahr wurde die vielfältige nationale Zusammenarbeit in verschiedenen, zum Teil übergreifenden Projekten weiter gepflegt. Damit findet innerhalb der Schweizer Photovoltaik-Gemeinschaft aus Forschung, Industrie und Anwendung ein reger Austausch statt. Die Zusammenarbeit mit Industrieunternehmen konnte deutlich intensiviert werden, sowohl in neuen Projekten mit der KTI als auch in der Form von direkten Mandaten der Industrie an ausgewählte Forschungsinstitute. Auf Programmebene wurde die Zusammenarbeit mit vielen Stellen des Bundes, der Kantone und der Elektrizitätswirtschaft weiter gepflegt.

Im Februar 2010 fand in Winterthur die 8. Nationale Photovoltaik-Tagung [5] statt, welcher der bisher grösste Erfolg beschieden war: Mehr als 450 Teilnehmer belegen das wachsende Interesse breiter Kreise an der Photovoltaik. Die Tagung folgte dem bewährten Ansatz einer Mischung aus marktrelevanten Informationen, technologischen Fortschritten und Ausblicken in die Zukunft. Von besonderem Interesse waren die ersten Erfahrungen mit der kostendeckenden Einspeisevergütung (KEV). Die begleitende Ausstellung umfasste wissenschaftliche Poster, industrielle Produkte und Dienstleistungen.

Im Juni 2010 fand unter dem Schirm des IEA PVPS Programms in Montreux die 5. Photovoltaic Executive Conference [6] statt, welche primär den Photovoltaikaspekten aus Sicht der Elektrizitätswirtschaft gewidmet war. An der überschaubaren Konferenz mit Teilnahme ausschliesslich auf Einladung nahmen ca. 80 Experten und Entscheidungsträger aus der ganzen Welt teil und tauschten Erfahrungen und Ansichten aus. Das Echo der Teilnehmer nach dieser Konferenz war sehr positiv.

Im November fand zudem noch der 2. Swiss Photovoltaic Summit [7] statt, welcher ganz im Zeichen des neu lancierten Masterplans Cleantech stand. Dieser wichtige Anlass führte die Entscheidungsträger aus Politik, Behörden, Photovoltaik Forschung und Industrie zusammen. Als konkretes Ergebnis erfolgte der Auftrag eines Masterplans Photovoltaik 2020, welcher bis Mitte 2011 ausgearbeitet werden soll.

Internationale Zusammenarbeit

Die institutionelle Zusammenarbeit innerhalb der IEA, der IEC und den Europäischen Netzwerkprojekten wurde im Berichtsjahr kontinuierlich fortgesetzt. Auf der Projektebene konnte die Zusammenarbeit innerhalb der EU in bestehenden und neuen Projekten sehr erfolgreich fortgesetzt werden. Im Jahr 2010 waren es rund 25 Projekte im 7. Rahmenforschungsprogramm der EU.

Die Beteiligung am Photovoltaikprogramm der IEA (IEA PVPS) wurde im Berichtsjahr fortgesetzt, sowohl auf der Projektebene als auch im Executive Committee (ExCo).

Die Firma Nova Energie vertritt die Schweiz in Task 1 des Implementing Agreements (IA) PVPS der IEA, welcher allgemeine Informationsaktivitäten zur Aufgabe hat. Im Berichtsjahr wurde ein weiterer nationaler Bericht über die Photovoltaik in der Schweiz bis 2009 [8] ausgearbeitet. Auf dieser Grundlage wurde die 15. Ausgabe des jährlichen internationalen Berichtes (Trends Report) über die Marktentwicklung der Photovoltaik in den IEA-Ländern erstellt [9].

Im Rahmen der interdepartementalen (SECO, DEZA, BAFU, BFE) Plattform REPIC zur Förderung der erneuerbaren Energien und der Energieeffizienz in der internationalen Zusammenarbeit [10] leistet das Ingenieurbüro Entec den Schweizer Beitrag zum IA PVPS Task 9 über die Photovoltaik-Entwicklungszusammenarbeit. Dieses Projekt befasst sich mit der nachhaltigen Verbreitung der Photovoltaik in Entwicklungsländern und thematisiert auch Aspekte der solaren Wasserversorgung.

ESU Services vertritt die Schweiz im IA PVPS Task 12 zu Umwelt-, Sicherheits- und Gesundheitsaspekten der Photovoltaik. In diesem Projekt sollen industriell möglichst aktuelle, relevante und international abgeglichene Informationen zu diesem bedeutenden Thema aufgearbeitet und publiziert werden.

Im Berichtsjahr haben zwei neue Tasks im IA PVPS ihre Arbeiten aufgenommen: Task 13 zu Performance und Zuverlässigkeit von Photovoltaik-Anlagen sowie Task 14 zur hohen Penetration von PV Anlagen in elektrischen Netzen.

Das Unternehmen Meteotest und die Groupe Energie an der Universität Genf erbringen zusammen den Schweizer Beitrag zum Task 36 Solar resource knowledge management. Task 36 ist Bestandteil des IA Solare Wärme und Kälte (SHC) der IEA, inhaltlich ist es jedoch für alle Solartechnologien relevant. Dementsprechend erfolgt eine Zusammenarbeit mit den weiteren IA zur Solarenergie (IA PVPS und IA SolarPACES). In diesem Projekt wird die Qualität verschiedener Strahlungsmodelle und daraus abgeleiteter Produkte verglichen und optimiert.

Ähnlich erfolgt im Task 41 Solar Energy and Architecture des IA SHC eine Mitwirkung der Schweiz durch die HSLU (CCTP) und das ISAAC an der SUPSI. Auch hier finden Photovoltaik-relevante Aktivitäten statt.

Swissolar vertritt die Schweiz im TC 82 der IEC zu Photovoltaik Normen.

Die Beteiligung am EU-Projekt PV-ERA-Net, welches Programmkoordinationsstellen und verantwortliche Ministerien unter dem ERA-Net-Schema zusammengeführt hatte, wurde im Berichtsjahr von den beteiligten Ländern als selbst getragenes Netzwerk weiterverfolgt [11]. Das entsprechende Sekretariat ist in der Schweiz angesiedelt.

Die Schweiz ist in der Europäischen Photovoltaik-Technologie-Plattform sowohl im Steuerungsausschuss wie in der Mirror Group vertreten [12]. Im Rahmen des von der Europäischen Kommission vorgeschlagenen Strategic Energy Technology Plan (SET Plan) wurde die Solar Europe Industry Initiative lanciert. Die Arbeiten im Rahmen dieser Initiative müssen noch konkretere Formen annehmen.

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Laufende und im Berichtsjahr abgeschlossene Projekte

(* IEA-Klassifikation)

NEW PROCESSES AND DEVICE STRUCTURES FOR THE FABRICATION OF HIGH EFFICIENCY THIN FILM SILICON PHOTOVOLTAIC MODULES

R+D (1a) 3.1.2*

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	BFE
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2007–2011

Abstract: New processes and device structures for the fabrication of high efficiency thin film silicon photovoltaic modules. Focus is on layers with new or better properties, on improved processes, on improved devices and on enhanced cells and modules reliability.

A NEW LOW ION ENERGY BOMBARDMENT PECVD REACTOR FOR THE DEPOSITION OF THIN FILM SILICON FOR SOLAR CELL APPLICATIONS.

R+D (1a) 3.1.2

Lead:	EPFL CRPP		Funding:	KTI
Contact:	Hollenstein Christoph	christophe.hollenstein@epfl.ch	Period:	2009–2012

Abstract: A novel electrode configuration is proposed for improved plasma-enhanced chemical vapour deposition of films such as amorphous silicon and micro-crystalline silicon.

FLEXIBLE PRODUCTION TECHNOLOGIES AND EQUIPMENT BASED ON ATMOSPHERIC PRESSURE PLASMA PROCESSING FOR 3D NANO STRUCTURED SURFACES (N2P)

R+D (1a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	SBF/EU
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2008–2012

Abstract: The overall objective of the project "N2P" (Nano to Production) is to develop and substantially enhance the position of Europe in the science, application and production technologies of surface 3D nano-structuring.

IMPROVED MATERIAL QUALITY AND LIGHT TRAPPING IN THIN FILM SILICON SOLAR CELLS (SILOCON_LIGHT)

R+D (1a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	SBF/EU
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2010–2012

Abstract: The project Si-Light is devoted to the investigation of n-i-p solar cells on flexible substrates with focus on material quality, interface properties, and light management.

INTERFACE TEXTURING FOR LIGHT TRAPPING IN SOLAR CELLS

R+D (1a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	SNF
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2009–2011

Abstract: The project is devoted to a fundamental understanding of the light trapping process in solar cells.

HIGH-EF: LARGE GRAINED, LOW STRESS MULTI-CRYSTALLINE SILICON THIN FILM SOLAR CELLS ON GLASS

R+D (1a) 3.1.2

Lead:	EMPA Thun		Funding:	SBF/EU
Contact:	Michler Johann	johann.michler@empa.ch	Period:	2008–2010

Abstract: The objective of the HIGH-EF project is to provide the silicon thin film photovoltaic (PV) industry with a process allowing high solar cell efficiencies (>10%) by large grains in the material at competitive production costs.

ZWEIDIMENSIONALE NANOSTRUKTUREN FÜR SILIZIUM-SOLARZELLEN

R+D (1a) 3.1.2

Lead:	PSI Paul Scherrer Institut		Funding:	BFE
Contact:	Gobrecht Jens	jens.gobrecht@psi.ch	Period:	2008–2012

Abstract: The main goal of the project is the development of efficient numerical methods to solve the Maxwell equations in order to calculate the optical properties of two-dimensional periodic grating structures rigorously. The structures shall be optimized for broad-band absorption of both polarizations in thin films. This optimization should take into account the experimental requirements and limitations. Prototype structures will be fabricated with e-beam lithography by the Laboratory for Micro- and Nanotechnology at PSI.

ALL-INORGANIC NANO-ROD BASED THIN-FILM SOLARCELLS ON GLASS (ROD-SOL)

R+D (1a) 3.1.2

Lead:	EMPA Thun		Funding:	SBF/EU
Contact:	Michler Johann	johann.michler@empa.ch	Period:	2009–2011

Abstract: The ROD-SOL project aims at the synthesis of Si nano-rods, densely packed at sufficiently large diameters (few 100 nm's) and lengths (>1 µm) directly on cheap substrates like glass or flexible metal foils.

HIGH EFFICIENCY THIN-FILM PASSIVATED SILICON SOLAR CELLS AND MODULES – THIFIC: THIN FILM ON CRYSTALLINE SI

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	Elektrizitätswerk
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2007–2011

Abstract: The THIFIC project aims at developing a new kind of ultra-high efficiency (20-22%) solar cells by depositing very thin silicon layers of amorphous and/or microcrystalline silicon on top of silicon wafers.

ULTRA-HIGH CONDUCTIVITY METALLIZATION PASTES FOR HETEROJUNCTION SOLAR CELLS (TCOC)

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	KTI
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2009–2011

Abstract: The TCOC project aims at developing nano-enabled low temperature curable silver pastes exhibiting very low resistivity compatible with high efficiency heterojunction solar cells (HJC).

ELECTROPLATED FRONT GRID FOR CRYSTALLINE SI HETERO JUNCTION SOLAR CELL

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	KTI
Contact:	Gutsche Martin	christophe.ballif@epfl.ch	Period:	2010–2012

Abstract: A new electroplating process for the fabrication of the front grid of hetero junction based silicon solar cells will be developed, characterized, and finally transferred to the industrial partner. The challenge is to deposit the front grid metallization directly on a transparent conductive ITO layer with excellent adhesion, specified electrical performance, and good long-term reliability.

20 PERCENT EFFICIENCY ON LESS THAN 100 µM THICK INDUSTRIALLY FEASIBLE C-SI SOLAR CELLS

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	SBF/EU
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2010–2013

Abstract: The guiding principle of the 20PLµS project is to develop new and innovative process steps for wafer fabrication and solar cell and module manufacturing, taking into consideration the transfer of the processes to a pilot production line.

HETSI - HETEROJUNCTION SOLAR CELLS BASED ON A-SI C-SI

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	SBF/EU
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2008–2011

Abstract: Hetsi (Heterojunction solar cells based on a-Si:H/c-Si) is a project sponsored by the European Com-mision. Its short term target is to demonstrate in Europe the industrial feasibility of heterojunction solar cells, by depositing very thin film silicon layers (typically 5-10 nanometers of amorphous and/or microcrystalline silicon) on top of silicon wafers.

FEBULAS

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf		Funding:	BFE
Contact:	Tiwari Ayodhya N.	ayodhya.tiwari@empa.ch	Period:	2009–2011

Abstract: FEBULAS - Flexible CIGS Solar Cells and Mini-Modules on polymer without - or with alternative buffer layer. Focus is on Cd-free buffer layers.

IMPUCIS

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf		Funding:	BFE
Contact:	Tiwari Ayodhya N.	ayodhya.tiwari@empa.ch	Period:	2009–2012
Abstract:	Influence of impurities on the performance of CIGS thin film solar cells. Focus is on achieving good performace CIGS solar cells with reduced material quality.			

NEW CONCEPTS FOR HIGH EFFICIENCY AND LOW COST IN-LINE MANUFACTURED FLEXIBLE CIGS SOLAR CELLS (HIPOCIGS)

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf		Funding:	SBF/EU
Contact:	Tiwari Ayodhya N.	ayodhya.tiwari@empa.ch	Period:	2010–2012
Abstract:	The HIPO-CIGS project aims at the development of cost efficient flexible solar cells and modules based on the compound semiconductor CIGS.			

NON-VACUUM PROCESSES FOR DEPOSITION OF CI(G)S ACTIVE LAYER IN PV CELLS (NOVA-CI(G)S)

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf		Funding:	SBF/EU
Contact:	Tiwari Ayodhya N.	ayodhya.tiwari@empa.ch	Period:	2010–2013
Abstract:	NOVA-CI(G)S proposes alternative, non-vacuum deposition processes for thin film CI(G)S photovoltaic cells. The low capital intensive, high throughput, high material yield processes are expected to deliver large area uniformity and optimum composition of cells.			

MULTIFUNCTIONAL BACK ELECTRICAL CONTACT FOR FLEXIBLE THIN FILM SOLAR CELLS

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf		Funding:	KTI
Contact:	Tiwari Ayodhya Nath	ayodhya.tiwari@empa.ch	Period:	2009–2011
Abstract:	The project will demonstrate development of next generation of high efficiency CIGS flexible thin film solar cells and monolithically interconnected modules based on 'alternative multilayer electrical back contact' that provides multi-functionality and overcomes the problems of conventionally used electrical back contact.			

APOLLO - EFFICIENT AREAL ORGANIC SOLAR CELLS VIA PRINTING

R+D (1d) 3.1.2

Lead:	ZHAW ICP		Funding:	BFE
Contact:	Ruhstaller Beat	beat.ruhstaller@zhaw.ch	Period:	2008–2011
Abstract:	This project aims to combine plastic electronics expertise in Europe for realizing organic solar cells for empowering printed electronics applications.			

HIOS-CELL

R+D (1d) 3.1.2

Lead:	EMPA Dübendorf		Funding:	BFE
Contact:	Heier Jakob	jakob.heier@empa.ch	Period:	2009–2011
Abstract:	The project explores nanoscale structuring of heterojunction ionic organic solar cells by liquid-liquid dewetting.			

TRANSPARENT FABRIC ELECTRODES FOR ORGANIC PHOTOVOLTAICS (FABRI-PV)

R+D (1d) 3.1.2

Lead:	EMPA Dübendorf		Funding:	KTI
Contact:	Nüesch Frank	frank.nuesch@empa.ch	Period:	2009–2011
Abstract:	Solar cells require at least one transparent electrode which are commonly made of transparent conducting metal-oxide films (TCOs) since they ally excellent conductivity and high optical transmission in the visible domain. The project explores transparent fabric electrodes for organic photovoltaics (FABRI-PV).			

EFFICIENT SOLAR CELLS BASED ON ORGANIC AND HYBRID TECHNOLOGY (ESCORT)

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI		Funding:	SBF/EU
Contact:	Graetzel Michael	michael.graetzel@epfl.ch	Period:	2010–2013

Abstract: The project's objectives are to exploit the joint leadership of the top European and Indian academic and industrial Institutions to foster the wide-spread uptake of Dye-Sensitized Solar Cells technology, by improving over the current state of the art by innovative materials and processes.

ALL-CARBON PLATFORMS FOR HIGHLY EFFICIENT MOLECULAR WIRE-COUPLED DYE-SENSITIZED SOLAR CELLS (MOLESOL)

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI		Funding:	SBF/EU
Contact:	Graetzel Michael	michael.graetzel@epfl.ch	Period:	2010–2013

Abstract: The proposed project comes with a visionary approach, aiming at development of highly efficient molecular-wire charge transfer platform to be used in a novel generation thin film dye-sensitized solar cells fabricated via organic chemistry routes. The proposed technology combines the assembled dye monolayer’s, linked with organic molecular wires to semiconducting thin film deposited on optically transparent substrates.

NEUARTIGE SENSIBILISATOREN FÜR FARBSTOFFSOLARZELLEN: SQUARAIN- UND HEPTAMETHINFARBSTOFFE MIT EINER GROSSEN SPEKTRALEN VIELFALT OBERHALB 700 NM.

R+D (1d) 3.1.2

Lead:	EMPA Dübendorf		Funding:	KTI
Contact:	Nüesch Frank	frank.nuesch@empa.ch	Period:	2009–2012

Abstract: Was für die Pflanzen bzw. für die Photosynthese die komplexen Chlorophyllmoleküle sind, sind für Solarzellen heutzutage photosensitive anorganische und organische Materialien, die in gleicher Weise wie das Chlorophyll effizient Licht absorbieren und in Energie umwandeln können. Die Entwicklung solcher organischer Materialien für Farbstoffsolarzellen ist das Ziel des Projektes.

ORDERED INORGANIC-ORGANIC HYBRIDS USING IONIC LIQUIDS FOR EMERGING APPLICATIONS (ORION)

R+D (1d) 3.1.2

Lead:	Solaronix SA		Funding:	SBF/EU
Contact:	Meyer Toby	toby.meyer@solaronix.com	Period:	2009–2013

Abstract: The ORION project puts together a multidisciplinary consortium of leading European universities, research institutes and industries with the overall goal of developing new knowledge on the fabrication of inorganic-organic hybrid materials using ionic liquids.

EFFICIENT AND ROBUST DYE SENSITZED SOLAR CELLS AND MODULES

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI		Funding:	SBF/EU
Contact:	Thampi Ravindranathan	ravindranathan.thampi@epfl.ch	Period:	2008–2011

Abstract: ROBUST DSC aims to develop materials and manufacturing procedures for Dye Sensitized Solar Cells (DSC) with long lifetime and increased module efficiencies (7% target). The project intends to accelerate the exploitation of the DSC technology in the energy supply market. The approach focuses on the development of large area, robust, 7% efficient DSC modules using scalable, reproducible and commercially viable fabrication procedures.

MODELLIERUNG VON FARBSTOFFSOLARZELLEN MODSOL

R+D (1d) 3.1.2

Lead:	ZHAW ICP		Funding:	diverse
Contact:	Schmid Matthias	matthias.schmid@zhaw.ch	Period:	2008–2010

Abstract: The goal of the ModSol project project is to develop validated numerical models for dye sensizized solar cells (DSC).

EXTREMLY THIN ABSORBER SOLAR CELLS BASED ON ELECTRODEPOSITED ZNO NANOSTRUCTURES

R+D (1e) 3.1.2

Lead:	EMPA Thun		Funding:	BFE
Contact:	Laetitia Philippe	laetitia.philippe@empa.ch	Period:	2009–2011

Abstract: The aim of the "ETA solar cells" project is to study separately the different materials used for the fabrication of this kind of photovoltaic device in order to improve the solar efficiency.

ENTWICKLUNG EFFIZIENTER LUMINESZENZKONZENTRATOREN BASIEREND AUF ANORGANISCH-ORGANISCHEN NANOMATERIALIEN ZUR SOLARENERGIEGEWINNUNG

R+D (1e) 3.1.2

Lead:	Universität Zürich, Institut für anorganische Chemie		Funding:	KTI
Contact:	Brühwiler Dominik	bruehwi@aci.uzh.ch	Period:	2008–2010

Abstract: Ziel des Projekts ist die Entwicklung von neuen, effizienten Lumineszenzkonzentratoren. Durch den Einschluss der Lumineszenzzentren in Zeolithe werden Stabilitätsprobleme gelöst, sowie Verluste durch Selbstabsorption verringert. In Kombination mit stabilen Lumineszenzkonzentratoren können Silizium-Solarzellen, ohne Verlust an Leistung, verkleinert werden.

NANOMATERIALS FOR HARVESTING SUB-BAND-GAP PHOTONS VIA UPCONVERSION TO INCREASE SOLAR CELL EFFICIENCIES (NANOSPEC)

R+D (1e) 3.1.2

Lead:	Universität Bern, Dept. Chemie & Biologie		Funding:	SBF/EU
Contact:	Krämer Karl	karl.kraemer@iac.unibe.ch	Period:	2010–2013

Abstract: Fundamental loss mechanisms limit the maximum achievable efficiency: around 20% of the incident power is lost, because photons with energies below the band-gap are transmitted. Upconversion of two low energy photons into one usable photon reduces these losses. In this project we will realize upconversion with the help of nanostructures and nanotechnoloy-based materials and show a significant improvement in solar cell efficiency.

INNOVATIVE MATERIALS FOR FUTURE GENERATION EXCITONIC SOLAR CELLS

R+D (1e) 3.1.2

Lead:	Solaronix SA		Funding:	SBF/EU
Contact:	Meyer Andreas	andreas.meyer@solaronix.com	Period:	2009–2012

Abstract: The main objective is to leapfrog current limitations of third-generation PV devices through a drastic improvement of the materials used for assembling excitonic solar cells.

PLASMONS GENERATING NANOCOMPOSITE MATERIALS (PGNM) FOR 3RD GENERATION THIN FILM SOLAR CELLS (SOLAMON)

R+D (1e) 3.1.2

Lead:	Solaronix SA		Funding:	SBF/EU
Contact:	Meyer Toby	toby.meyer@solaronix.com	Period:	2009–2011

Abstract: The objective of the SOLAMON project is to develop high potential Plasmon Generating Nanocompo-site Materials (PGNM) which will pave the way to the generation III solar cells (high efficiency & low cost).

ADVANCED LASERS FOR PHOTOVOLTAIC INDUSTRIAL PROCESSING ENHANCEMENT (ALPINE)

R+D (1e) 3.1.2

Lead:	Oclaro (Switzerland) AG		Funding:	SBF/EU
Contact:	Schmid Manuel	www.oclaro.com	Period:	2009–2012

Abstract: ALPINE aims to push forward the European research and development of fiber laser systems for the scribing of photovoltaic modules, joining together two exciting challenges: the fiber laser development for advanced industrial processing and the solar energy exploitation.

THINPV: COST EFFICIENT THIN FILM PHOTOVOLTAICS FOR FUTURE ELECTRICITY GENERATION

R+D (1e) 3.1.2

Lead:	EMPA Dübendorf		Funding:	diverse
Contact:	Nüesch Frank	frank.nueesch@empa.ch	Period:	2006–2009

Abstract: THINPV: Cost efficient thin film photovoltaics for future electricity generation. This project brings the different Swiss PV research groups in thin film solar cells together and works on relevant crosscutting issues.

SMARTTILE: INNOVATIVE PHOTOVOLTAIK INDACHLÖSUNG

P+D (2a) 3.1.2

Lead:	3S Swiss Solar Systems AG		Funding:	BFE
Contact:	Szacsvay Tamás	tamas.szacsvay@3-s.ch	Period:	2008–2010

Abstract: Die zunehmende Industrialisierung der Fertigungsprozesse von Photovoltaik (PV) Modulen eröffnet neue Möglichkeiten für die Massenfertigung. Im Projekt SmartTile wird ein neues Solardachelement nach neusten Erkenntnissen entwickelt.

BUILDING INTEGRATED PHOTOVOLTAICS THERMAL ASPECTS

R+D (2a) 3.1.2

Lead:	SUPSI ISAAC		Funding:	BFE
Contact:	Frontini Francesco	francesco.frontini@supsi.ch	Period:	2009–2011

Abstract: PV industries offering products that can be integrated as building materials represent so far a niche but promising market. The intentions of this project are to: Analyze building integrated PV products in order to define their electrical and thermal cha-racteristics. Analyze the interaction between these materials and the building. Demonstrate what BiPV modules look like and how to integrate them into the building con-cept.

UNIQUE AND INNOVATIVE SOLUTION OF THIN SILICON FILMS MODULES BUILDING INTEGRATION

P+D (2a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	BFE
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2010–2013

Abstract: This project aims to develop and test a new generation of photovoltaic building elements based on thin film silicon technology (single amorphous and tandem amorph/microcrystalline cells).

LASERBEARBEITUNG VON SOLARPANELS

R+D (2a) 3.1.2

Lead:	FHNW IPPE		Funding:	KTI
Contact:	Lüscher Beat	beat.luescher@fhnw.ch	Period:	2010–2011

Abstract: Ziel des Projektes ist die Verringerung der Herstellkosten und die Effizienzsteigerung von Dünnschichtsolarzellen mittels Einsatz neuester Laser-Technologie. Innovative Laserverfahren sollen in die industrielle Fertigung implementiert werden und konventionelle, zeitaufwändige Prozessschritte ersetzen.

PROFILED PHOTOVOLTAIC MODULES

R+D (2a) 3.1.2

Lead:	EPFL-STI-IMX-LTC		Funding:	KTI
Contact:	Leterrier Yves	yves.leterrier@epfl.ch	Period:	2009–2012

Abstract: The objective of this collaboration is to develop a materials system and process for profiled encapsulation of thin film silicon photovoltaic devices with improved efficiency for structured roofing elements.

TEXTILE PHOTOVOLTAIK: INTEGRATION VON MINIATURISIERTEN SOLARMODULEN AUF TEXTILE FLÄCHEN MITTELS STICKEREITECHNIK

R+D (2a) 3.1.2

Lead:	NTB		Funding:	KTI
Contact:	Gutsche Martin	martin.gutsche@ntb.ch	Period:	2010–2012

Abstract: Im Projekt Textile Photovoltaik werden durch die Kombination von bestehenden Techniken miniaturisierte Solarmodule hergestellt und mittels Sticktechnik zu einem neuen Gewebeverbund verarbeitet. Die erarbeiteten Techniken erlauben es zum ersten Mal, vollflexible Flächengebilde mit photovoltaischer Funktion zu erzeugen.

LARGE AREA SOLAR SIMULATOR INTEGRATING POWER LIGHT EMITTING DIODES FOR PERFORMANCE MEASUREMENT OF NEW GENERATIONS OF PHOTOVOLTAIC MODULES (SUNSIM)

R+D (2b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	KTI
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2009–2011

Abstract: High precision solar simulators will become crucial to characterize the next generation of low cost PV modules. In this project, a new large area characterization tool, satisfying criteria on homogeneity, spectrum, and temporal stability will be developed, prototyped and tested.

LED-BASIERTE QUALITÄTSKONTROLLE IM PRODUKTIONSABLAUF FÜR SOLARMODULE

R+D (2b) 3.1.2

Lead:	ZHAW ICP		Funding:	KTI
Contact:	Reinke Nils	nils.reinke@zhaw.ch	Period:	2010–2010

Abstract: Gegenstand der vorliegenden Machbarkeitsstudie ist die Untersuchung einer Lichtquelle auf Basis von lichtemittierenden Dioden (LEDs). Diese Lichtquelle soll für die Qualitätskontrolle von Solarmodulen in Produktionsanlagen integriert werden können.

MULTI-PURPOSE PV MODULE TESTER (MPVT).

R+D (2b) 3.1.2

Lead:	SUPSI ISAAC		Funding:	KTI
Contact:	Chianese Domenico	domenico.chianese@supsi.ch	Period:	2008–2010

Abstract: The objective of this project is to develop a new high flexible electronic load which responds to the present needs of research and test laboratories and which is the basis for the development of a high efficient and cost effective in-line tester for module manufacturers.

LIFETIME, MECHANICAL AND SECURITY TESTING FOR PV MODULE CERTIFICATION

R+D (2c) 3.1.2

Lead:	SUPSI ISAAC		Funding:	BFE
Contact:	Rudel Roman	roman.rudel@supsi.ch	Period:	2008–2010

Abstract: In the strongly expanding PV market certification capacities constitute a serious bottleneck. Based on the long experience in module testing at ISAAC (SUPSI), a PV module test center for certified module measurements according to IEC standards is being built up.

QUALITÀ E RESA ENERGETICA DI MODULI PV, CENTRALE ISAAC-TISO - PERIODO VIII: 2007–2010

R+D (2c) 3.1.2

Lead:	SUPSI ISAAC		Funding:	BFE
Contact:	Rudel Roman	roman.rudel@supsi.ch	Period:	2007–2010

Abstract: With this project, the ISAAC (SUPSI) develops appropriate module measurement techniques in view of qualtiy assurance and energy rating of PV modules. Extended measurement campaigns are carried out for market relevant PV modules and new technologies.

MOBILES PV MESSSYSTEM

P+D (2c) 3.1.2

Lead:	ZHAW IEFE		Funding:	diverse
Contact:	Baumgartner Franz	franz.baumgartner@zhaw.ch	Period:	

Abstract: Ein Messsystem für PV-Module ist auf einem Kleinbus montiert und erlaubt so Messungen von PV-Modulen an einem beliebigen Ort. Damit können langwierige Transporte von grösseren Mengen von zu testenden Modulen vermieden werden.

APPLICATION DE MODULES PV FLEXIBLES SUR LE SITE DE PRODUCTION FLEXCELL

P+D (2d) 3.1.2

Lead:	VHF Technologies SA		Funding:	BFE
Contact:	Fischer Diego	diego.fischer@flexcell.com	Period:	2009–2012

Abstract: The goal of this project to develop, install and monitor various building integrated PV products and installation solutions based on Flexcell's technology on buildings of Flexcell's production site in Yverdon.

PHOTOVOLTAIK IM VERBUND MIT DÄMMSTOFF FOAMGLAS

P+D (2d) 3.1.2

Lead:	Basler & Hofmann AG		Funding:	BFE
Contact:	Bucher Christof	christof.bucher@baslerhofmann.ch	Period:	2010–2013

Abstract: In diesem Projekt soll mindestens ein Produkt aus PV und FOAMGLAS entwickelt werden.

BISOL – BUILDING INTEGRATED SOLAR NETWORK – BRENET

R+D (2e) 3.1.2

Lead:	SUPSI ISAAC		Funding:	BFE
Contact:	Rudel Roman	roman.rudel@supsi.ch	Period:	2009–2011

Abstract: The aim of the BiSol project is to create a competence network between specialists from various stakeholders so as to maximize solar energy integration into the built environment and overcome the related technical and non technical issues.

BIPV TOOLS

WTT (2e) 3.1.2

Lead:	SUPSI ISAAC	Funding:	BFE
Contact:	Frontini Francesco francesco.frontini@supsi.ch	Period:	2009–2011

Abstract: The BiPV Tools project is addressed specifically to architects. Its aim is to provide information and tools which will allow a correct and appropriate integration of photovoltaics into the building design concept.

PHOTOVOLTAIK SYSTEMTECHNIK 2007–2010

R+D (3) 3.1.2

Lead:	HTI Burgdorf	Funding:	BFE
Contact:	Häberlin Heinrich heinrich.haeberlin@bfh.ch	Period:	2007–2010

Abstract: Bau eines neuen Solargenerator-Simulators von 100 kW zusätzlich zu den bisherigen Geräten von 20 kW und 25 kW. Wartung und laufende Weiterentwicklung der Mess-Software der vorhandenen Solargenerator-Simulatoren.

PRAXISTEST BACKUP WECHSELRICHTER

P+D (3) 3.1.2

Lead:	Basler & Hofmann AG	Funding:	BFE
Contact:	Stettler Sandra sandra.stettler@baslerhofmann.ch	Period:	2008–2010

Abstract: Das Projekt Praxistest Backup Wechselrichter soll auf der Basis von detaillierten Messungen eines aktuellen Produkts das genaue Verhalten und die Tauglichkeit eines Wechselrichters mit Back-up Funktion evaluieren.

SIMULATION APPROACH TO INVESTIGATE THE IMPACT OF DISTRIBUTED POWER GENERATION WITH PHOTOVOLTAICS ON A POWER GRID (PV ERA NET PROJECT PV+GRID_06_DPVG)

R+D (3) 3.1.2

Lead:	Basler & Hofmann AG	Funding:	BFE
Contact:	Bucher Christof christof.bucher@baslerhofmann.ch	Period:	2010–2012

Abstract: Simulation Approach to Investigate the Impact of Distributed Power Generation with Photovoltaics on a Power Grid. The project addresses the important topic of grid integration of variable production from phovoltaics.

SOLAR WINGS: SEIL-BASIERTES PHOTOVOLTAIK-NACHFÜHRSYSTEM 2-ACHSIG

P+D (3) 3.1.2

Lead:	PAMAG Engineering	Funding:	BFE
Contact:	Kessler Hugo hke.pamag@flumroc.ch	Period:	2009–2011

Abstract: Im Pilotprojekt Solar Wings wird erstmalig das Verhalten eines Seil-basierten 2-achsig nachgeführten Photovoltaiksystems erprobt und mit einer fix installierten Anlage verglichen.

AUTONOMOUS CLEANING ROBOT FOR LARGE SCALE PHOTOVOLTAIC POWER PLANTS IN EUROPE RESULTING IN 5% COST REDUCTION OF ELECTRICITY (PV-SERVITOR)

R+D (3) 3.1.2

Lead:	HTI Burgdorf	Funding:	SBF/EU
Contact:	Häberlin Heinrich heinrich.haeberlin@bfh.ch	Period:	2009–2011

Abstract: The PV-Servitor project focuses on concepts for a fully autonomous cleaning robot for ground mounted large scale photovoltaic power plants consisting of several 100 kW units. The PV-Servitor shall be able to automatically clean glass surfaces of solar modules in several areas of up to 2,500 square meters in an unrestricted way.

PV TESTANLAGE DIETIKON

P+D (3) 3.1.2

Lead:	ZHAW IEFE	Funding:	diverse
Contact:	Baumgartner Franz franz.baumgartner@zhaw.ch	Period:	

Abstract: In einer Testanlage werden verschiedene Photovoltaik-Modultechnologien erprobt und miteinander verglichen.

INPHOCUS – INFLATED PHOTOVOLTAIC ULTRA-LIGHT MIRROR CONCENTRATORS
R+D (4) 3.1.2

Lead:	SUPSI ICMSI		Funding:	KTI
Contact:	Boër Claudio	claudio.boer@icimsi.ch	Period:	2010–2012

Abstract: The goal of this project is to realize a commercially cost competitive innovative Concentrating PhotoVoltaic (CPV) system. The project will cover the design, construction and performance testing of the innovative system. The concentrator will be equipped with unconventional pneumatic multilayer Mylar mirrors, will have an innovative fiber reinforced concrete structure and an original tilting mechanism to track the sun.

MESSKAMPAGNE PHOTOVOLTAIK SCHALLSCHUTZANLAGE MÜNSINGEN
R+D (4) 3.1.2

Lead:	TNC Consulting AG		Funding:	BFE
Contact:	Nordmann Thomas	nordmann@tnc.ch	Period:	2009–2011

Abstract: In dieser Messkampagne wird das Verhalten der bifacialen Photovoltaik Schallschutzanlage beim Bahnhof Münsingen (Kt. BE) analysiert.

RESOURCE- AND COST-EFFECTIVE INTEGRATION OF RENEWABLES IN EXISTING HIGH-RISE BUILDINGS (COST-EFFECTIVE)
R+D (4) 3.1.2

Lead:	Emmer Pfenninger Partner AG		Funding:	SBF/EU
Contact:	Emmer Andreas	andreas.emmer@eppag.ch	Period:	2008–2012

Abstract: The main focus of the project is to convert facades of existing "high-rise buildings" into multifunctional, energy gaining components. This goal will be achieved by: development of integrated building concepts, development of new multi-functional façade components and development of new business and cost models.

SCHWEIZER PV ENERGIESTATISTIK
R+D (4) 3.1.2

Lead:	Ingenieurbüro Hostettler		Funding:	BFE und weitere
Contact:	Hostettler Thomas	hostettler_engineering@compuserve.com	Period:	

Abstract: In der Schweizer PV Energiestatistik wird die Energieprodutkion einer repräsentativen Menge von ausgewählten PV-Anlagen erfasst und auf die Gesamtanzahl PV-Anlagen hochgerechnet.

NORMENARBEIT FÜR PV SYSTEME
WTT (4) 3.1.2

Lead:	Basler & Hofmann AG		Funding:	Swisssolar
Contact:	Toggweiler Peter	peter.toggweiler@baslerhofmann.ch	Period:	2007-

Abstract: Normen sind ein wichtiges Instrument zur Qualitätssicherung sowie zum sicheren und zuverlässigen Betrieb von PV-Anlagen. Das Projekt umfasst den Schweizer Beitrag zu den entsprechenden Arbeiten im IEC Technischen Kommittee 82.

LEITUNG DES FORSCHUNGSPROGRAMMS «PHOTOVOLTAIK»
R+D (4) 3.1.2

Lead:	NET AG		Funding:	BFE
Contact:	Nowak Stefan	stefan.nowak@netenergy.ch	Period:	1993–2012

Abstract: Das Projekt umfasst Strategie und Leitung des Schweizer Photovoltaik-Forschungsprogramms, die Begleitung der Projekte (F+E, P+D) sowie die gesamtschweizerische Koordination.

SCHWEIZER BEITRAG IEA PVPS TASK 1 – 2010
R+D (5) 3.1.2

Lead:	Nova Energie GmbH		Funding:	BFE
Contact:	Hüsser Pius	pius.huesser@novaenergie.ch	Period:	2010–2011

Abstract: IEA PVPS Task 1 befasst sich mit Informationsaufgaben zum Stand der Photovoltaik in den Mitgliedländern des IEA PVPS Programms. Dazu leistet dieses Projekt den Schweizer Beitrag, insbesondere zur Entwicklung von Industrie und Markt sowie des regulatorischen Kontextes.

SCHWEIZER BEITRAG IEA PVPS TASK 12

R+D (5) 3.1.2

Lead:	ESU-Services AG		Funding:	BFE
Contact:	Frischknecht Rolf	frischknecht@esu-services.ch	Period:	2006–2010
Abstract:	IEA PVPS Task 12 befasst sich mit Umweltaspekten der Photovoltaik ausgehend von Analysen in den Mitgliedländern des IEA PVPS Programms. Dazu leistet dieses Projekt den Schweizer Beitrag, insbesondere zur Lebenszyklusanalyse (LCA) von PV-Systemen.			

IEA PVPS – KICK-OFF MEETING IEA PVPS TASK 13

R+D (5) 3.1.2

Lead:	TNC Consulting AG		Funding:	BFE
Contact:	Nordmann Thomas	nordmann@tnc.ch	Period:	2010–2010
Abstract:	IEA PVPS Task 13 befasst sich mit Performance und Zuverlässigkeit von PV-Kompenten und PV-Anlagen in den Mitgliedländern des IEA PVPS Programms. Mit diesem Projekt wird der Schweizer Beitrag zu diesem neuen internationalen Vorhaben vorbereitet.			

SOLAR RESOURCE MANAGEMENT, IEA SOLAR HEATING & COOLING PROGRAMME, TASK 36

R+D (5) 3.1.2

Lead:	Meteotest		Funding:	BFE
Contact:	Kunz Stefan	stefan.kunz@meteotest.ch	Period:	2005–2010
Abstract:	In the framework of IEA Solar Heating and Cooling (SHC) Task 36, Meteotest investigates the possibilities and quality of global radiation forecast, the trend of recent global radiation data and distribution of atmospheric aerosols.			

IEA SHC TASK 41 « SOLAR ENERGY AND ARCHITECTURE » – DIRECTION DE LA SOUS-TÂCHE A « CRITERIA FOR ARCHITECTURAL INTEGRATION »

R+D (5) 3.1.2

Lead:	EPFL LESO		Funding:	BFE
Contact:	Roecker Christian	christian.roecker@epfl.ch	Period:	2009–2012
Abstract:	The main goals of IEA SHC Task 41 are to help achieving high quality architecture for buildings integrating solar energy systems, as well as improving the qualifications of the architects, their communications and interactions with engineers, manufactures and clients. Increased user acceptance of solar designs and technologies will accelerate the market penetration.			

PV ERA NET: NETWORKING AND INTEGRATION OF NATIONAL AND REGIONAL PROGRAMMES IN THE FIELD OF PHOTOVOLTAIC (PV) SOLAR ENERGY RESEARCH AND TECHNOLOGICAL

R+D (5) 3.1.2

Lead:	NET AG		Funding:	diverse
Contact:	Nowak Stefan	stefan.nowak@netenergy.ch	Period:	2004–2009
Abstract:	PV ERA NET: The objective of the network is to enhance the cooperation between regional and national PV RTD programmes in Europe. The activities include information exchange, best practice in PV RTD as well as specific joint calls between several regional/national PV RTD programmes.			

Solarzellen

NEW PROCESSES AND DEVICE STRUCTURES FOR THE FABRICATION OF HIGH EFFICIENCY THIN FILM SILICON PHOTOVOLTAIC MODULES

Annual Report 2010

Authors	C. Battaglia and C. Ballif
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Project- / Contract Number	SI/500031 / SI500031-01 (101191 / 153032)
Duration of the Project (from– to)	1.12.2007-31.12.2011
Date	November 30, 2010

ABSTRACT

This project has four axes which focus on layers with new or better properties (e.g. new materials to be incorporated into devices), on improved processes (e.g. new plasma regimes leading to higher quality layers), on improved devices, and on enhanced cells and modules reliability. The final objective is to contribute to the field by findings that will eventually lead to increased module efficiencies while ensuring lower costs and long-term reliability.

One of the major achievements of this third year of the project was the development and optimization of p- and n-doped nanocrystalline silicon oxides. Their successful integration into single junction and multi-junctions (tandem and triple) solar cells allowed in each case for the use of more aggressive light trapping schemes via nanotextured substrates, while retaining excellent electrical cell performances. These doped layers combined with optimized zinc oxide electrode design, enhanced stability of the amorphous silicon absorber layer and improved microcrystalline silicon absorber layer quality, lead to the fabrication of micromorph tandem junction cells with new lab record efficiencies of 13.7% initial and 11.5% stable. A thinner version of this cell, with a total thickness below 1.5 μm, was realized in our industrial KAI reactors with 12.7% initial and 11.3% stable efficiency, which is among the highest thin film silicon solar cell stabilized efficiencies reported so far for such a thickness.

Furthermore we demonstrated similar high-efficiency micromorph cells on nanotextured substrates fabricated via nanoimprinting on glass validating nanoimprinting as a powerful tool to integrate a large variety of novel photonic nanostructures into high-efficiency devices. We also explored the use of plasmonic nanoparticles in amorphous single junction cells resulting in a current enhancement of 20%. Furthermore we deposited first triple junction solar cells with initial efficiencies of up to 11. 4% with no anti-reflective coating applied to the front glass.

Introduction

2010 has been an outstanding year with respect to research results on thin-film silicon solar cells. With the thin-film silicon photovoltaic industry still recovering from the recent economic crisis, significant progress in materials processing and characterization as well as innovative new device structures, which translated directly into several record efficiencies, are essential to relaunch the thin-film silicon industry. Adding to the economic uncertainties, Applied Materials announced to shift its focus from thin-film silicon to crystalline silicon. However, new confidence is back in the markets thanks to the new certified world record micromorph cell achieved by Oerlikon Solar this year. More importantly, Oerlikon Solar announced record potential breaking production costs of € 0.5 per Watt peak rendering thin-film silicon competitive with cadmium telluride and low cost multicrystalline products. Good news comes also from several thin-film silicon module manufacturers, presenting micromorph modules with stabilized efficiencies above 10% at this year’s Photovoltaic Solar Energy Conference in Valencia, Spain. A range of new companies has entered the thin-film market and a second major investment cycle is predicted for 2011. In this economic environment, EPFL’s PV-Lab continues to play its key role in pushing established boundaries and provide industry with truly innovative ideas and concepts to further improve conversion efficiencies and reduce production costs.

Goals of the project

In the general economic context, the present project remains fully relevant, as its global objective is to allow for a lowering of the cost of solar electricity based on thin film silicon. In particular, this projects aims at developing materials, processes and device structures for the future generation of thin film silicon modules, based on amorphous silicon or silicon-germanium alloys, and microcrystalline silicon. The objective of this “technology push” project is, hence to make the breakthroughs that will allow in the medium to long term, to further reduce module production costs at elevated efficiencies, while ensuring perfect module reliability.

Short project description

The project has four major research axes, and two transversal domains, described in Fig. 1 .

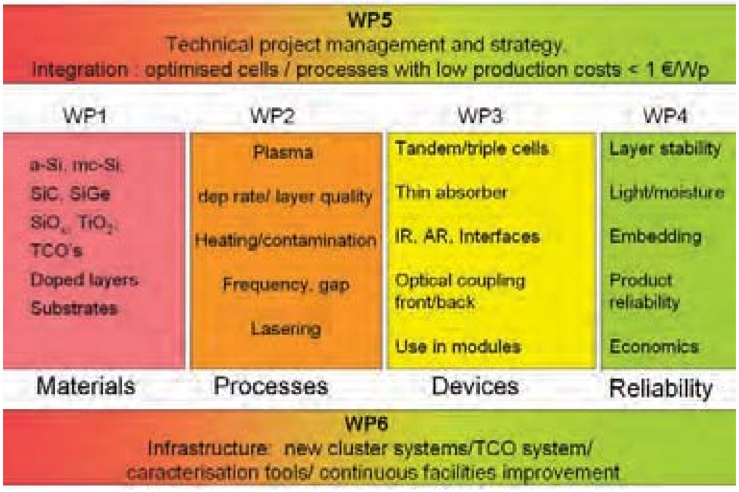


Fig. 1 Summary of the major workpackages of the SFOE-IMT project 2008-2011.

The project’s goals are, hence, to be achieved by introducing innovation and optimisation in four major areas:

- Layers with new or better properties (e.g. new materials with higher transparency)
- Improved processes (more stable, faster processes, yielding higher quality layers)
- Increased device and module efficiency
- Enhanced cells and modules reliability.

For 2010, the major objectives have been to

- Improve understanding of structure and properties of silicon oxide material
- Integration of silicon oxide based layers into solar cells
- Increase quality of intrinsic layers to minimize impact of light induced degradation and cracks
- Develop novel sub-/superstrates
- Optimize zinc oxide layer transparency and electrical properties
- Establish strict test criteria to quantify main failure mechanism of modules.

The detailed scientific results are reported in the publications list at the end of the report, which the reader is invited to consider.

Work performed and results achieved in 2010

1. Materials

1.1 Doped nanocrystalline silicon oxide layers

Lower absorption, lower refractive index, and tunable resistance are three advantages of nanocrystalline silicon oxide (nc-SiO_x) layers compared to their microcrystalline silicon (µc-Si) counterparts. Many of the interesting physical properties are related to the nanostructure of this material consisting of nanocrystalline silicon grains embedded in an amorphous silicon oxide tissue [Cuo10]. So far we demonstrated the usefulness of n-type (phosphorus doped) SiO_x layers as intermediate reflector and resistive interlayer. In 2010, we succeed for the first time in developing p-type (boron doped) SiO_x layers and integrated them successfully in various cell configurations leading, together with additional advances, to several lab record efficiencies.

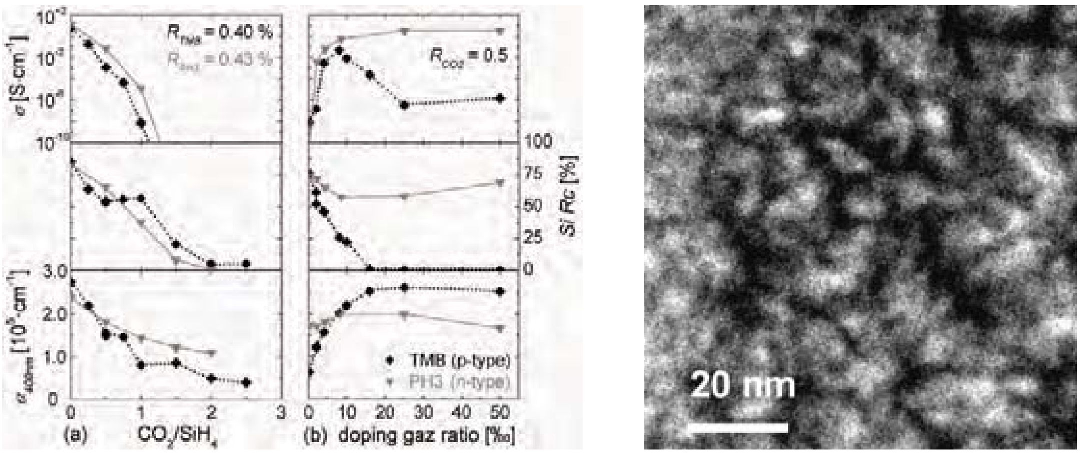


Fig. 2 The graph on the left shows the dark conductivity (σ), Raman crystalline fraction of the silicon phase and absorption coefficient (α), of nanocrystalline SiO_x layers as a function of CO2/SiH4 gas ratio (a) and doping gas ratio (b). The SiO_x layers are doped p- and n-type with boron (black) and phosphorous (grey), respectively. The right shows an energy-filtered transmission electron microscopy image showing the phase separation in SiO_x films into silicon-rich regions (white) and oxygen-rich regions (black).

Fig. 2 shows that p- and n-type SiO_x show very similar properties with respect to increasing CO_2 gas flow [Mar10]. For both, an increasing CO_2 gas flow is dramatically reducing the dark conductivity (σ) and the crystallinity (Si Rc), while increasing the film transparency. Whereas for the n-type doping, the phosphorous content can be increased without restriction, the p-type doping with boron strongly reduces the crystalline fraction of the silicon phase. This leads to a sharp conductivity optimum at a doping gas ratio at 0.8% until which the boron is increasing conductivity due to the doping effect, and beyond which boron is reducing conductivity due to its amorphizing effect. Fig. 2 shows further an energy-filtered transmission electron microscopy image demonstrating that there is a phase separation on the nanometer scale in SiO_x films into silicon-rich and oxygen-rich regions.

Various p-type SiO_x films have been incorporated in µc-Si cells and the best cells were then compared to the cells with standard p-type µc-Si layers. Figure 2 shows this comparison for two different substrates. For both substrates it can be seen that the current density (J) is increased with the p-SiO_x layer due to the increased transparency of this layer when compared to the p-µc-Si layer. More importantly is the effect on the open circuit voltage V_{oc}. For the as-grown substrate, the V_{oc} is improving dramatically when replacing the standard p-µc-Si layer by p-SiO_x, as the SiO_x is able to quench local current drains due to spatial non-uniformities (so-called "cracks") in the microcrystalline absorber layer caused by the rough texture [Cuo10b, Cuo10c, Cuo10d]. The effect is less pronounced for the less rough surface-treated substrate, on which the absorber layer grows with a lower crack density. However, the surface treatment leads to a reduced light trapping reflected in the lower current density.

Thus the new p-type nanocrystalline SiO_x layers do not only improve light absorption due to their improved transparency, but enable to boost light trapping by introducing rougher substrates, without paying the price of reduced electrical performance. The increased robustness of the cells opens many possibilities to explore novel, more aggressive light trapping schemes.

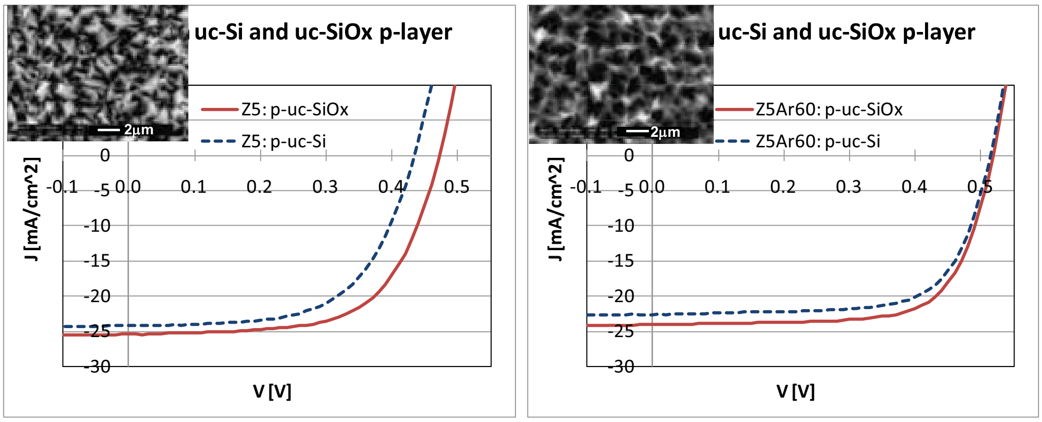
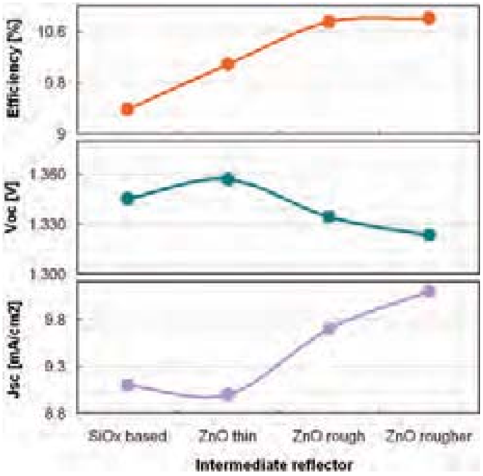


Fig. 3 The J-V curves compare µc-Si cell characteristics with standard p-type µc-Si (dashed blue) and with new p-type SiO_x (solid red) layer. On the left, a very rough 5 µm thick ZnO is used as substrate and front electrode and on the right, a surface-treated ZnO with a smoother morphology is used (SEM micrographs of the corresponding substrates are shown in the inserts).

[Cuo10] P. Cuony, D. T. L. Alexander and et al., to be published (2010)
[Mar10] M. Marending, Master Thesis, EPFL (2010).
[Cuo10b] P. Cuony, M. Despeisse, G. Parascandolo and C. Ballif (patent filed in July 2010).
[Cuo10c] P. Cuony, M. Marending, D. T. L. Alexander, M. Boccard, G. Bugnon, M. Despeisse and C. Ballif, accepted for publication in Appl. Phys. Lett. (2010)
[Cuo10d] P. Cuony et al., Proceedings of the 25th EU-PVSEC, Valencia (2010)

1.2 Asymmetric zinc oxide intermediate reflector

In a micromorph solar cell, the amorphous top cell and the microcrystalline bottom cell have different requirements in terms of light management and growth dynamics. Classically, the morphology of the front electrode is used to tune the optical absorption in the individual subcells. State-of-the-art micromorph cells include an intermediate reflector that reflects part of the incoming light back into the top cell. Conformal SiO_x-based intermediate reflectors (SOIR) have been introduced by our lab earlier and were studied extensively. To allow optimum growth conditions and to tailor light absorption for both top and bottom cells individually, an asymmetric zinc oxide (ZnO) intermediate reflector (ZIR) was implemented into the micromorph cell. By adapting the morphology of the front electrode for the top cell and the morphology of the intermediate reflector for the bottom cell, significant efficiency improvements could be achieved. This mostly comes from an enhancement in bottom cell current thanks to improved light scattering at the rough intermediate reflector. However, we faced issues with reproducibility and yield for large area cells when using zinc oxide based intermediate reflector. Further investigations are required to overcome these difficulties. The standard approach with a rough front electrode adapted for both top and bottom cells light trapping combined with doped SiO_x layers and high quality absorber layers developed within this year were still yielding maximum efficiency.



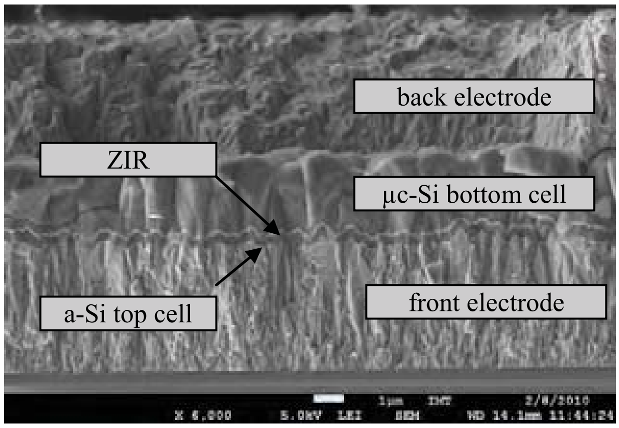


Fig. 4 (left) Efficiencies, open-circuit voltages and short-circuit current densities of micromorph cells using different intermediate reflectors; the first one is a state-of-the-art silicon oxide based intermediate reflector, the second one is an equivalent one made of zinc oxide (see scanning electron microscopy image of a cell crossection on the right), and the last two are asymmetric ones made of zinc oxide.

1.3 Bilayer front electrodes

To better understand the relative influences of light trapping and absorption on the photocurrent generated by the cells we developed bi-layer front electrodes. A flat indium tin oxide (ITO) layer ensures conduction and allows one to vary absorption, while light scattering can be varied by adjusting the thickness of a highly transparent rough ZnO layer deposited on top of the ITO layer. We observed that already a minimum amount of absorption in the electrode, accounting only for a few percents of absorption for a single light pass, leads to a massive reduction of the cell current in the infrared part of the spectrum, where the light travels many times across the cell. Furthermore a current enhancement is observed for increasing front electrode haze up to a saturation level [Boc10], which correlates remarkably well with the amount of light diffusively transmitted by the front electrode into silicon. Thus relatively small surface feature sizes (with characteristic sizes of around 400 nm) prove to be large enough to scatter light efficiently across the full spectral range exploited by the micromorph cell.

To improve the trade-off between optical and electrical properties of ZnO layers, an alternative approach investigated at IMT is to decouple the conductive part from the light scattering part by means of multistack deposition of intentionally and non-intentionally doped ZnO sublayers in the same growth run. This allows one to achieve conduction channels with less electron scattering impurities in such polycrystalline material, while providing at the same time more transparent films with higher light scattering abilities. By using bilayers, we were able to simultaneously enhance light scattering, while rendering the layers more transparent and less resistive.

[Boc10] M. Boccard, P. Cuony, C. Battaglia, M. Despeisse, C. Ballif, accepted for publication in Phys. Stat. Sol. RRL (2010)
[Din10] L. Ding et al., Proceedings of the 25th EU-PVSEC, Valencia (2010)

1.4 Interaction between back reflector and front ZnO

In thin-film silicon solar cells we use textured substrates to increase light-trapping in the thin absorber layer and thus enhance light absorption. Once a given texture is chosen, this texture usually defines all the subsequent optical interfaces. To better understand the role of the different optical interfaces and to improve them, we designed and built a new setup to polish different textured layers on 4 x 8 cm^2 substrates. Fig. 5 shows the external quantum efficiency (EQE) of a µc-Si cell with different front ZnO morphology and back reflector configurations. The first three curves (from the left), show cells deposited on a polished front ZnO. Here the ZnO/silicon front interface is flat and the silicon/ZnO back interface shows only the small roughness induced by the µc-Si growth itself. Not surprisingly, this is a very poor configuration for light-trapping and results in very low EQE in the infrared range. The lowest EQE is measured when no back reflector (BR) is applied to the rough back ZnO. When applying a white diffuser (WD) on the back, the EQE can be increased, but the interference fringes in the µc-Si still remain, indicating that a large portion of the light remains specular within the absorber layer and does not reach the diffusive BR. Rough ZnO/silicon and/or silicon/ZnO interfaces are therefore necessary to promote light diffusion in the silicon absorber layer. The five EQE curves on the right are from cells deposited onto a rough front ZnO. The lowest EQE is in this case obtained when applying sputtered and annealed silver onto the rough back ZnO because the rough ZnO/silver is absorbing strongly (this is not yet fully understood, but has been documented by other groups).

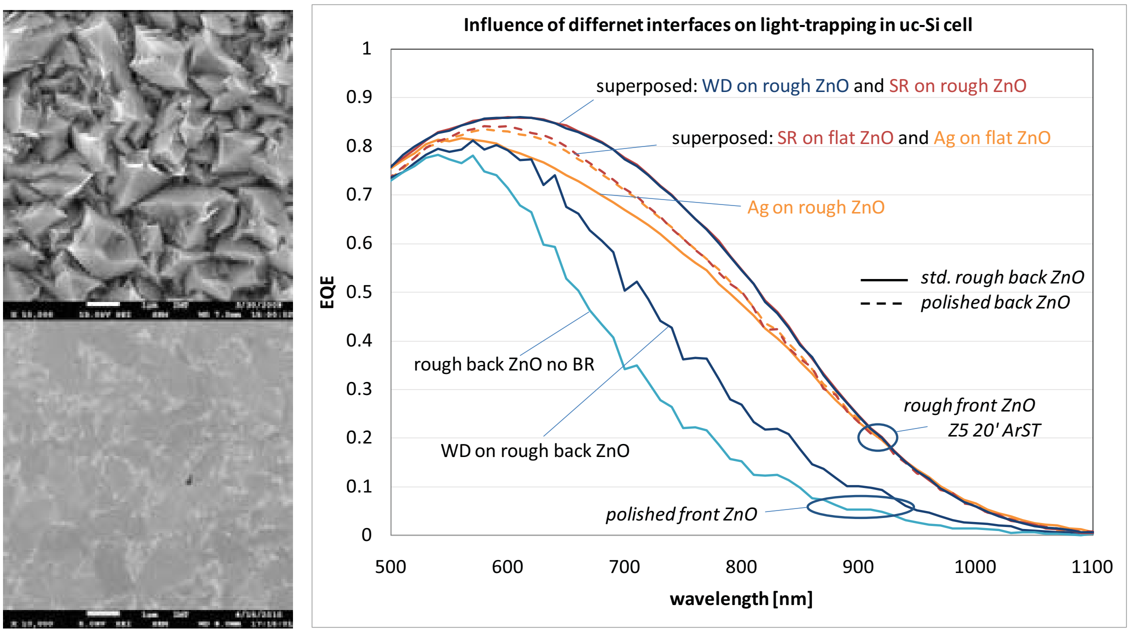


Fig. 5 Figure 1: SEM image of very rough ZnO layer as grown (upper left) and after polishing (lower left). On the right the external quantum efficiency of a microcrystalline cell on rough and flat front ZnO and with different back reflectors (Ag = sputtered silver; WD = white dielectric diffuser; SR = specularly reflecting film)

When polishing the rough back ZnO and using the sputtered silver in a flat ZnO/silver configuration, the EQE is increasing. In this case the EQE is the same as if a 100% specular reflecting film is used instead of the sputtered silver. This indicates that our sputtered flat silver is a good reflector. Nevertheless the highest EQE is achieved when a non-metallic reflector is added on top of our rough back ZnO. In this case, the same EQE is measured as if we apply a white diffuser or a specularly reflecting film. From this we can conclude that our current cell configuration with a rough front electrode and a rough back electrode is optimal. But as seen below for this case, we do not really need a diffuse reflector at the back. The rough ZnO seems to sufficiently diffuse the reflected light in combination with a specularly reflecting film.

1.5 Advanced substrates and superstrates

Nanotextured sub- and superstrates, fabricated via our recently developed high-fidelity ultra–violet nanoimprint lithography (UV-NIL) process [Esc10], were integrated into amorphous, microcrystalline and micromorph tandem solar cells both in sub- and superstrate configuration [Bat10, Bat10b, Bir10]. Excellent light incoupling is achieved, enabling remarkable efficiencies, as high as for cells on state-of-the-art ZnO layers grown by low-pressure chemical vapor deposition (LP-CVD). In particular, for the superstrate configuration, this was made possible by the development of hydrogenated indium oxide (In_2O_3:H), a high-mobility, ultra-low absorption alternative to the more conventional indium tin oxide (ITO). Our results validate UV-NIL as an experimental platform for the search of the most efficient light trapping structure. UV-NIL provides full flexibility in integrating a large number of nanostructures into high-efficiency devices and allows in principle for high-throughput large-area nanoscale patterning at low cost, as is required for photovoltaic applications. We anticipate that our results will trigger many subsequent experimental studies focusing not only on device performance but also targeting a more fundamental understanding of nanophotonic effects in devices.

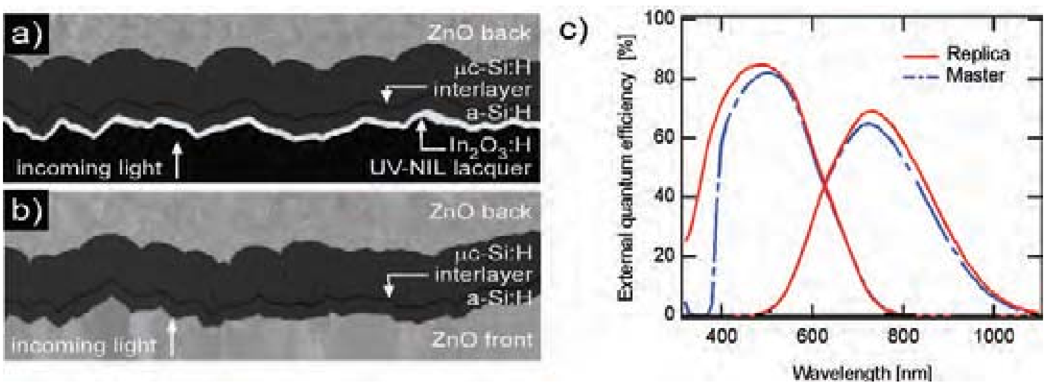


Fig. 6 Scanning electron microscopy cross section of a micromorph solar cell on a replicated transparent superstrate (a) with In_2O_3:H front electrode and the standard ZnO front electrode (b), which served as a master for the replication process. Both cells have an initial efficiency of 12.0%. External quantum efficiencies showing substantial current improvement with 25.9 mA/cm^2 total current (12.9 mA/cm^2 top and 13.0 mA/cm^2 bottom) on the nanoimprinted superstrate vs 24.0 mA/cm^2 total current (11.9 mA/cm^2 top and 12.1 mA/cm^2 bottom) on the master ZnO reference cell.

[Esc10] J. Escarré, K. Söderström, C. Battaglia, F.-J. Haug, and C. Ballif, accepted for publication in Sol. Ene. Mat. Sol. Cells (2010)
[Bat10] C. Battaglia, K. Söderström, J. Escarré, F.-J. Haug, D. Dominé, P. Cuony, M. Boccard, G. Bugnon, C. Denizot, M. Despeisse, A. Feltrin, and C. Ballif, Appl. Phys. Lett. 96, 213504 (2010)
[Bat10b] C. Battaglia, J. Escarré, K. Söderström, L. Erni, L. Ding, G. Bugnon, A. Billet, M. Boccard, L. Barraud, S. De Wolf, F.-J. Haug, M. Despeisse, and C. Ballif, submitted (2010)
[Bir10] R. Biron, C. Eminian, J. Escarré, K. Söderström, F.-J. Haug, V. Terrazzoni-Daudrix and C. Ballif, to be published (2010)

1.6 Plasmonic effects for light scattering

Free electrons in a small metallic particle can respond to the alternating electromagnetic field of light waves by collective oscillations, so called plasmons. In small particles, plasmons respond almost instantaneously to the light, resulting in a strongly radiating dipole field with a uniform intensity profile around the dipole axis. This latter aspect can be used for light scattering and makes localized plasmon resonances attractive for solar cells. Silver or gold nanoparticles are normally used, because their resonance frequencies are in the range of visible light, and because they are excellent conductors that exhibit only a relatively small amount of parasitic losses by Ohmic damping within the particle. Silver nanoparticles can easily be formed by recrystallization. After deposition of thin films with typical thicknesses between 15 and 25 nm, a simple thermal annealing step at 180°C is sufficient to contract the continuous film into small particles, similar to condensation of water vapor on a glass plate. Particles size and density are related to the initial film thickness. Fig. 7 shows nanoparticles with a typical size of about 100 to 150 nm.

We integrated these nanoparticles into the back reflector of amorphous thin-film solar cells. Fig. 7 includes a comparison of EQEs measured on cells with and without nanoparticles. Clearly, the effect of light scattering is evident for wavelengths between 600 and 750 nm, resulting in an enhancement of the photocurrent by 20%. While encouraging, the effect is smaller than standard texturing methods. In future experiments we plan to work on a better control of the particle shape because theoretical work suggests that oblate deviations from the ideal spherical shape results in absorption losses.

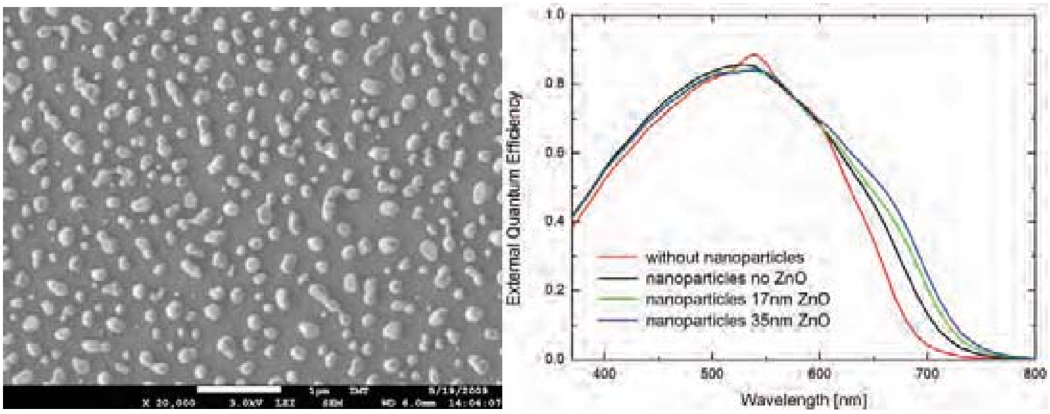


Fig. 7 Silver nanoparticles formed by recrystallization of a 15 nm thick silver film (left). After integration into solar cells, the nanoparticles yield current enhancement by scattering of long wavelength light (right).

[Emi10] C. Eminian, F.-J. Haug, O. Cubero, X. Niquille, C. Ballif, Progress in Photovoltaics (2010)
[Emi10b] C. Eminian et al., Proceedings of the 25th EU-PVSEC, Valencia (2010)

2. Processes

2.1 Amorphous silicon solar cells

In order to further increase the stabilized efficiency of hydrogenated amorphous silicon (a-Si:H) cells, theoretical studies on the impact of electrical field deformation due to charged band tail states and dangling bonds were conducted [Stu10]. These studies will be further continued in order to determine which parameter limits the degraded fill factor. The different a-Si:H cells developed and degraded throughout this year permitted to identify the main optimizations to be carried out:

1. realizing an efficient light trapping: this permits using thinner intrinsic films, reducing the metastable defect density impact on the cell electrical performances. This is viable only for cells retaining high electrical performance on textured substrates.
2. developing an absorber layer with low microstructure factor (low micro-void density) and low defect density in the degraded state
3. optimizing the p-i and i-n interfaces with control at the nanometer scale of doping, bandgap and structural composition, in order to limit electric field deformation

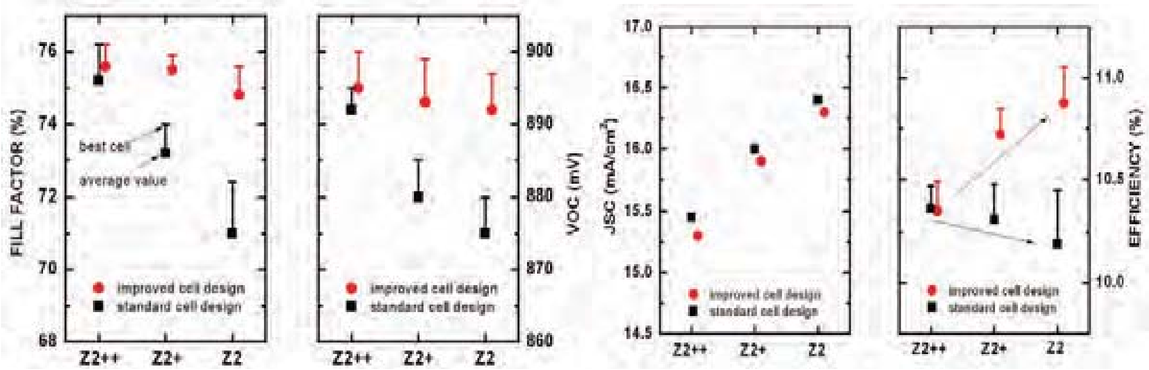


Fig. 8 Initial performance of 250 nm thick amorphous silicon cell deposited on as-grown ZnO (Z2), lightly and heavily treated ZnO (Z2+ and Z2++), for a standard design and an optimized design with a n-type doped silicon oxide interlayer and improved i-layer

In order to benefit from an efficient light trapping (point 1), highly textured substrates are used but can result in the creation of undesired local current drains, degrading the electrical performance and the reliability of the solar cells [Des10, Des10b], (see Fig. 8). Benefits of the texture on efficiency can thus be partly or even completely lost. Strong light trapping has therefore to be realized while maintaining optimum electrical properties of the cells. The optimization of this trade-off is essential and was realized by combining n-type nanocrystalline SiO_x interlayers together with novel intrinsic amorphous silicon absorber layers deposited at 1.5 Å/s [Des10b]. This cell design allows one therefore to benefit from an efficient light trapping to realize a thinner cell, which in turn will be less sensitive to light induced degradation. Results obtained with a 250 nm thick amorphous cell on increasingly rough front electrodes (Z2++: heavily treated ZnO, Z2+: lightly treated ZnO and Z2: as-grown ZnO) are presented in Fig. 8 both for the standard cell design and for cells implementing this year's developments.

Optimizations of the absorber layers (point 2) keeping a low bandgap were conducted in both the small-area PECVD system and the KAI reactor, with a reduction by a factor of 2 of the deposition rate, resulting in a slight decrease in the cells degradation. Finally, a clear roadmap to conduct optimization of point 3 was established. While more efficient light trapping can be used thanks to the new cell design and while next steps of developments were identified (points 2 and 3), the next studies will clearly be eased thanks to the effort carried out in this year on the characterization tools: FTIR and PDS set-ups were customized for efficient assessment of absorber layer quality, a new-generation light-induced-degradation system was purchased and a novel system for accelerated degradation is under development to speed up the studies and optimizations.

[Stu10] M. Stückelberger, A. Shah, J. Krc, M. Despeisse, F. Meillaud, and C. Ballif, Proceedings of the 35th PVSEC, Hawaii, (2010)
[Des10] M. Despeisse, G. Bugnon, A. Feltrin, M. Stueckelberger, P. Cuony, F. Meillaud, A. Billet, and C. Ballif, Appl. Phys. Lett., 96, 073507 (2010)
[Des10b] M. Despeisse et al., to be published (2010)

2.2 High-quality microcrystalline layers in KAI system

Because thick intrinsic microcrystalline silicon (µc-Si:H) layers are required for obtaining high-efficiency tandem a-Si:H/µc-Si:H devices, finding plasma conditions which allow for a high deposition rate while retaining good material quality material is essential for reducing production costs. In particular the role of secondary gas-phase reactions during plasma deposition was studied in the KAI-M system, via infrared laser-based silane sensor (ILSS), laser light scattering (LLS), and optical emission spectroscopy [Par10]. A systematic improvement of the material properties with enhancement of such reactions was observed (Fig. 9), leading to increased efficiencies. We could show that powder-rich processes or processes at the onset to powder formation are favorable for the deposition of device-grade µc-Si:H. Our conclusion is supported by state of the art single-junction and tandem devices deposited at high rate (1 nm/s) having initial conversion efficiencies of 7.9% and 11.9%.

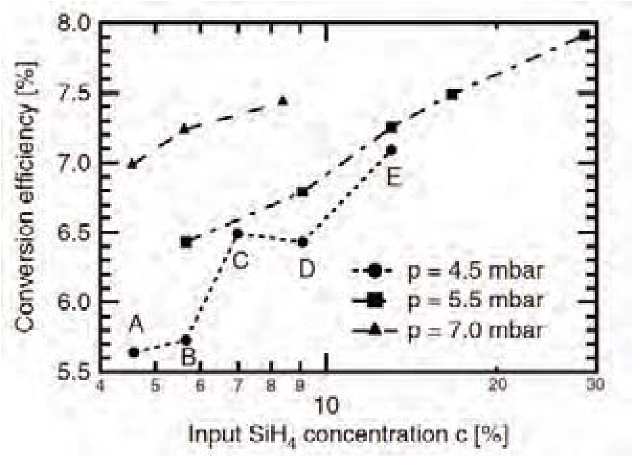


Fig. 9 Efficiency of microcrystalline solar cells deposited at 1 nm/s using process pressures of 4.5, 5.5 and 7.0 mbar as a function of input silane concentration for their intrinsic layer deposition. Lines are guides for the eye.

Improvement of intrinsic µc-Si:H material quality was also obtained at a lower growth rate, mainly thanks to the possibility of using increased deposition pressure for the intrinsic µc-Si:H plasma processes. An initial efficiency of 8.8% was obtained for a 1.6 µm thick single junction p-i-n cell.

The novel low-conductivity nanocrystalline silicon oxide doped layers were also developed in the KAI-M and introduced in the µc-Si:H cell design. These allowed reaching even higher efficiencies, thanks to the added benefit of an increased resilience of the cell when deposited on highly textured substrates. µc-Si:H material is known to be very sensitive to the substrate roughness with localized microcracks developing from the bottom of the V-shaped valleys on the substrate, when growth fronts encounter each other during the deposition. Nanocrystalline silicon oxide layers enable also here the use of rougher substrates enhancing the short-circuit current density, without sacrificing open-circuit voltage and fill factor, as it was typically the case with standard doped layers (see Fig.10) [Des10]. All current processes for both low and high growth rates benefited from a substantial efficiency boost thanks to these layers, with a maximum observed for the most sensitive deposition processes (higher growth rates) up to 20%. Further studies are on-going to estimate the impact of the i-layer process conditions onto the material bulk quality and onto the density and amplitude of the local current drains. These studies combined with additional comparisons of cells integrating standard or nc-SiO_X:H doped layers for other TCO morphologies will allow for an improved understanding of such possible quenching effects, and on the exact requirements for high quality absorber layer; both for its bulk and for its passivated grain boundaries qualities.

Thanks to these doped layers and absorber layers developments, high initial conversion efficiencies of 9.5% for a µc-Si:H p-i-n single junction deposited at 0.3 nm/s could be obtained in the KAI-M system and 9.9% in the small-area system at 0.2 nm/s, both with no anti-reflective coating applied on the air-side of the front glass, therefore approaching record efficiencies for µc-Si:H single junctions.

[Par10] G. Parascandolo, R. Bartlome, G. Bugnon, T. Söderström, B. Strahm, A. Feltrin, and C. Ballif, Appl. Phys. Lett 96, 233508 (2010)
[Des10c] M. Despeisse, M. Boccard, G. Bugnon, P. Cuony, T. Soderstrom, G. Parascandolo, M. Stuckelberger, M. Charrière, L. Lofgren, C. Battaglia, S. Hänni, A. Billet, F. Meillaud and C. Ballif, Proceedings of the 25th EU-PVSEC, Valencia (2010)
[Bug10] G. Bugnon et al., Proceedings of the 25th EU-PVSEC, Valencia (2010)

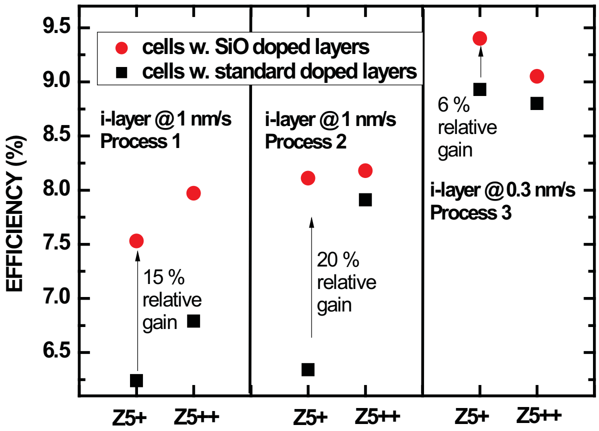


Fig. 10 Impact of front electrode surface roughness (Z5+ rougher than Z5++ with less front TCO treatment time) and of the use of doped oxide layers onto the performance of 1.6 µm thick µc-Si:H cells.

2.3 Nanocrystalline silicon oxide as transparent window layer

Owing to its location at the front of the device, the p-layer is responsible for substantial absorption losses in the blue part of the spectrum. Because there is not much margin in further reducing its thickness, an alternate possibility to reduce the absorption is increasing the band gap, e.g. by alloying of silicon with carbon to form p-doped amorphous silicon carbide.

We investigated silicon oxide as an alternative route: Silicon oxide is obtained by adding CO_2 to the silane-hydrogen mixture that is typically used for microcrystalline p-layers. Fig. 11 shows that the addition of CO_2 reduces the conductivity while the activation energy increases. Despite the high hydrogen dilution, the crystallinity of these films drops from microcrystalline to almost fully amorphous.

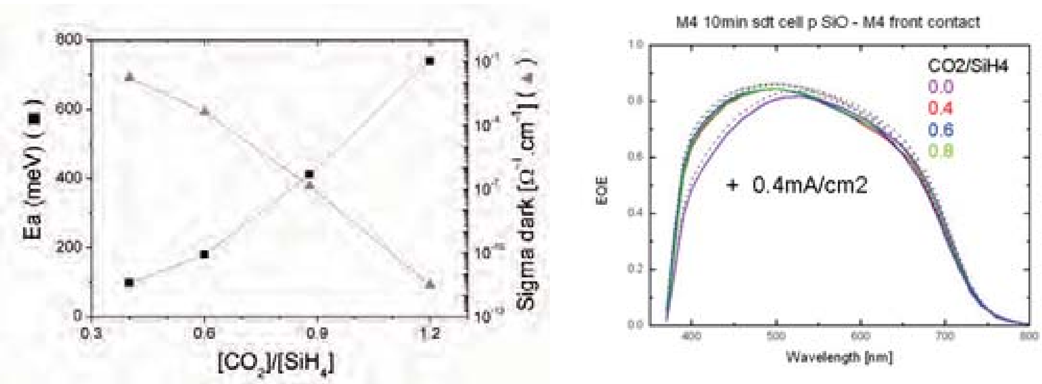


Fig. 11 Variation of activation energy and conductivity of p-doped SiO_x layers (left). Their incorporation into n-i-p cells layers yields better spectral response in the blue (right).

The external quantum efficiency in Fig. 11 shows that the optical effects are very sensitive to the presence of oxygen. Compared to a cell with the standard p-layer, an increased blue response equivalent to 0.4 mA/cm^2 is already noted for a CO_2 to silane ratio of 0.4; increasing the CO_2 flux further yields no more optical gain, but FF starts dropping because of increasing series resistance.

3. Devices

3.1 High efficiency micromorph developments

Several recent advances in materials and process development, discussed in the previous sections, were combined in micromorph devices. The newly developed doped silicon oxide layers and optimized amorphous and microcrystalline material qualities allow boosting light absorption in the cell, by using rougher substrates, while maintaining good electrical properties in the cell [Des10]. A better understanding of the optical requirements of the front electrode was achieved thanks to the study involving bilayers made of ITO and ZnO [Boc10]. Not only transparency of the front electrodes was improved, but also the interaction between front electrode and intermediate reflector was optimized. Based on these improvements, new lab-record micromorph cells with 13.7% initial efficiency and a total current of 27.7 mA/cm^2 could be obtained with 240 nm top and 2.8 µm bottom cell thicknesses [Boc10b]. A relative degradation of 16% after 1000 h light soaking experiment led to a stabilized efficiency of 11.5%. A thinner tandem cell with reduced degradation (only 10%), with only 1.1 µm for the bottom cell was also fabricated, showing an excellent initial efficiency of 12.7% and 11.3% stabilized [Des10c]. These values are amongst the highest efficiencies reported this year and further careful optimization of these cells should lead to even better results.

[Boc10] M. Boccard, P. Cuony, C. Battaglia, M. Despeisse, C. Ballif, Phys. Stat. Sol. RRL (2010)
[Boc10b] M. Boccard, P. Cuony, T. Söderström, G. Bugnon, M. Despeisse, C. Battaglia, L. Ding, S. Nicolay and C. Ballif, Proceedings of the 25th EU-PVSEC, Valencia (2010)
[Des10] M. Despeisse, G. Bugnon, A. Feltrin, M. Stueckelberger, P. Cuony, F. Meillaud, A. Billet, and C. Ballif , Appl. Phys. Lett. 96, 073507 (2010)
[Des10c] M. Despeisse, M. Boccard, G. Bugnon, P. Cuony, T. Soderstrom, G. Parascandolo, M. Stuckelberger, M. Charrière, L. Lofgren, C. Battaglia, S. Hänni, A. Billet, F. Meillaud and C. Ballif, Proceedings of the 25th EU-PVSEC, Valencia (2010)

3.2 Triple junction cell developments

To limit the effect of light-induced degradation of amorphous silicon on conversion efficiency, the use of thinner amorphous silicon layers is clearly beneficial. With respect to the micromorph tandem junction, where an amorphous top cell is used, a triple junction design allows one to further reduce the thickness of the amorphous layers. We have tested a triple junction p-i-n solar cells with a-Si/µc-Si:H/µc-Si:H structure, promising a high efficiency potential with a very thin amorphous top cell.

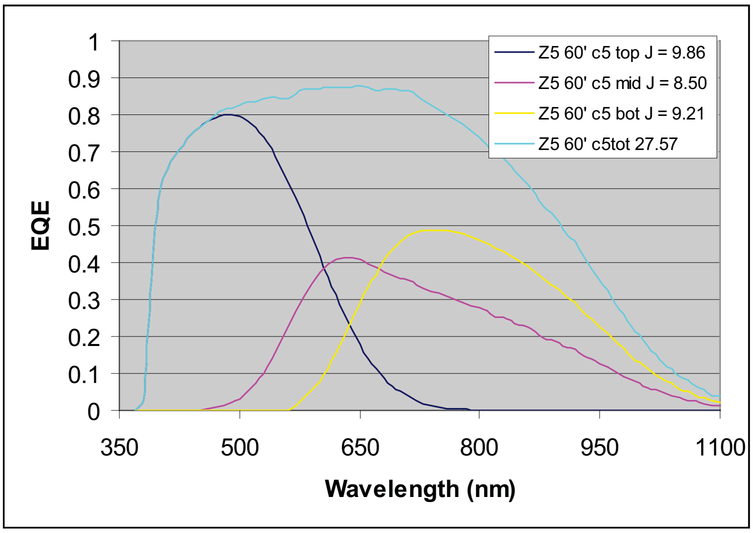


Fig. 12 EQEs of the three subcells of the a-Si/µc-Si:H/µc-Si:H triple junction device made in the KAI-M system. Total current is also indicated.

The best device so far obtained has thicknesses of 140 nm for the amorphous top cell, 1.5 µm and 2.6 µm for the microcrystalline middle and bottom cells. As of now, the best initial efficiency is 11.4%. Efficiency is mainly limited by the low V_{oc} of only 1.76 V. This low V_{oc} can be attributed to the non-optimal tunnel recombination junctions. Values above 1.85 V should be attainable in the near future by working on the doped layers. The total current of 27.6 mA/cm^2 may also be improved using rougher substrates.

Proper determination of triple junction device efficiency is also under investigation as one has to take care of artifacts appearing in the measurement of the external quantum efficiency when working under light and voltage bias conditions. Proper procedures to measure such devices are under development.

4. Reliability

A constantly increasing number of polymeric films and back-foils are put to sustain reliability tests. Ongoing measurements show variable levels of compatibility between encapsulation materials and thin film silicon photovoltaic technology. Usually, the processes for the encapsulation films are optimized in order to obtain the best results in the reliability tests, which generally is the case, when adhesion has been maximized.

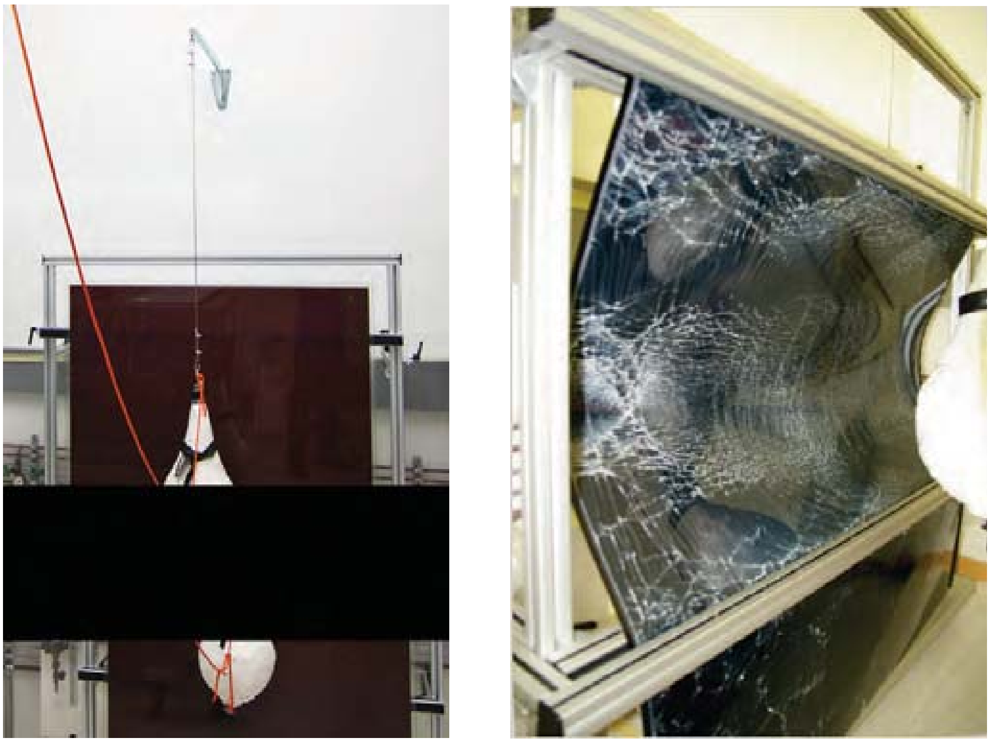


Fig. 13 Breakage test, the 45 kg impactor is thrown towards the module until the later breaks. In the case shown here (right), there are almost no glass pieces that have been detached from the module and the test should be considered as passed.

The mechanical load test, according to IEC 61730 norm, has been implemented by means of a simple setup of weights which can be smoothly deposited on the system to be tested. The two layers of weights correspond to the 2400 Pa and 5400 Pa loads. The modeling of the stresses generated by the load is achieved by finite elements analyses and confirmed with the experimental measurements of the deformations and the maximum load that the module can withstand.

The breakage test, according to IEC 61730 norm, has been installed. The goal of this test is to probe the safety level brought by a given encapsulation scheme in the case of somebody (or any heavy load) falling on the module. The pass criterion is related to the number and size of the glass fragments after breakage. The impactor is a 45 kg, lead filled, punch ball which is sent against the PV module from increasing heights until the module breaks (see Fig. 13). Preliminary results seem to indicate that an encapsulation solution may pass the breakage test before the exposure to damp heat, but fail afterwards due to the degradation of the adhesion of the encapsulant film. An optimized lamination process should prevent failure after accelerated aging.

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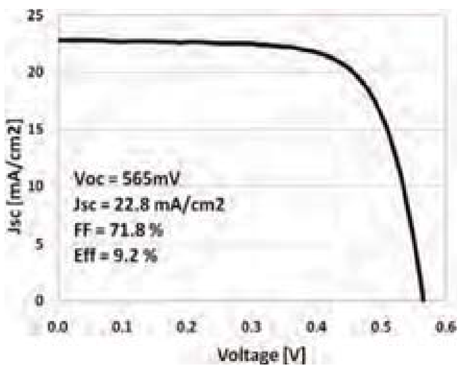
5. Infrastructure improvements

In 2010, the effort was continued tu upgrade/renew the infrastructure.

- First cell results were obtained in the newly installed Octopus cluster PE-CVD systems. The system is up and running at full speed. Microcrystalline p-i-n cells with excellent efficiencies of up to 9.2% have already been achieved (see Fig. 14). Also n-i-p cells are under development with current initial efficiencies reaching 7.3% for amorphous cells. Several hard- and software updates have been performed to optimally adapt the cluster system to cell deposition.
- One of our multi-target sputtering tools has been upgraded to allow the deposition of hydrogenated indium oxide, which represents an extremely interesting high-mobility alternative to the well established indium tin oxide. Electron mobilities above 100 cm^2/V.s are now routinely achieved with record layers achieving mobilities above 120 cm^2/V.s.
- A new state-of-the-art dual-lamp simulator with high-quality spectrum has been installed and is used on a daily basis. The air conditioning system of the measurement room has been upgraded to compensate for the additional heat dissipation and guarantee standard test conditions.
- At the photothermal deflection spectroscopy (PDS) setup, a new detector for transmittance was installed. In addition a newly installed shielding box and optimized optics allow for a higher signal-to-noise ratio. Currently monitoring of layer deposition, surface defect layers or material stability is performed on this setup and the potentials and limitations of PDS are assessed.
- The thermo-lockin setup has been upgraded with a monochromatic light source provided by an array of LED's allowing to image shunts in an array of cells much faster than on the previous setup, as tedious contacting of each individual cell is not anymore required.
- A chemical mechanical polishing (CMP) setup has been developed allowing a reduction the surface roughness of various layers down to a few nanometers.
- Regarding the development of the new large-area LP-CVD tool, the deposition chamber and load-lock chamber are installed. Gas lines and gas cabinets are being prepared, while the pumping system is also being put in place. First depositions are expected by February 2011.
- Concerning the infrastructure with respect to reliability, a temperature and humidity controlled polymer storage room has been installed and is running. In addition a full set-up for mechanical load and breakage tests has been installed and is operational.
- Furthermore a desktop laminator used for optimizing lamination processes has been designed and fabricated. An up-grade is planned for next year in order to make this laminator partly transparent.
- In a project with another entity, a new hybrid LED/halogen large-area solar simulator allowing for a variable spectrum and a variable illumination pulse shape was built satisfying the AAA classification norms [LO10].



a)

b)

Fig. 14 a) J-V curve of the best µc-Si:H cell so far obtained on the newly installed Octopus PE-CVD cluster tool. b) Picture of the new LP-CVD deposition system.

Collaboration and synergies with other projects

Regular academic contacts/scientific and sample exchanges continued to be maintained throughout the project both with national and international entities (AIST Japan, University of Ljubljana, University of Delft, University of Patras, Forschungszentrum Jülich, Friedrich-Schiller

Universität Jena, Academy of Science Prague, Energy Research Center Netherlands, Stanford University, National University of Singapore ...). J. Holovski, Academy of Science Prague and T. Matsui, AIST Japan, are and were respectively guest scientists focusing on FTPS and on the stability of the amorphous silicon cell respectively during their stay at the PV-Lab.
IMT continues to be involved in several European projects: N2P, HETSI. The new FP7 projects Silicon Light and Pepper were started. IMT is also involved in the Swiss CCEM-CH/Swiss Electric Research Thin film PV project and in the recently accepted DURSOL project. A strong synergy is or could be realized between all these projects and this running SFOE project. National collaborations with industrial partners are ongoing, either in the frame of CTI projects or through direct mandates, e.g. with OC Oerlikon, VHF-Technologies, Roth & Rau Switzerland, 3S, Pasan, Metalor etc. As highlights at the 25th EUPVSC, IMT coauthored the Oerlikon paper of J. Bailat et al. on the new certified record micromorph on glass at 11.9% and the Roth & Rau Switzerland paper of D. Lachenal reporting 21% efficient heterojunction c-Si cells. Together with the company Brightview, IMT also reported at this conference on a new in-line fast mapping tool [Wyr10].

Evaluation of 2010 / perspectives for 2011

As the results of 2010 demonstrate, nanocrystalline silicon oxide is a highly interesting material for photovoltaic applications. Further investigations are however necessary to fully understand the structure and properties of this new material and investigate its influence on the stability of the cells. The improved device tolerance to rough substrates, obtained trough the integration of nanocrystalline silicon oxide layers into devices as well as improved silicon absorbers, resulted in a significant efficiency boost in all devices leading to record internal efficiencies. Eventually this will help control better the interaction between top cell and bottom cell, which influences each other during processing. In parallel, the validation of nanoimprinting as an experimental platform to integrate novel photonic nanostructures directly into high-efficiency devices, will allow to implement even more aggressive light trapping schemes in the future. Following these developments, we anticipate a trend towards thinner cells, as this not only reduces material consumption and deposition time, but also leads to improved stability with respect to light induced degradation. As our preliminary results on thin micromorph cells clearly demonstrate, thin cells are capable of achieving very high efficiencies and further efficiency improvements are in close reach.

Acknowledgements

All the PV-Lab collaborators, who contributed to the results presented in this report, are warmly acknowledged. We also thank D. Alexander, A. Hessler, M. Dadras and M. Leboeuf for assistance and support in electron and scanning probe microscopy.

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Most of these references acknowledge the SFOE support under project 101191. Preprints of most papers are available from http://pvlab.epfl.ch/.

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A NEW LOW ION ENERGY BOMBARDMENT PECVD REACTOR

DEPOSITION OF THIN FILM SILICON FOR SOLAR CELL APPLICATIONS

Annual Report 2010

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Date	10.12.2010

ABSTRACT

A novel electrode configuration is proposed for improved plasma-enhanced chemical vapour deposition of films such as amorphous silicon and micro-crystalline silicon. The new electrodes are designed to de-couple the film deposition from the plasma generation zone. The deposited films are thus protected from damage by plasma ion bombardment, which is crucial for the manufacture of high-performance photovoltaic material. The new plasma reactor concept is being optimised in laboratory experiments and has been developed into a R&D industrial pilot reactor. Film quality tests are currently underway. Finally, a feasibility study for a large area reactor will be carried out to evaluate the usefulness and cost-of-ownership for production of next-generation thin film equipment.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Département fédéral de l'environnement,
des transports, de l'énergie et de la communication DETEC

Office fédéral de l'énergie OFEN

FLE IBLE PROD CTION TEC NOLOGIES AND E IPMENT BASED ON ATMOSP ER IC PRESS RE PLASMA PROCESSING FOR D NANO STR CT RED S RFACES N P

Annual Report 2010

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Project- / Contract Number	CP-IP 214134-2 N2P
Duration of the Project (from – to)	June 2008 to December 2012
Date	14.12.2010

ABSTRACT

Although important progresses have been made in the development of novel structures for 3D nano-surfaces applications, their use at large scale is still partly limited by lack of high throughput suitable manufacturing technologies.The overall objective of this project "N2P" (Nano to Production) is to develop and substantially enhance the position of Europe in the science, application and production technologies of surface 3D nano-structuring. In this proposal, the consortium develops innovative in-line high throughput manufacturing technologies based on atmospheric pressure vapour phase surface and plasma processing technologies. Both approaches have significant potential for 3D nano-structuring, but their effective simultaneous combination is particularly promising. It is proposed to merge the unique potential of atmospheric pressure based plasma-chemical etching with vapour phase based nucleation and growth.

The role of the PV-Lab is to guide the development of SnO2 TCO layers for thin film silicon photovoltaic activities by working in close collaboration with the University of Salford and CVD Technologies Limited, both specialists in atmospheric CVD. Regarding photovoltaic applications, the goal is to optimize the TCO film in order to achieve energy conversion efficiencies higher (>7% relative) than the ones obtained with in-line produced industrially available TCO.

Another part of the photovoltaic related development of the project consists in developing atmospheric plasma etching for post surface treatment of the TCO films, which is needed to allow the deposition of a good quality absorber material. Both these objectives are pursued by carefully correlating the optical, electrical and morphological properties of the TCO films with the performances of the cells deposited on these films.

It has been shown in the first two years that devices with relative efficiency increase of 20% compared to in-line products can be achieved on the newly developed TCO layers. In addition, the reached efficiencies are comparable to those obtained with off-line (higher quality) produced TCO.

Pr ec G al

Although important progresses have been made in the development of novel structures for 3D nano-surfaces applications, their use at large scale is still partly limited by lack of high throughput suitable manufacturing technologies. The overall objective of this project “N2P” (Nano to Production) is to develop and substantially enhance the position of Europe in the science, application and production technologies of surface 3D nano-structuring.

Regarding the thin film silicon development, the main goal of the project is to develop the atmospheric CVD (ACVD) process for in-line TCO (SnO_2:F) on glass production in order to achieve a relative increase of 7% solar cell efficiency compared to industrially available in-line products on both single junction and micromorph devices. Another goal is to demonstrate the possibility to use atmospheric plasma etching as an efficient way to modify the surface morphology of TCO films allowing developing high efficiency cells by combining at the same time high photo-generated current and high FF and Voc.[1]

During the first two years of the project, the development of the ACVD process led to the demonstration that it was possible to produce TCO films with higher transparency and diffusive power on the whole wavelength range compared to industrially available products (both in-line and off-line). This led to higher photo-generated current in the thin film solar cells. In addition, the devices deposited on the new TCOs showed similar electrical properties compared to the in-line industrial standard but lower Voc and FF compared to the off-line product. This was mainly ascribed to the presence of more defective absorber material deposited on the new SnO_2 films.[1] **E en all ingle nc i n a Si cell de i ed n e ne TCO fil are c arac eri ed an efficienc ig er an de ice de i ed n ind rial in line r d ced fil and e a e cell a e an efficienc c ara le e ne gr n n ff line r d c**

De cri i n f e r ec

The project takes place in the framework of the FP7 theme 4: Nanosciences, Nanotechnologies, Materials and new Production Technologies. Compatible with the call, the research focus is on the application of basic research results for the development of new manufacturing processes and equipment for new science based products in order to create potentially disruptive products and production systems. The project relies on strong collaborations between teams in charge of depositing the TCO films (Universit of Salford (USAL), UK), equipment development (CVD Tech (UK), Manchester University (UK)), evaluation (EPFL) and demonstration (Nuon Helianthos (NL)) as shown in Fig. 1.

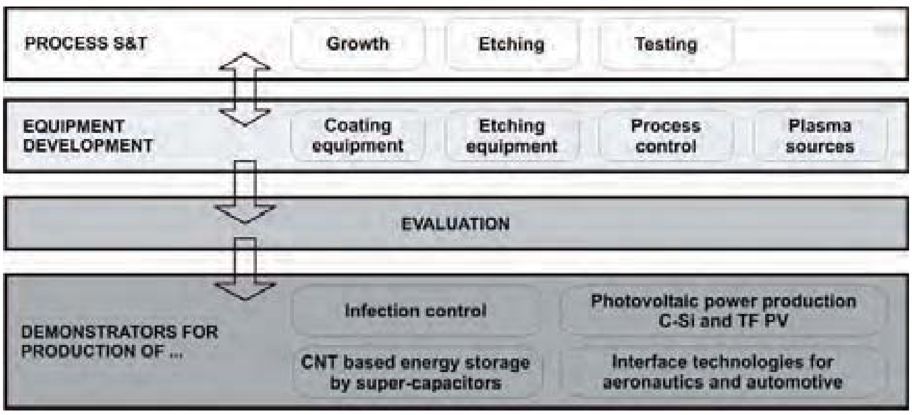

Fig.1. Structure of the project (N2P project proposal)

W r and re l af er n

In the development of the new ACVD process, two different Sn precursors are used: tin tetrachloride (TTC) and monobutyl tin trichloride (MBTC). As grown TCO layers were characterized both at EPFL and USAL by photospectrometry, angular resolved scattering measurement and Hall Effect measurement. Cells deposition was performed at EPFL by plasma enhanced CVD (PECVD) while these cells were characterized by I-V and spectral response measurements. The diffusion of light and the free carrier absorption of light inside TCO are of major importance for TF cells. The former should be the highest possible for improved photogenerated current while the latter should be as small as possible to achieve high transparency electrode films. Therefore, a major emphasize has been brought first to investigate these parameters on the TCO films deposited at USAL. Samples E6-E7-E10 were deposited with MBTC with a thickness of 650 nm, while samples E71R1 and E71R6 were deposited with TTC and are 800 nm thick. Industrial in-line product TCO 1 (+/- 700 nm thick) and off-line product TCO 2 (+/- 1 µm thick) were used as reference samples. The optical properties of these layers are shown in Fig. 2.

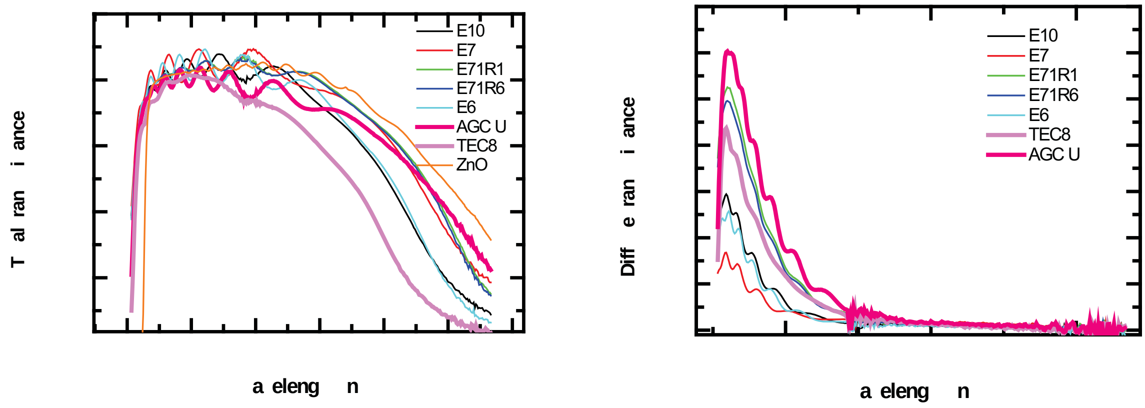

Fig. 2: TT and TD of USAL TCO samples compared to TT and TD of industrial TCOs.

It is clearly seen from these figures that the TTC samples have the lowest FCA, along with MBTC sample E7 probably indicating an unexpected growth parameter variation. This is confirmed on the diffuse transmittance figure where E7 diffusion is the lowest one of both TTC and MBTC samples. From the measurements of total transmittance and diffuse transmittance, it can be said that, **in e e c ndi i n TTC a le are e i ed f r e de i i n f lar cell**

Fig. 3 shows the external quantum efficiency measured on the a-Si cells deposited on the different TCO as well as the photo-generated current in each case.

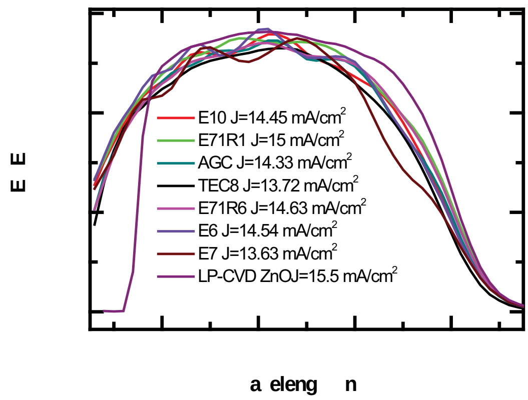

Fig.3: EQE measurements on solar cells deposited on SnO_2 and ZnO substrates.

Fr e e re l i i een a e ig e genera ed c rren n e SnO i ac ie ed n e TTC a le E R ic i c n i en i i l FCA and ig diff i e a ili This current is also higher than both currents measured on commercially available TCOs 1 and 2.

I(V) measurements were also carried out on these samples to calculate the efficiency of the cells. Those measurements were performed at normal illumination but also at low illumination (40%) which gives information on the shunt density present in the layers.

E6:

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
14.323	0.874	0.744	3503.758	5.370	12.917	0.718	9.271	0.057	0.502	0.361	18739.068	0.650

Initial efficiency: 9.4%

3/5

E7:

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
13.357	0.880	0.714	1976.935	6.090	11.701	0.717	8.392	0.046	0.264	0.312	7702.183	0.628

Initial efficiency: 8.6%

E10:

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
13.577	0.873	0.727	2184.051	6.217	12.116	0.709	8.591	0.061	0.407	0.323	11444.264	0.635

Initial efficiency: 9.2%

E71R1:

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
16.846	0.852	0.643	575.383	5.925	13.716	0.671	9.210	0.057	0.049	0.000	822.418	0.548

Initial efficiency: 8.2 %

E71R6 :

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
7.744	0.867	0.704	2769.667	11.009	6.771	0.700	4.742	0.024	0.206	0.267	9734.021	0.610

Initial efficiency: 8.9 %

TCO 1 :

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
14.133	0.851	0.688	2736.436	7.037	12.305	0.671	8.263	0.064	0.322	0.316	7493.780	0.585

Initial efficiency: 8%

TCO 2:

Isc mA/cm²	Voc (V)	FF	Rsc Ohm.cm²	Roc Ohm.cm²	Imax mA/cm²	Vmax (V)	Eff (%)	Isc 0.4 mA/cm²	Voc 0.4 (V)	FF 0.4	Rsc 0.4 Ohm.cm²	FF*Voc
15.605	0.880	0.734	1829.587	5.397	14.142	0.713	10.080	0.055	0.638	0.473	38749.487	0.646

Initial efficiency: 9.3%

Fr e e re l e can ee a e ig e efficienc ac ie ed n e SAL TCO i ea red ar nd c ara le e efficienc f e cell de i ed n ffline TCO and ell a e e ea red n cell c de i ed n e ind rial in line andard TCO

In addition, it is interesting to note that the layer providing the highest cell efficiency is characterized neither by the highest haze nor by the lowest FCA. This is attributed to the better electrical properties of the cell deposited on this sample. Indeed, it has the lowest contact resistance and highest shunt resistance which leads to higher Voc and FF and as a consequence to higher efficiency. Although the TTC samples provide a higher photo-generated current, the cells deposited on them are characterized by low shunt resistance values and relatively higher contact resistance which translates into lower FF and Voc leading to lower efficiency. Typically, low shunt resistance values are ascribed to the formation of voids or region of lesser quality in the absorber material when it is deposited on rough or too acute surfaces. **T i i an i r an in a i lead f c re n e rface r l g in e iga i n f e SAL TCO ac ie e de i i n f g d Si a erial ali T i ld e r ain c nd c ing line ac ie e efficienc a e e ne f ff line TCO**

T e receding re l are ell a e a c ld e fir e ec ed fr TCO de i ed i ne l de el ed r ce e T e SAL fil erc e nline ind rial r d c re an and are e en c ara le e ffline r d c

In addition, these first experiments allowed us to investigate the effect of the different growth parameters on the optical and electrical properties of the TCO films. This leads us to focus our future research on the relation between TCO surface morphology and cell electrical quality in order to achieve higher efficiency.

In erna i nal C lla ra i n

As stated above, the N2P project relies on strong cross cutting activities between equipment development, process optimization, device evaluation and final transfer towards a demonstrator. General assembly meetings bringing together all the partners involved in the project are organized every 6 months. In addition, for the thin film PV cells, a strong collaboration between EPFL and USAL/CVD Tech (UK) is ongoing in the form of regular intermediate technical meetings to ensure an optimum follow up of the progress. Eventually, the PV-Lab also works in close collaboration with the Fraunhofer IWS in Dresden, coordinator of the project, for the development of plasma etching technique on LPCVD ZnO.

e al a i n and r ec f r

During the first years of the project, the development of the ACVD process led to the demonstration that it was possible to produce TCO films with higher transparency and diffusive power on the whole wavelength range compared to industrially available products (both in-line and off-line). In addition, single junction a-Si cells deposited on the new TCO films were characterized by an efficiency 18% higher than devices deposited on industrial in-line produced films and the same cells have an efficiency comparable to the one grown on off-line products. These results are above the expected initially set up project milestones regarding the comparison with in-line industrial products. However, regarding atmospheric plasma etching particles re-deposition in the process have hindered up to now the possibility to achieve good results on plasma treated TCOs.

In the following years, further emphasis will be put on the development of the atmospheric plasma etching process and on the development of TCO films leading to cells characterized by efficiency higher than the one measured on devices deposited on the high quality off-line industrial products. In addition, we will also start to deposit tandem a-Si/µc-Si cells on the new TCOs in order to evaluate the suitability of the new processes with the more sensitive micromorph combination.

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Si LIG T IMPROVED MATERIAL ALITY AND LIG T TRAPPING IN T IN FILM SILI CON SOLAR CELLS

FP-7 PROJECT 241277

Annual Report 2010

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Project- / Contract Number	241277
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Date	Dec. 15th, 2010

ABSTRACT

The project Si-Light is devoted to the investigation of n-i-p solar cells on flexible substrates with focus on material quality, interface properties, and light management. During the first year, work was devoted mostly to higher operation voltages for the amorphous top cells and to nucleation of the microcrystalline bottom cell on strongly textured substrates. Microcrystalline cells require textured substrates for light trapping, but on strong textures they suffer from the formation of zones with bad material quality that forms above V-shaped trenches. Transmission electron microscopy was used to study the extent of such zones with respect to deposition parameters like precursor gas composition and substrate temperature. A second aspect, the development of amorphous top cells with higher operation voltages, necessitates an understanding of the front interface between the p-layer and the transparent conducting oxide (TCO). Combining the two types of cell into a series-connected tandem device still requires careful matching of the current densities. Cells with stabilized efficiency above 10% have thus been obtained.

E FP Pr ec Silic n Lig

The EU project Silicon-Light started in January 2010, its main aspects are flexible thin film silicon solar cells in n-i-p configuration. The consortium consists of:

- ECN (National Energy Research Laboratory of Holland, large area silicon deposition, coordination
- EPFL PV-Lab (high efficiency devices)
- University of Ljubljana (optical modeling)
- Technical University of Denmark (TEM analysis)
- Polytechnic University of Valencia (Mastering of nano-structures)
- Shanghai Jiatong University (Mastering of nano-structures)
- Umicore AG (Liechtenstein, manufacturer of sputtering targets)
- nanotpics GmbH (Germany, roll-to-roll processing of textured plastic substrates)
- VHF technologies S.A. - Flexcell (integration into modules)

W r erf r ed in e re r ing eri d

In the first year, the main points of work at the PV-Lab were the development of high voltage amorphous cells and a systematic investigation of ITO transparent conducting films.

Figure 1 shows the changes of the p-layer conductivity and its activation energy with hydrogen dilution. For dilutions of R = 1 and R>100, the parameters exhibit typical values of amorphous and microcrystalline material, respectively. Intermediate dilutions are called protocrystalline region because the material will eventually nucleate small crystallites and develop into mixed phase or microcrystalline material. In the literature this is reported to show better film quality than amorphous silicon but the measurements of activation energy and conductivity do not support this claim.

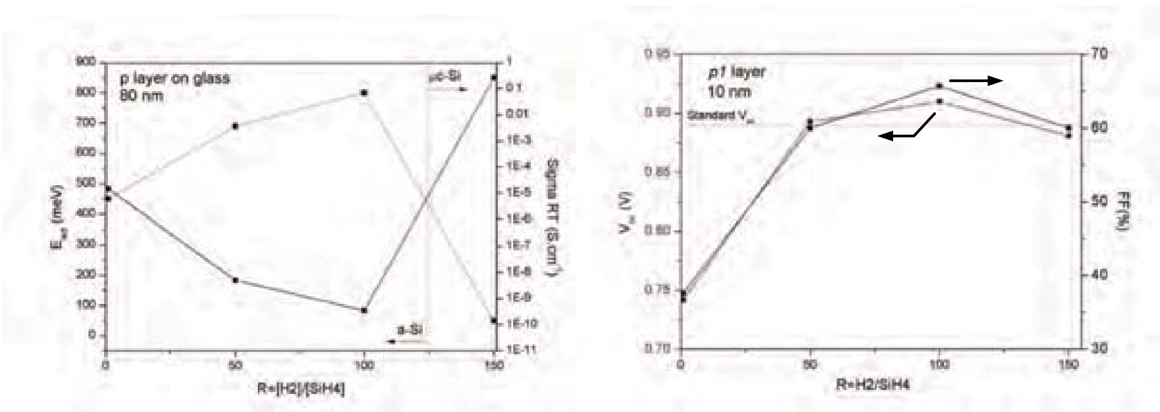

Figure 1 : Variation of the p-layer conductivity and activation energy with hydrogen dilution (left) and behaviour of Voc and FF upon integration of these films into a-Si solar cells.

The p-layers shown in Figure 1 were integrated into solar cells in the following configuration; starting from standard n-i stacks, 10 nm thick p-layers (p1) with various dilutions were applied, followed by a plasma treatment and a second, microcrystalline p-layer (p2) that establishes a good contact to the transparent front ITO. Surprisingly, the dilution of 100 which exhibits the worst material quality on the reference layers, yields the highest values for Voc and FF [1].

Figure 2 compares cross section images of microcrystalline cells on two different types of substrate texture; one is a relatively flat one which forms when silver is deposited onto a heated substrate, here flat glass, the other one is the pyramidal texture of ZnO deposited by low pressure chemical vapour deposition. Compared to textured silver, ZnO represents a texture with much higher aspect ratio, resulting in the formation of defective growth zones above V-shaped trenches.

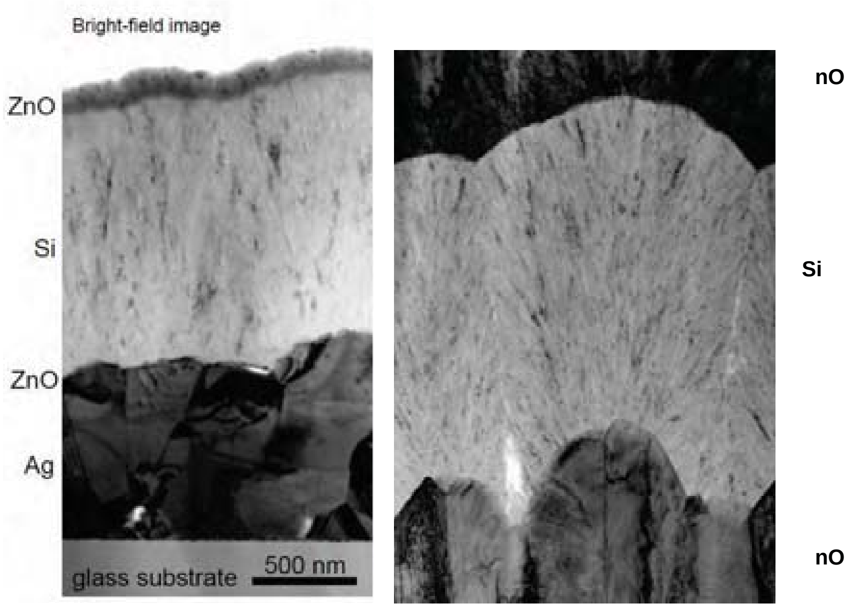

Figure 2: TEM cross section images of microcrystalline cells on textured silver (left) and textured ZnO (right).

Microcrystalline and amorphous cells can be developed quite independently and then be combined into tandem cells. Here we report on a collaboration with the Institute of Advanced Industrial Science and Technology (AIST) in Japan. They delivered microcrystalline bottom cells on Asahi-U substrate, a texture with roughness between the two cases shown in Figure 2. Tandem devices with efficiencies up to 12% (initial) were manufactured by deposition of an asymmetric intermediate reflector and the top cell at EPFL. After exposure to continuous illumination with an intensity corresponding to sunlight and at a temperature of 50°C, these tandem devices stabilized at close to 10% [2]. The external quantum efficiency and the current voltage characteristics of one such cell in initial and stabilized state is shown in Figure 3.

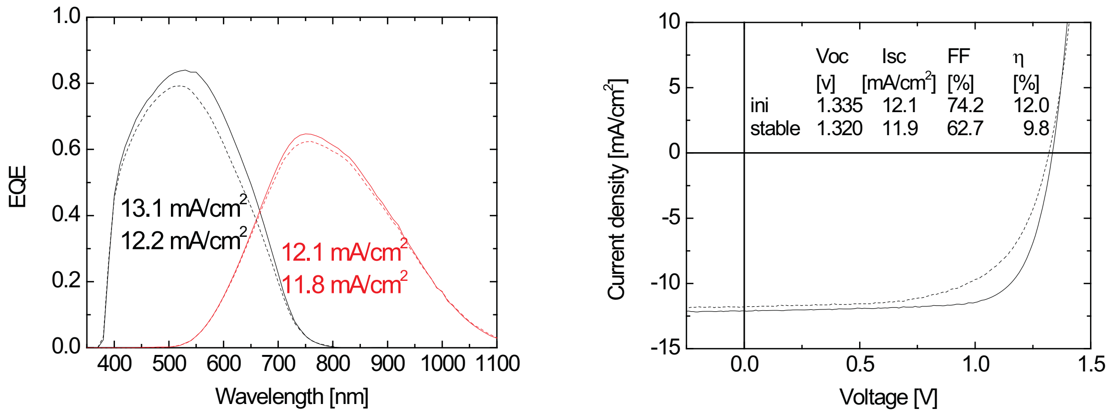

Figure 3: Current voltage characteristics of the micromorph tandem cell in initial (full lines) and stabilized state (dashed lines).

[1] R. Biron et.al., Open circuit voltage improvement using amorphous silicon p-layer for flexible n-i-p solar cells, 5th World Conference on PV Energy Conversion, Valencia, Sep. 2010

[2] F.-J. Haug et.al., Micromorph n-i-p tandem cells with asymmetric intermediate reflectors, 5th World Conference on PV Energy Conversion, Valencia, Sep. 2010

INTERFACE TE T RING FOR LIG T TRAP PING IN SOLAR CELLS

SNF PROJECT 200021_125177/1

Annual Report 2010

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Date	Dec. 15th, 2010

ABSTRACT

The project granted by the Swiss National Science foundation is devoted to a fundamental understanding of the light trapping process. Most solar cell devices make use of fully random structures for light trapping, but light scattering takes place at several interfaces within the device, and superposition of the scattered electric fields makes it difficult to understand the process globally. In the initial phase of the project, the level of complication was therefore reduced by concentrating on periodic structures. Rather than increasing light absorption in a wide range, they result a series of well defined resonances that depend on the period and the shape of the grating structure. A second aspect is the development of modelling tools for the design of novel structures with enhanced light trapping capability. In the first year, the predictive power of the models was tested against the experimental observations in order to gain confidence in the numerical approach, and also to study the influence of morphologic changes of a given initial texture by non-conformal covering.

SNF r ec In erface e ring

The project started in October 2009 as joint collaboration between the PV-Lab and the group for advanced optics. Currently, two PhD students work on the development of optical simulation tools and experimental analysis of dedicated interface textures like periodic grating structures.

In a naïve way of looking at the light trapping process, one would assume that light with perpendicular incidence gets scattered at the textured surfaces and then propagates under an oblique angle to the back contact where it gets scattered once more. If it is weakly absorbed, it might make another passage through the absorber towards the front contact. Because the front contact has a lower refractive index than the silicon absorber, we can expect total internal reflection if the oblique light path is above the Brewster angle of this interface. Very weakly absorbed light can thus bounce back and forth several times. In optical terms this situation represents a waveguide where light is guided in a high index medium by multiple internal reflections.

W r erf r ed in e re r ing eri d

During the first year, periodic textures were investigated because their reduced degree of freedom permits a better separation of the effects that contribute to light trapping. For example, a random texture always yields diffuse scattering, even if the wavelength of the incident light is well defined; just imagine a white sheet of paper. Light scattering from a periodic texture proceeds differently; it takes place into well defined angles by diffraction. Periodic textures can therefore serve as test structure for the more difficult situation of diffuse scattering at a random texture. In thin films the above representation must additionally take into account coherence effects because the electric field amplitude at the front interface superposes with light that went back and forth through the absorber layer. Like interference effects in a flat cell, we expect therefore constructive or destructive superposition between the diffraction orders.

Figure 1 shows that the external quantum efficiency of a solar cell on a periodic texture exhibits well defined absorption peaks in the weakly absorbing region between 550 and 750 nm. They are due to the resonant coupling of incident light to waveguide modes [1]. Figure 1 also shows the variation of these resonances in the EQE with the variation of the incident angle from 0° (perpendicular) to 55°.

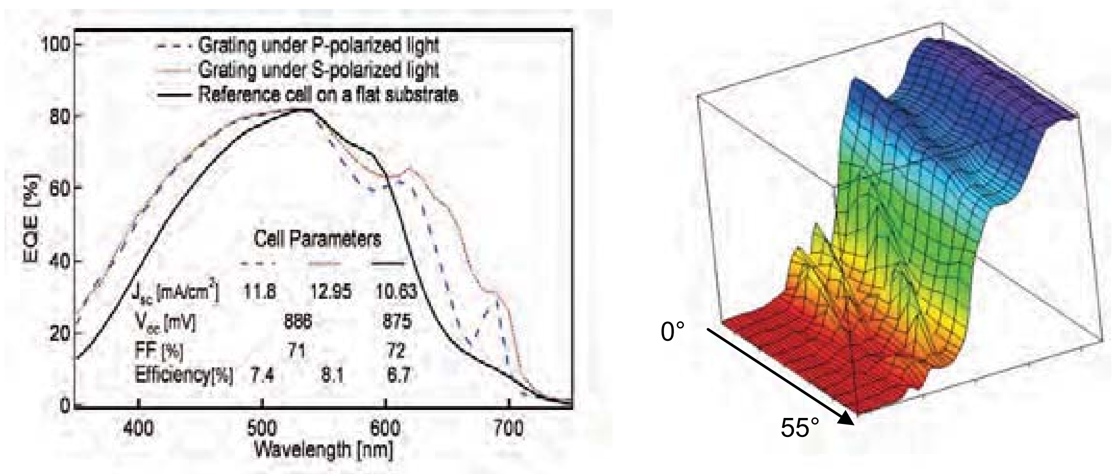

Figure 1: The left panel shows the external quantum efficiency of solar cells on flat reference substrate (black full line) and on a line grating of period 550 nm (dashed and dotted line for TE (P) and TM (S) polarization, respectively). The right panel illustrates the angular variation of the resonances with incident angle between 0 (perpendicular) and 55°.

The measurement of the angular variation can be useful to assess solar cell performance under realistic illumination conditions during the day and throughout the year. Within the project, the detailed analysis of the peak intensity and their angular variation gives valuable input to modeling. Ultimately, this will allow the design of interface textures for ideal light trapping.

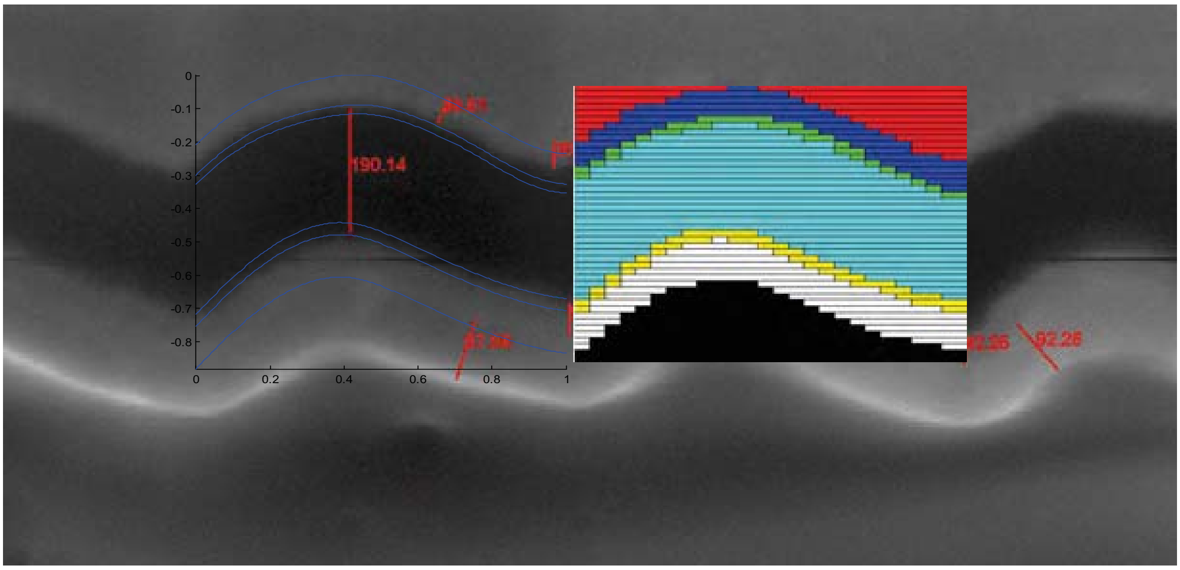

Figure 2: cross section through an n-i-p solar cell structure on a triangular shaped (blazed) grating and the slicing used for modeling. The period and depth are 550 and 140 nm, respectively.

An example of the modeling approach is shown in Figure 2. The solar cell stack is represented by a stack of slices that mimic the exact interface texture. Rigid coupled wave analysis (RCWA) was chosen for the modeling because it allows correct handling of the dielectric data [2]. The competing method of finite difference time domain (FDTD) is notoriously weak in this respect because the frequency dispersion of the refractive indices has to be parameterized and must then be extrapolated to zero frequency in order to represent the steady state solution. RCWA assumes an incident plane wave and calculates the reflected and transmitted waves by solving the boundary conditions within each individual slice, and then between the ensemble of slices and the surrounding media. Slicing can be done to any required degree of accuracy.

The literature on light trapping simulations often proposes structures with vertical faces and sharp tips as “ideal for light trapping”; however, such structures might be difficult to fabricate, and at any rate they would get smoothed out by non-conformal growth. Figure 2 illustrates the experimental realization of a blazed grating that should ideally look like a saw-tooth. It does have relatively straight facets but it already exhibits a slightly rounded tip. Throughout the individual layers of the device, this shape gets further rounded out into a dome-like structure. It turns out that a correct description of the experimental observations must take into account such variations.

After quantifying the numerical model with the experimental situation, a systematic variation of the grating parameters was carried out, using the experimental shape of Figure 2. The resulting map in Figure 3 summarizes the projected current densities which can be calculated from the external quantum efficiency integration. The current densities of 11.8 and 12.95 mA/cm^2 for P- and S-polarizations (c.f. Figure 1) are indicated by black ovals. It appears that slightly deeper gratings promise higher currents, but it is also observed that this particular grating shape has a poor overlap between the polarization directions while it is clearly the goal to design suitable structures for unpolarized sunlight. One possibility to reduce the effect of polarizations, is the introduction of crossed or hexagonal gratings. These will require the development of numerical tools that can handle an additional dimension and will be carried out the next reporting period.

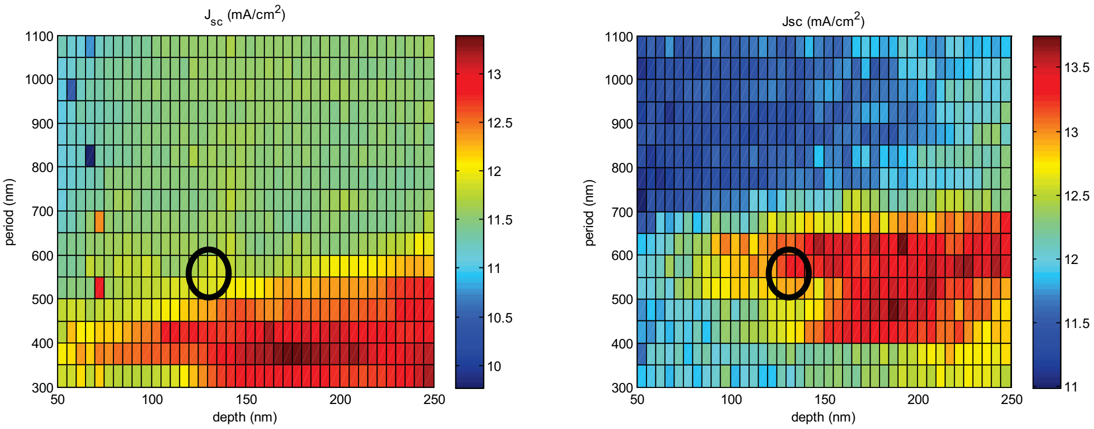

Figure 3: Maps of the current density for a variation of grating parameters. Period and depth are varied by linearly scaling the experimental shape shown in Figure 2.

In summary, our experimental work could clearly show that the excitation of waveguide modes is responsible for light trapping in solar cells with textured interfaces. At the same time, reliable numerical models show excellent quantitative agreement for the tested grating dimensions. Further work in the coming reporting period will investigate a wider range of interface textures.

Reference

[1] K. Söderström et.al, Photocurrent increase in n-i-p thin film silicon solar cells by guided mode excitation via grating coupler, Applied Physics Letters 96, 213508 (2010)

[2] A. Naqavi, Enhanced photocurrent in real thin film solar cells using optimal one-dimensional gratings, submitted to Optics Express

[3] K. Söderström et.al, Photocurrent increase in thin film solar cells by guided mode excitation, OSA optics and photonics congress, Karlsruhe, Aug 2010

[4] A. Naqavi et.al, An RCWA analysis of solar cell back reflectors: Comparison between modeling and experiment, OSA optics and photonics congress, Karlsruhe, Aug 2010

IG EF

LARGE GRAINED, LOW STRESS MULTI-CRYSTALLINE SILICON THIN FILM SOLAR CELLS ON GLASS BY A NOVEL COMBINED DIODE LASER AND SOLID PHASE CRYSTAL-LIZATION PROCESS

Annual Report 2010

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ABSTRACT

The objective of the HIGH-EF project is to provide the silicon thin film photovoltaic (PV) industry with a process allowing high solar cell efficiencies (>10%) by large grains in the material at competitive production costs. The process is based on a combination of laser melt-mediated crystallization of an amorphous silicon (a-Si) seed layer (<500 nm thickness) and an epitaxial thickening (to > 2 µm) of the seed layer by solid phase epitaxy (SPE) process. The combined laser – SPE process represents a major break-through in silicon thin film photovoltaics on glass as it substantially enhances the grain size and reduces the defect density and the stress levels compared to e.g. standard solid phase crystallisation processes (SPC) on glass which provides grains less than 10 µm in diameter with a high density of internal extended defects. A low cost laser processing will be developed in HIGH-EF using highly efficient laser diodes with a wide line focus for the crystallisation of a large module area within one scan. The main tasks of EMPA in the project are i) grains size, grain boundaries, texture and lattice defects characterizations of the Si thin film by electron backscatter diffraction techniques (EBSD), ii) elastic strain and residual stress measurements by EBSD and iii) mechanical testing of the material.

In r d c i n r ec g al

In the PV industry, crystalline silicon (single and multicrystalline) bulk material dominates the market with 78% market share. The difficulty in securing a feedstock supply to produce conventional wafer-based solar cells has encouraged a frenzy of industry projects related to thin-film solar cells. These last years, large amounts of money have been spent to build new thin-films plants and at this pace, by 2013 thin film cells could represent about 25% of the PV technology installed worldwide (source: EPIA). The HIGH-EF European project has the goal to provide one of the thin-film photovoltaic (PV) manufacturers, CSG Solar AG, with a novel silicon thin film material that can be produced at competitive costs and with an efficiency of greater than 10% [1].

The crystallization of a silicon thin film on a temperature sensitive inexpensive substrate such as glass is a challenging issue. Several methods can be used to obtain a crystalline silicon thin film at a maximum temperature of 650°C that the glass can endure as for example standard solid phase crystallisation processes in a furnace which produces grain smaller than 10 µm's in diameter. Laser crystallization offers the advantage to produce large grains over several 100 µm in size with very short melt duration, minimizing the heating of the temperature-sensitive glass. The laser crystallized films can be used as a seed layer for a subsequent epitaxial growth of Si. HIGH-EF has the objective to develop such a combined process of laser-crystallization of an amorphous silicon (a-Si) seed layer (<500 nm thickness) and epitaxial thickening (to > 2 µm) of the seed layer by solid phase epitaxy (SPE) (Fig. 1).

HIGH-EF is a European cooperative project involving research institutes and companies in France (Iness-CNRS Strasbourg; Horiba Jobin Yvon), Germany (IPHT Jena; CSG Solar AG), Hungary (MFA-research Institute for Technical Physics and Materials Science) and Switzerland (EMPA; Oclaro Switzerland AG) (for more information, visit www.high.eu). The main tasks of EMPA in the project are:

- To provide detailed microstructure investigations of the Si thin film by electron backscatter diffraction technique (EBSD) including grain size, grain boundaries, texture and lattice defects characterizations.
- To develop a suitable technique for strain and residual stress measurements in the polycrystalline Si thin Film with EBSD.
- To perform mechanical tests on the solar cells in order to investigate their mechanical reliability and the adhesion of the Si thin film on the glass substrate.

S r de cri i n f e r ec

HIGH-EF aims to provide the silicon thin film PV industry with a unique process based on a combination of melt-mediated crystallization of an amorphous silicon (a-Si) seed layer (<500 nm thickness) and epitaxial thickening (to >2 µm) of the seed layer by a solid phase epitaxy (SPE) process (Fig. 2) [1]. Melting the a-Si layer and solidifying large grains (about 100 µm) will be obtained by scanning a beam of a diode laser array. Epitaxial thickening of the large grained seed layer (including a pn-junction) is realized by deposition of doped a-Si atop the seed layer and a subsequent SPE process by way of a furnace anneal. Such a combined laser-SPE process represents a major break-through in silicon thin film photovoltaic on glass as it will substantially enhance the grain size and reduce the defect density and stress levels of multi-crystalline thin layers on glass compared e.g. to standard SPE processes on glass, which provide grains that are less than 10 µm in diameter with a high density of internal extended defects, which all hamper high solar cell efficiencies. It is, however, essential for the industrial laser-SPE implementation that such a process will not be more expensive than the established pure SPE process. Therefore, a low cost laser processing route will be developed in HIGH-EF using highly efficient laser diodes, combined to form a line focus that allows the crystallization of an entire module with a single scan.

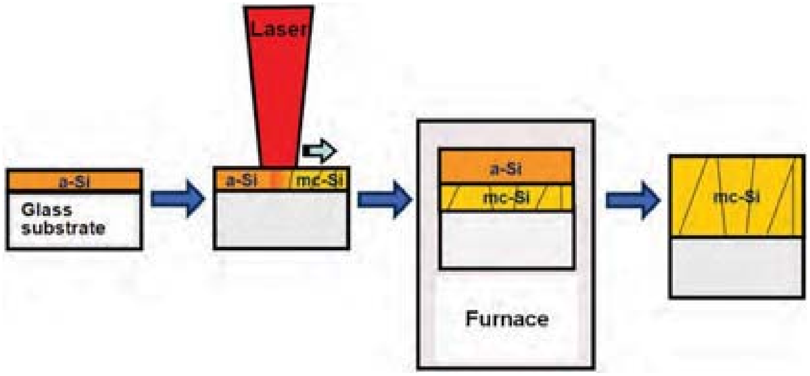

Fig . Schematic of the laser-SPE process to realize large grained silicon layer on glass

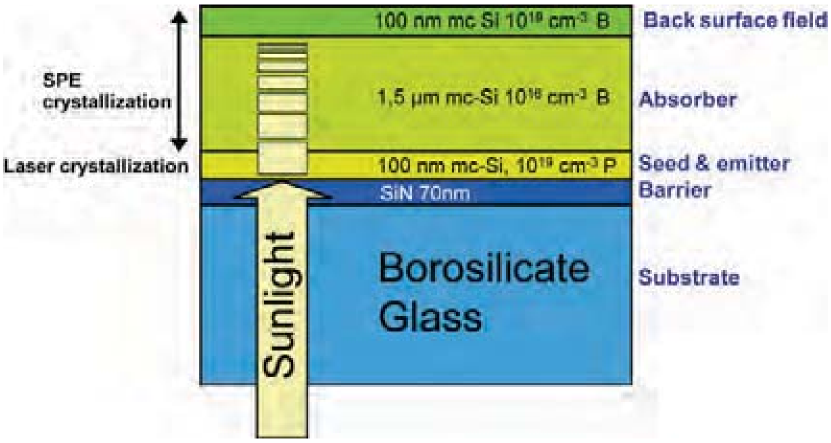

Fig . Schematic of the structure of the solar cell developed in the HIGH-EF project.

Re l

<u>Micr r c re c arac eri a i n f e Si in fil EBSD</u>

The laser-crystallization process successfully produced grains in the order of several 10's µm wide and several 100's µm long (Fig. 3). The grain shape is anisotropic, elongated in the direction of the laser path. The grain boundary population is dominated by twin boundaries of first (Σ3) and second order (Σ9). Low angle boundaries (<15%) usually form 5-25% of the total boundaries. A systematic progressive intrargranular lattice rotation is observed, generally between 10 and 25° from one side of the grain to the other and can be up to 50° in the strongest cases [2]. Intragranular misorientation rate varies between less than 0.1 and up to 0.8 degree per micron, constant for several hundred microns. The misorientation axes are orientated parallel to the thin film plane, preferentially aligned subparallel or at small angle to the laser direction. Low angle boundaries form between domains where the crystal orientation evolves in different directions within a grain. In such cases the progressive evolution of a low angle boundary into a high angle boundary is commonly observed, progressively separating two domains in the grains where the lattice rotates in different directions and intensities. Intragranular misorientation can be realized with a dislocation arrangement which is similar to the one observed in low angle twist boundaries. In such a case, the easiest dislocation configuration is a regularly spaced parallel array of screw dislocations orientated normal to the misorientation axis. The density of geometrically necessary screw dislocation can be estimated in range of $6.0\cdot10^{6}$ to $4.0\cdot10^{7}$ [mm^{-2}] depending of the misorientation rate. Electron beam induced current (EBIC) measurements show that areas with strong lattice rotation exhibit more electron recombination than other areas. Therefore, the geometrically necessary dislocations and low angle boundaries associated with the intragranular misorientation serve as recombination centre for electron-hole pairs. Since the lateral grain size is up to two orders of magnitude larger than the film thickness, these dislocations and low angle grain boundaries are an important factor in the degradation of the solar cell performance.

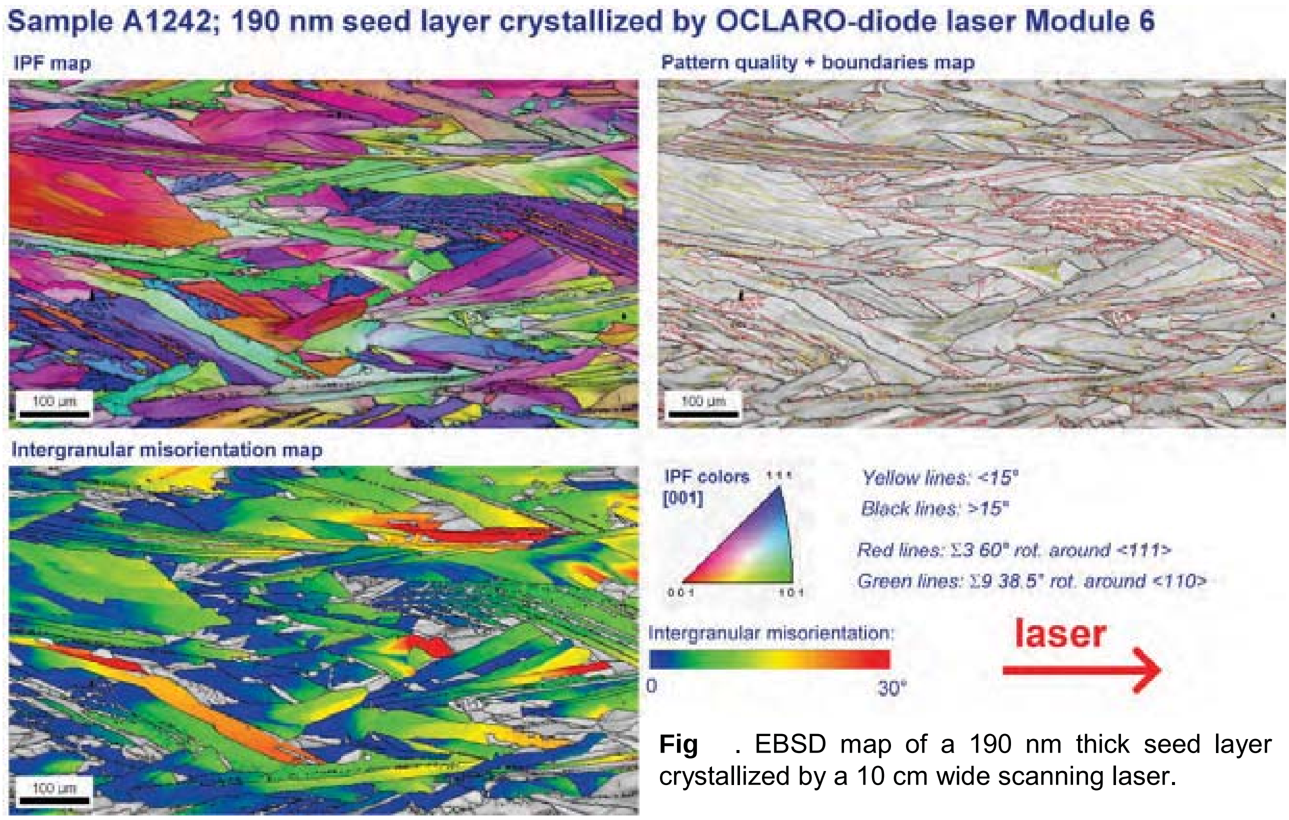

Fig . EBSD map of a 190 nm thick seed layer crystallized by a 10 cm wide scanning laser.

Re id al re ea re en EBSD cr c rrela i n ec ni e

A cross-correlation based technique is used to measure the relative shifts between EBSD patterns caused by small lattice rotations or elastic strains. The comparison is made between a reference pattern in an unstrained region of the analyzed crystalline grain with all other patterns in the grain. Given the information about the geometry of the experimental set-up, the software can calculate a distortion tensor which can be divided into normal strain, shear strain and rotation tensors. The stress tensor is then calculated with the stiffness coefficients of the crystal. The method is described more in detail by Wilkinson et al. in [3; 4]. We use the program CrossCourt 3.0 to process entire EBSD maps. A reference pattern is chosen for each grain or for a certain area within the grain when the lattice bending is strong. Individual calculations are then conducted according to each reference patterns. Criteria such as pattern quality, confidence index and fit, which partly depend on the state of the residual stress, are determined for each point of the EBSD map and can be directly used to select possible stress-free reference patterns. The pattern shift is corrected for each point of the map. 2D stress mapping allows a direct comparison with EBSD orientation maps and raman stresses measurements.

Figure 4 shows analyses made on a grain in a seed layer crystallized by laser. The grain shows some lattice bending of up to about 25° from one side of the grain to the other. It is crossed by several low angle boundaries, separating domains where the sense or the amount of lattice rotation changes. The optical microscope image made with a Nomarski type lens show that low angle boundaries are marked by topography. The Raman map shows tensile stress over the entire grain with minimum values of 0.3 GPa and peaks up to 1.2 GPa. Tensile stress values seem to be the main trends of the thin film crystallized with the laser. The reference patterns for the EBSD stress calculations have been chosen in the areas where the Raman stress was minimal and the pattern quality optimal. The EBSD results show mainly tensile stresses, but also some compressive stresses in some regions like inside the fork drawn by the low angle boundaries in the left-lower or in the left-upper part of the grain (see stress tensor component σ_{11} and σ_{22}). The EBSD stress tensor maps show that the main components of stress in this specific grain are the shear stresses σ_{12} and σ_{31}. Usually the main components are the normal stresses σ_{22} and σ_{11} as for instance show the figure 5. The Raman residual stress map does not exactly match with the EBSD stresses map, but some regions of high stresses can be well correlated, as the lower part of the grain, inside the forks drawn by the low angle boundaries where the lattice bending is strong and in the middle-right part of the grain between the two low angle boundaries. The Raman map shows high tensile stresses in the upper right part of the grain which is not shown by the EBSD calculations. The EBSD calculations give higher residual stresses values. This is believed to be due to the difference in the probing depth between the two methods (maximum 20 nm from the surface for the EBSD and 762 nm for the Raman (Ar+ laser, 514.5 nm wavelength)).

Figures 5 shows another example of comparison between EBSD orientation and stress map. EBSD misorientation map correlates well with the EBSD stress maps. The grains with strong intragranular lattice misorientation show high residual stresses and the ones where the lattice orientation remains constant inside the grain show low or no residual stress values. Figure 5 shows also well that in the areas where the pattern quality is lower (darker regions in the EBSD pattern quality maps), the residual stress is higher. Those regions are believed to have higher defect concentrations.

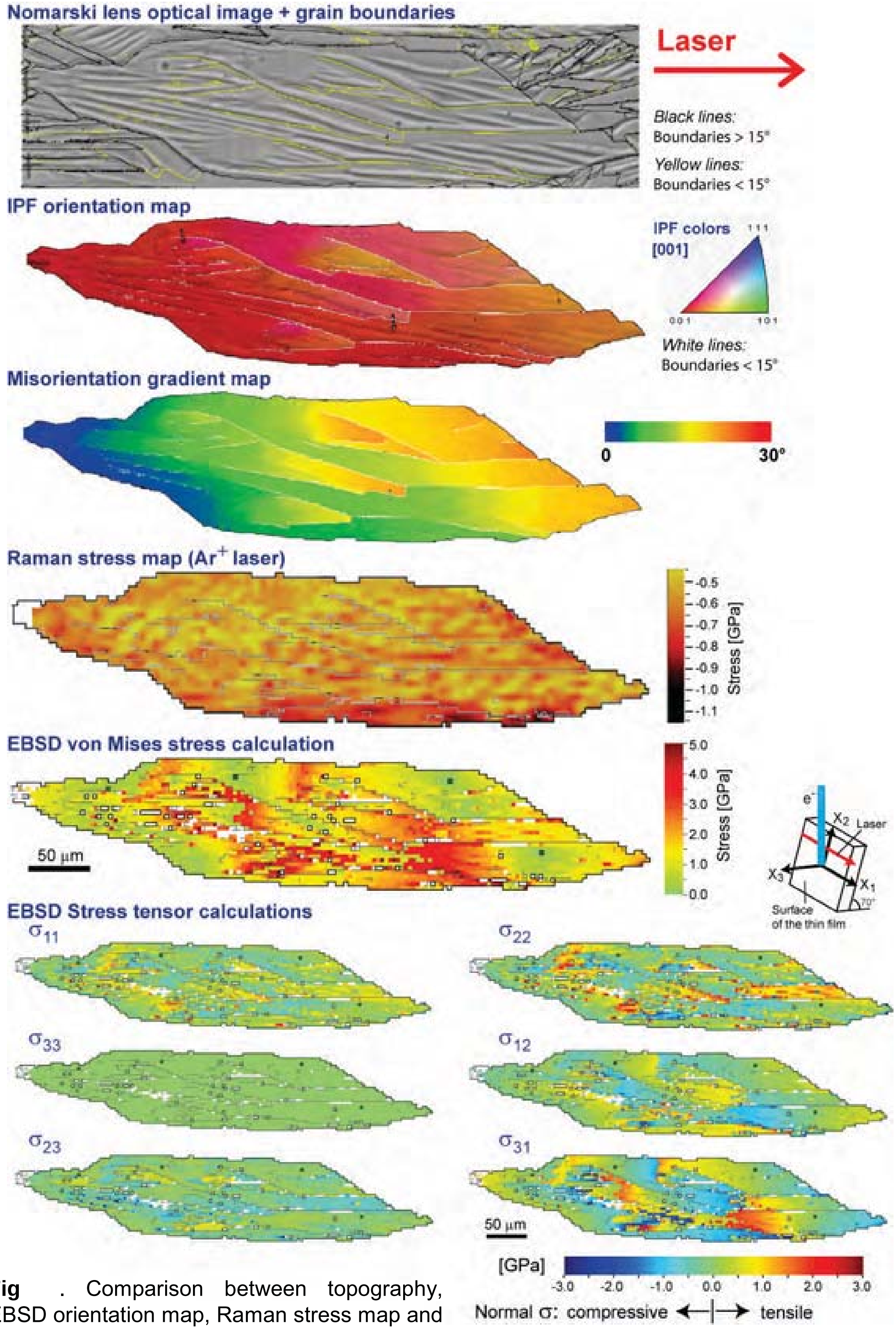

Fig . Comparison between topography, EBSD orientation map, Raman stress map and EBSD stresses calculations in 190 nm seed layer crystallized by laser

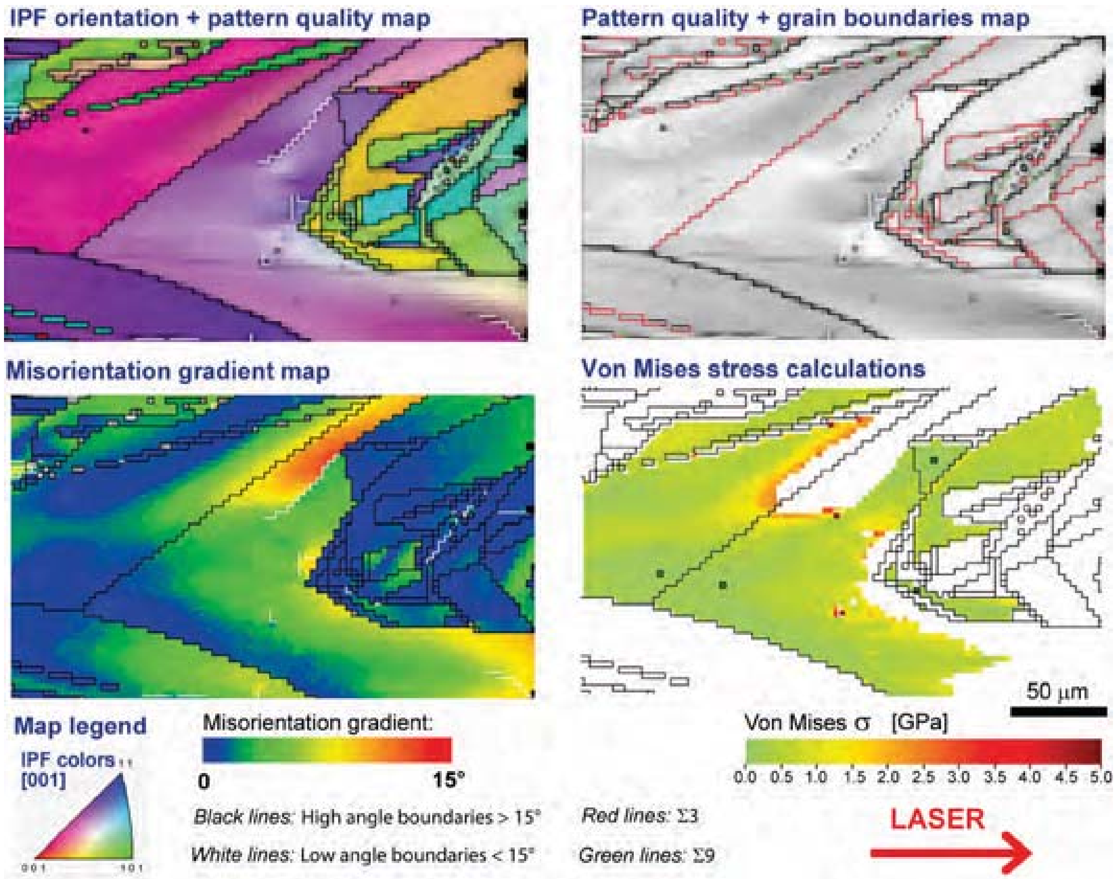

Fig . Residual stresses measurements on a 400nm seed layer crystallized by laser

<u>Mec anical e ing</u>

The mechanical reliability of the Si thin film is an important issue for the quality and the lifetime of the solar cells. During processing, extended defect configurations and thermal mismatch between silicon and glass can destabilize the material. Crack formation due to mechanical loading of the silicon layer on the glass substrate can be studied by carrying out various standard tests including scratch, indentation, bend and pull tests. The key material parameters that should be measured are the fracture toughness of the coating and the fracture energy for interfacial debonding. However none of the above mentioned tests were successful at inducing interfacial debonding of the film from the substrate. Fracture events during indentation and scratch tests were limited to channel cracking (vertical cracks contained within the silicon film) and spalling which were larger events that went through the film and included the glass substrate. Therefore it was concluded early on that interfacial debonding was not a major factor for the reliability of the silicon films that were tested. In order to investigate the fracture toughness of the film both scratch and nanoindentation tests were used.

Once EBSD has identified areas of the silicon film with high tensile stresses, SEM in-situ scratch tests are performed. This can be seen in Fig 6 (scratch direction is from right to left). It is apparent that major fracture and delamination events occur when the tip traverses grain boundaries and twins. It is currently thought that the relatively low toughness of these features could be due to either high localized stress (as seen in Raman and EBSD), to the segregation of impurities to grain boundaries and twins during recystallization, or to a combination of both.

With EMPA's new nanoindenter, the Hysitron Ubi, it is possible to scan the surface of the material with the indenter tip like an AFM as shown in Fig. 7. In this way it is possible to correlate the surface topography to EBSD images and locate the highly stressed areas of the film. The indenter can be programmed to carry out arrays of indents mapping an entire area. Additionally, with careful positioning, it is possible to align the apex of the tip with specific twins and grain boundaries. In this way, the localized intergranualar and intertwin fracture toughness can be determined. To our knowledge, this is the first time this technique has been conducted on grain boundaries or twins.

An example of how coupling EBSD, Raman and indentation together in order to identify areas of high stress and quantify their fracture toughness values can be seen in Fig. 7. In this case, an array of 60 indents spaced 25 µm apart was run a sample with 400nm seed layer and 1.6µm epitaxial layer in an area that had previously been mapped with standard EBSD (a), with advanced EBSD cross-correlation stress mapping (b) and with Raman stress mapping (c). The black rectangle repeated in each portion indicates where the indents were for reference while the dotted lines in show surface features as revealed using the AFM imaging capabilities of the Hysitron indenter. These surface features in most, but not all cases, correlate to grain boundaries or twins. Part (d) of Fig. 7 shows the optical image from the Hysitron indenter that is used in order to initially position the indenter tip while part (e) shows the deflection image from the AFM imaging of the indenter. The indents were run with constant loading and unloading rates of 100 µN/s to a maximum load of 10 mN. In order to record the hardness and elastic modulus at each location, a partial unloading segment was run at 2 mN. This load was chosen since it was prior to any indentation cracking (initiated between 4-5 mN). These values were calculated using a standard Oliver-Pharr method which can be affected once the material cracks or fractures. The red box superimposed on each image shows the location of 6 indentations. According to both cross-correlation EBSD and Raman results, the center and right portions of this box should have high residual stress components. These high stress values are corroborated with the indentation results as can be seen in Fig. 7. It is very clear that the crack length going towards the top of the page in Fig. 7 (indents (1)-(6)) is increased by the high residual stress values at those locations. This implies that there are large tensile stresses in these locations parallel to the laser direction. The accepted indentation fracture toughness value for stress-free single crystal silicon is approximately 0.7 MPa*m½. This makes Si rather brittle; generally ceramics are between 0.1-10 MPa*m½, while metals can range from 10-100 MPa*m½. For the arrays seen in Fig. 7, the average fracture toughness value was 0.49 ± 0.15 MPa*m, which is 30% lower than stress-free single crystal silicon. Overall these results agree quite well with the stress measurements from EBSD and Raman which show a general trend of tensile stress within the film. The toughness values of the indents (4)-(6), in the area where the tensile stress is the highest, are approximately 85% lower than unstressed Si.

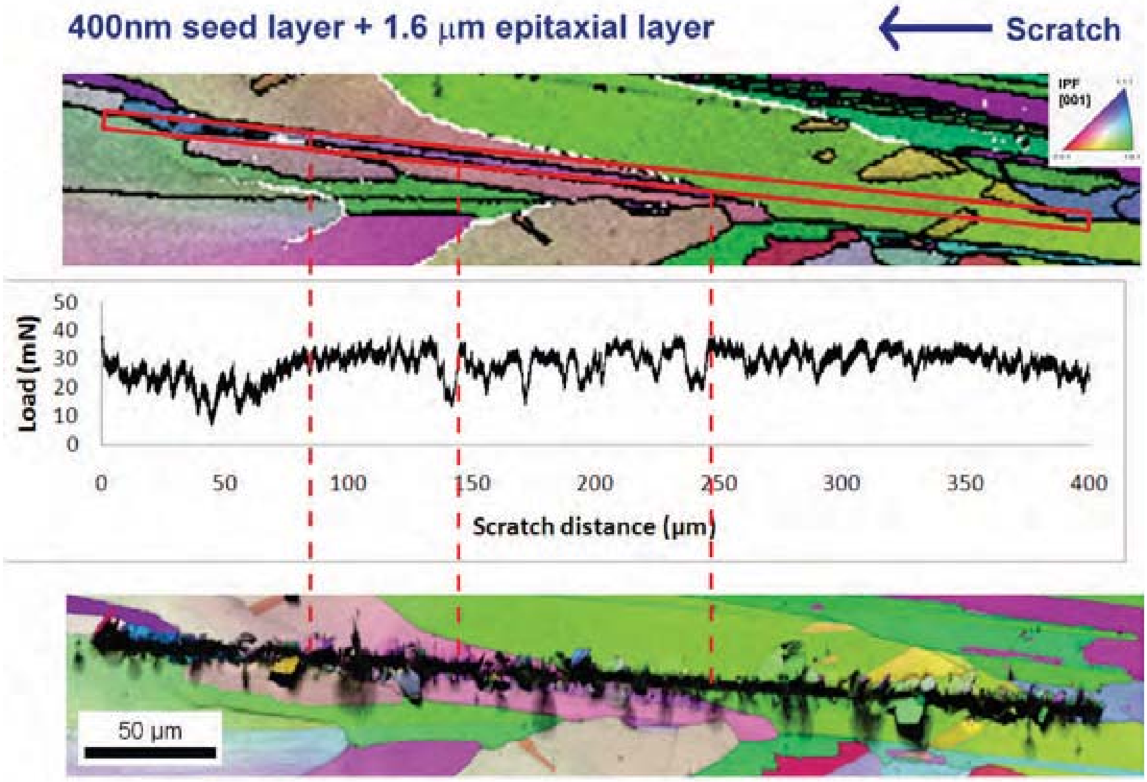

Fig Scratch test on Si thin film with seed and epitaxial layer on glass substrate. EBSD orientation map is used to locate where fractures and delimitations occur.

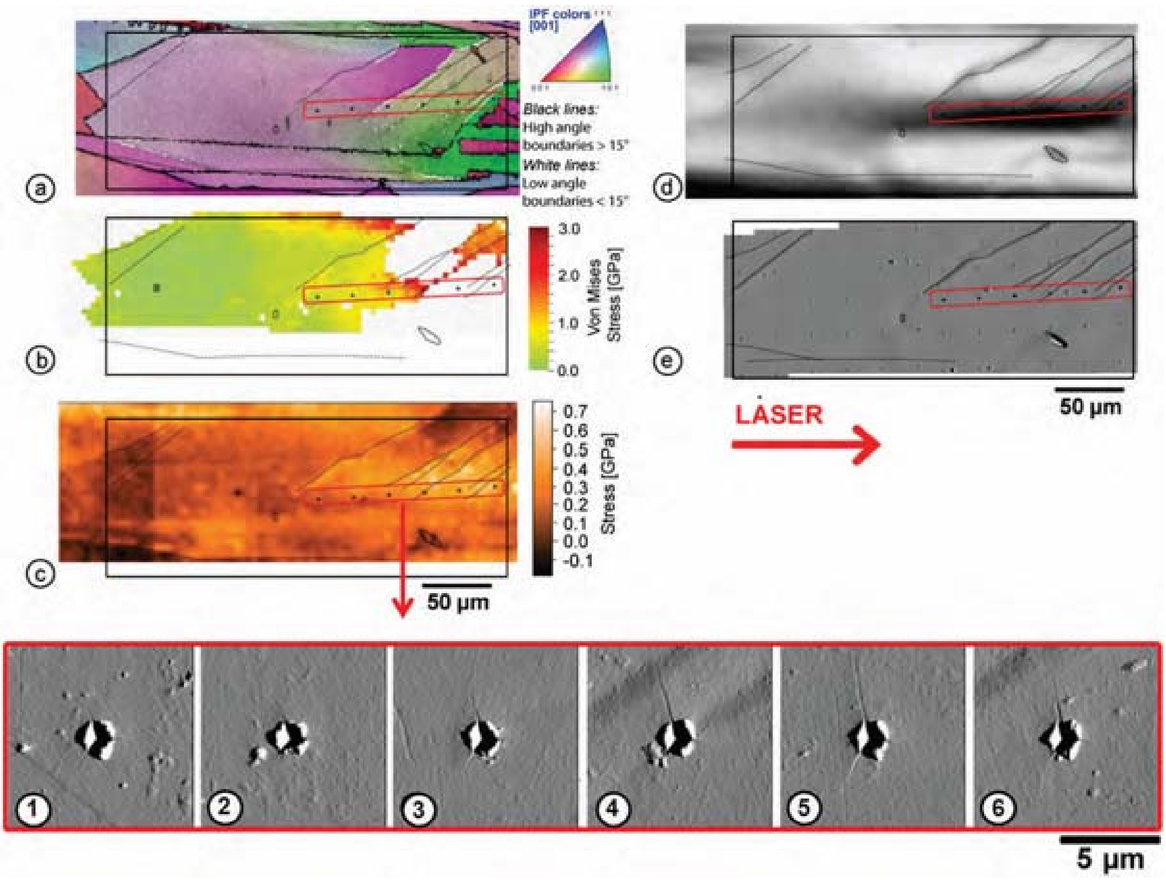

Fig *Correlation between standard EBSD (a), advanced cross-correlation mapping (b), Raman stress analysis (c), and accurately positioning nanoindents with the indenter optics (d) and AFM capabilities (e) on a sample with 400nm seed layer and 1.6 µm epitaxial layer. Indents (1) through (6) are seen in the red box. The crack emanating from the top corner of the indent grows to a maximum length for indent (5). This indent corresponds to a location of high stress as seen in (b) and (c) and therefore has low indentation fracture toughness.*

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WEIDIMENSIONALE NANOSTR T REN F R SILI I M SOLAR ELLEN

Annual Report 2010

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Date	08.12.2010

ABSTRACT

The main goal of the project is the development of **efficien n erical e d** to solve the Maxwell equations in order to calculate the optical properties of crossed gratings rigorously.

The structures shall be optimized for **r ad and a r i n f lari a i n in in fil** . This optimization should take into account the various experimental limitations. Prototypes should be fabricated with e-beam lithography by the LMN of PSI, and experimental characterisation of the structures, as well as a prototype solar cell fabrication is to be done by the IMT in Neuchâtel.

Einlei ng Pr e iele

In diesem Projekt sollen zweidimensional-periodische Nanostrukturen durch numerische Berechnungen untersucht werden. Diese sind von besonderem Interesse für die Photovoltaik, da sie es ermöglichen, die Lichtabsorption in dünnen Schichten stark zu verbessern. Dabei sollen solche Strukturen für eine möglichst **rei andige A r i n eider P lari a i nen** optimiert werden.

Die Motivation für das Projekt ergibt sich aus Resultaten sowohl für die TM Polarisation der Absorbtion bei eindimensionalen Gittern (z.B. [1],[2]), wie auch aus Resultaten für schmalbandige totale Absorbtion bei zweidimensionalen Gittern (z.B. in [3]). Deshalb wird eine spürbare Effizienzsteigerung von Dünnschichtsolarzellen bei relativ geringen Zusatzkosten erwartet.

Zunächst soll ein Computerprogramm geschrieben werden, das die Analyse **eidi en i naler S r ren** erlaubt. Dabei wird ein Schwerpunkt auf die Untersuchung von idealisierten Strukturen gelegt, um numerisch exakte Referenzresultate für reale Strukturen zu erhalten. Parallel zur Arbeit von A. Naqavi am IMT Neuchâtel werden verschiedene Strukturen untersucht, vor allem solche, die sich später für kostengünstige Massenfabrikation eignen könnten. Die gezielte Suche nach optimalen Strukturen wird voraussichtlich am IMT durchgeführt, um diese konkret an die realen Verhältnisse anzupassen. Unter anderem sollen die Halbleitereigenschaften der Materialien nicht tangiert werden. Dabei sollen in Zusammenarbeit mit dem IMT und dem Labor für Mikro- und Nanotechnik Strukturen mit Hilfe von Elektronenstrahl-Lithographie konkret realisiert werden, und mit diversen Methoden untersucht werden.

r e c rie de Pr e der Anlage

Im Rahmen des neuen Codes werden die Maxwell'schen Gleichungen gelöst für stationäre Zustände. Dies im Rahmen einer modalen Methode, das heisst, dass das elektromagnetische Feld nach Eigenfunktionen entwickelt wird. Dieses Verfahren erlaubt für das vorliegende Problem effizientere Rechnungen, verglichen mit in der Industrie üblichen Verfahren (z.B. FDTD, [4]). Wie man eine modale Methode auf ein beliebiges, eindimensionales Beugungsgitter anwendet, findet sich zum Beispiel in [5,6].

Bei der Entwicklung nach Fourier-Moden konvergierten transversal elektrische (TE) und transversal magnetische (TM) Polarisation nicht gleich schnell, wo im Folgenden n die Anzahl der berücksichtigten Moden bedeutet. Für eine derartige Entwicklung sinkt der Fehler für die TE Polarisation wie $1/n^3$, für die TM Polarisation wie $1/n^2$, und für konische Diffraktionsprobleme sind die beiden Polarisationen gekoppelt und daher wird die Konvergenz durch die langsamer konvergierende Polarisation begrenzt, wie bereits letztes Jahr ausgeführt.

Die Verallgemeinerung auf zweidimensionale Strukturen wurde behandelt in [7], für die die Rechnungen noch langsamer konvergieren weil E- und H-feld immer gekoppelt auftreten, und damit die langsamere Konvergenz des H-Falls immer limitierend wirkt. Konkret konvergieren die Eigenwerte auf Grund der quadratisch wachsenden Modenzahlen sogar nur wie $1/n$. In den Ref. [8],[9] wurde eine Methode gefunden, um die Konvergenz von quadratisch auf kubisch zu verbessern, wobei eine detaillierte Erklärung in [10] zu finden ist. Diese Verbesserung ist entscheidend, denn nun sinkt der Fehler wie $1/n^{3/2}$ in zwei Dimensionen. In [11] wurde diese Methode mit zusätzlichem Formalismus für zwei Dimensionen und nicht-rechtwinklige Elementarzellen verallgemeinert. Unter Berücksichtigung von Symmetrien kann der Rechenaufwand reduziert werden, wie in [12] dargelegt wird, und in [13] für hexagonale Symmetrien, und in [14] für quadratische Symmetrien, wobei die Konvergenz im Prinzip nicht verändert wird.

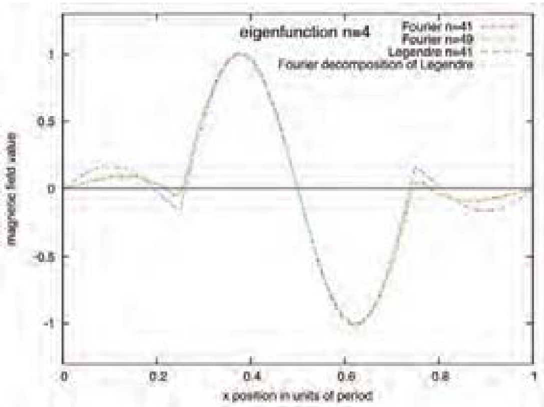
Die Diskussion der Konvergenz ist wesentlich im Rahmen des verbesserten Lichteinfangs, weil die zu untersuchenden Solarzellen zum einen aus stark reflektierenden Metallen an den Kontakten, und zum anderen aus sehr dünnen, schwach absorbierenden Halbleiterschichten bestehen. Die Herausforderung besteht darin, dass die Absorptionskonstanten in dem Wellenlängenbereich sehr gering sind, wo der Lichteinfang besonders benötigt werden. Die geforderte hohe Absorption für schwach absorbierende Materialien führt zu Strukturen mit hoher Güte und dementsprechend zu Resonanzen, die berechnet werden müssen. Dabei soll möglichst nur die Absorption in der optoelektrisch aktiven Schicht erhöht werden.

In diesem Bereich hoher Resonanz ist es anspruchsvoll, die Maxwell'schen Gleichungen numerisch exakt zu lösen, da die Anzahl der Moden zunimmt, die berücksichtigt werden müssen. Daher haben traditionelle Verfahren in diesem Bereich Mühe, numerisch exakte Resultate zu erhalten.

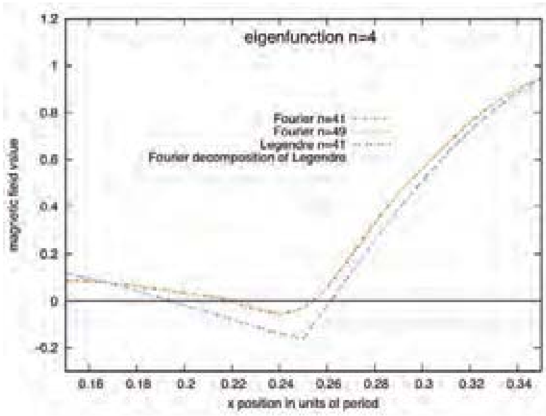
Diese numerische Exaktheit erfordert eine exponentielle Konvergenz. Wie im letzten Bericht beschrieben, wird die Methode aus [15] in zwei Dimensionen verallgemeinert. Dieser Code entwickelt das elektromagnetische Feld nach Eigenfunktionen der Helmholtzgleichung, wobei diese Eigenfunktionen dann in Regionen mit jeweils konstanter Permittivität nach Legendre-Polynomen entwickelt werden. An den Grenzflächen müssen die *E*- bzw. -Felder die exakten Randbedingungen erfüllen, das heisst, dass sowohl die Felder stetig sein müssen, wie auch dass d*E*/dn und (1/ε)d /dn, wobei n die Normale auf die Grenzschicht bezeichnet. Dank dieser Trennung in Regionen mit konstanter Permeabilität gelingt es, die exponentielle Konvergenz bezüglich der Ordnung *n* der Entwicklung zu garantieren, wie es eben nach der Approximationstheorie möglich sein muss für Systeme, in denen das Feld überall unendlich oft differenzierbar ist mit Ausnahme der Ränder des Gebiets der Entwicklung.

D rc gef r e Ar ei en nd erreic e Erge ni e

Um das Verhalten der metallischen Schichten besser verstehen zu können, was höhere Modenzahlen erfordert, wurden auch Rechnungen mit rein negativen Permeabilitäten durchgeführt. Dies entspricht einem idealisierten, absorptionsfreien Metall. Dabei konnten für den transversal magnetischen Fall zwei bemerkenswerte Feststellungen gemacht werden:



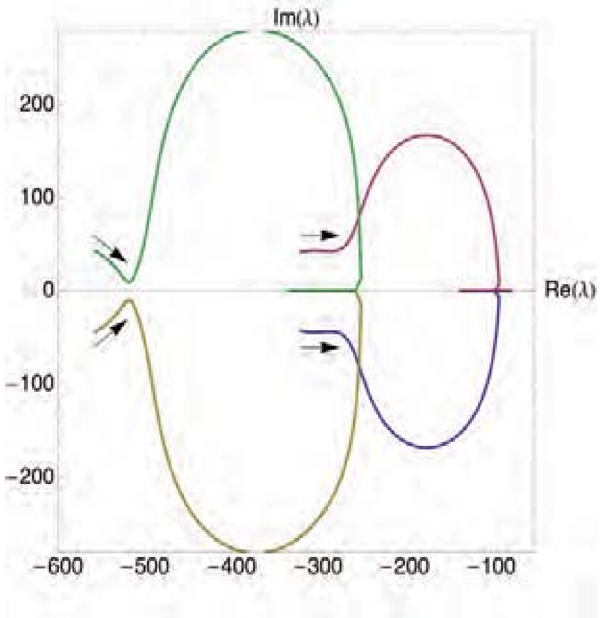
Figur 1 Eigenfunktion f r die elmholt gleichung, wobei das Mittelst ck von 0. 5 bis 0. 5 eine negative ermeabilit t von -6. 5 aufweist. Die egendre-Entwicklung wurde bis um olynomgrad 41 durchge-f hrt.



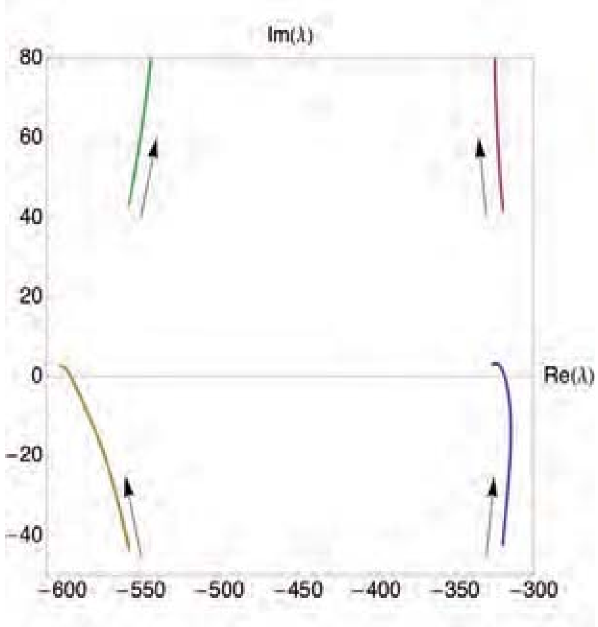
Figur Die gleiche Eigenfunktion wie in Figur 1 ge- eigt, vergr ssert ge eigt beim Material bergang. Die vierte urve ist eine Fourier erlegung der sung, die mit egendrepolynomen berechnet wurde.

Wie den Figuren 1 und 2 zu entnehmen ist, sind die Eigenfunktionen am Übergang zwischen Vakuum und Metall stetig, aber nicht differenzierbar. Dies kann mit einer Polynomentwicklung präzise dargestellt werden, nicht aber mit einer Fourierentwicklung. Insbesondere ist im Fourier Fall die Funktion nicht nur direkt beim Übergang falsch, sondern die Amplitude bleibt in einer ganzen Region um mehr als einen Faktor 2 zu tief. Die Zerlegung der mit Legendrepolynomen berechneten Eigenfunktion in Fouriermoden in Figur 2 zeigt, dass der Fehler der Fouriermethode reduzierbar ist.

Zum anderen weist der zu diagonalisierende Operator im Falle einer negativen Permeabilität im transversal magnetischen Fall nicht mehr nur reelle oder rein imaginäre Eigenwerte auf, sondern besitzt auch Eigenwerte mit Imaginär- und Realteil, obwohl in der Struktur kein Licht absorbiert wird, was einem selbstadjungierten Differential-Operator entspricht. Das ist insofern nicht ausgeschlossen, als für die Entwicklung nach Fourier-Moden ein verallgemeinertes Eigenwertproblem gelöst wird, wobei nur die beiden Teilmatrizen selbstadjungiert sind, nicht aber der gesamte Operator. Dieselben komplexen Eigenwerte können auch mit der Legendremethode errechnet werden, wiederum ist die zu diagonalisierende Matrix nicht mehr selbstadjungiert.



Figur Die Tra ektorie der beiden niedrigsten komplexen Eigenwerte als Funktion einer von -6. 5 bis 4 variierenden ermeabilit t. Die feile geben die Richtung der steigenden ermeabilit t

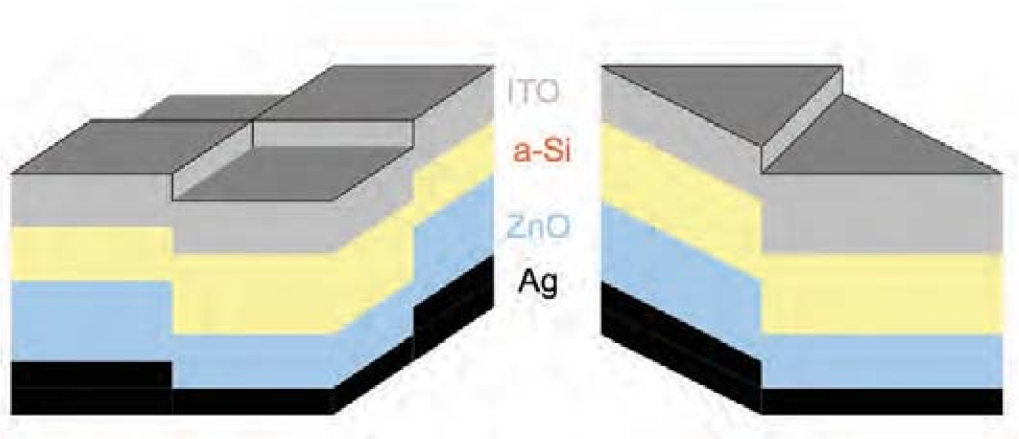


Figur 4 Die Tra ektorie der beiden niedrigsten komplexen Eigenwerte als Funktion einer von -6. 5 bis -6. 5 56i variierenden ermeabilit t. Die feile geben die Richtung des steigenden Imagin rteils der ermeabilit t

Diese Werte konnten auch mit einer analytischen Methode folgend [16-18] berechnet werden. Den Figuren 3 und 4 sind die komplexen Trajektorien der niedrigsten komplexen Eigenwerte für eine variierende Permeabilität zu entnehmen. In Figur 3 ist der Übergang von den komplexen Eigenwerten für negative Permeabilitäten zu den reellen Eigenwerten für positive Permeabilitäten zu sehen, und Figur 4 entnimmt man den stetigen Übergang von den erwarteten komplexen Eigenwerten für eine komplexe Permeabilität zu den unerwarteten komplexen Eigenwerten für die reelle Permeabilität. Dieses Resultat ist Gegenstand einer Publikation in Arbeit.

Be er ng nd A lic

Die Resultate 2010 bilden eine notwendige Voraussetzung für die Ziele 2011, vor allem wurde das Verständnis für die Schwierigkeiten bei der Berechnung solcher Nanostrukturen vertieft. Die bereits existierende Zusammenarbeit mit A. Naqavi vom IMT Neuchâtel soll im kommenden Jahr weiter ausgebaut werden, um Rechnungen für numerisch exakte Referenzresultate an Strukturen (siehe Figur 5) besser mit den Ergebnissen für reale Strukturen vergleichen zu können. Dabei sollten die Gitter-Parameter wie Periode und Strukturtiefen unabhängig von den Schichtdicken der einzelnen Materialien gewählt werden.



Figur 5 Rechteckige und hexagonale Strukturen, wie sie in numerisch exakten Rechnungen untersucht werden, um Beispiel bestehend aus Indium innoxid, amorphem Sili ium, inkoxid und Silber .

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ROD SOL

ALL-INORGANIC NANO-ROD BASED THIN-FILM SOLAR CELLS ON GLASS

Annual Report 2010

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Date	

ABSTRACT

Thin film solar cells, based on non-toxic, abundant and air-stable silicon (Si) will probably, based on forecasts, dominate the photovoltaic market in the future and thus replace bulk Si from its leading position. This prognosis is fostered by the strong cost reduction potential due to highly effective materials utilization at low energy consumption. However, thin film Si suffers from inherently small grains, which limits efficiencies to ~10% due to carrier recombination at grain boundaries.

A radical innovation of the Si thin film materials synthesis route is needed to circumvent this problem. The FP7 European Project ROD-SOL aims at the synthesis of Si nano-rods, densely packed at sufficiently large diameters (few 100 nm's) and lengths (>1µm for sufficient carrier absorption in indirect semiconductors) directly on cheap substrates like glass or flexible metal foils. The idea is to grow Si nano-rods from the gas phase that are inherently defect free, with a wrapped around pn-junction that bares the potential to decouple absorption of light from charge transport by allowing lateral diffusion of minority carriers to the pn-junction, which is at most a few hundred nm away, rather than a few µm as in conventional thin film solar cells. That way, efficiencies as in bulk Si are expectable, however, with the advantage that the 'nano-rod carpet' layer, is at most a few µm thick. A 'nano-rod carpet' that thin shows a strongly increased optical absorption.

Thus, the 'nano-rod carpet' is not only the active solar cell element but at the same time its own light trapping structure. For synthesis of the nano-rods, development of suitable contact materials and characterization of physical and structural properties four experienced research institutes have joined forces. Despite the fundamental materials research to be in focus, three companies joined the consortium to directly test and implement the novel materials and processes in a well proven, industrially viable thin film solar cell concept.

Einlei ng Pr e iele

Globally, the FP7 European Project ROD_SOL project aims at making available to the markets novel materials and nanomatrials for energy applications and a thin film solar cell based on silicon nanorods (NRs).

Materials developments and optimization based on NRs are one of the major tasks in ROD-SOL next to the integration of these NRs in working thin-film solar cell devices, their testing and the benchmarking of the solar cell parameters. The leading European materials oriented research groups contribute to this task.

Innovation will take place in areas of materials processing of NRs such as adequate preferably radial doping, NR contacting based on conformally wrapped around transparent conducting oxide (TCO) layers. These materials developments will be guided by device simulations.

To support the strategic objective to enable the European thin film PV community to commercialize a new innovative thin film cell based on semiconductor NRs with potential for enhanced efficiencies at competitive costs, solid materials developments with huge innovation requests at the nanoscale need to be carried out. From this, the following scientific objectives are derived.

1. semiconductor (mostly Si) NR deposition or integration on glass or foil substrates need to be developed and among different options of deposition/synthesis such as bottom-up and top-down methods the most promising one with the potential for best materials/device properties, best up-scalability at lowest production costs needs to be identified;
2. Identification of the most suitable material based on numerical and physical device simulations and experimental solar cell parameter extraction based on electrical measurements (ensembles and single processed NRs) is needed;
3. Establishment of physical device simulations for the novel 3D NR-based solar cell using the COMSOL and r-soft and ATLAS simulation software;
4. Establish parameter extraction from electrical measurements that need to be established for single processed NRs and NR ensembles (preferably also at an end user test site-BISOL);
5. Materials optimization based on combined structural, electrical, optical and mechanical characterization by TEM and SEM techniques, I-V measurements based on 4-point-probe measurements or AFM-tip based contacting of single NRs in an SEM and contacting processed NR ensembles, as well as optical characterization in an integrating sphere of wavelength dependent light absorption or optical standard characterization for solar cells at the end users site as well as mechanical tests of stability of single processed NRs and reliability tests of embedded NR-based thin films with respect to delamination, bending, cracking and disintegration of components.

These developments are carried out by researchers at six different research institutions involved in this project.

The integration of selected processes in a technological process or processing environment (up-scaling) with the potential to yield a highly efficient and cost effective fabrication route to produce thin film NR based solar cells on cheap substrates are carried out by the four industry/SME partners.

r e c rie de Pr e der Anlage

The goal of the FP7 European Collaborative Project ROD_SOL is to realize optimized thin film material systems based on semiconductor NRs that show photovoltaic behavior and properties optimized for that application. Detailed information about materials and devices cannot be disclosed since we are required to keep confidentiality. Figure 1 presents one possible layout of the targeted solar concept. The SiNRs are not only the light trapping structure but at the same time the active solar cell element. The SiNRs, p or n doped are covered by a n or p-type transparent conductive oxides (TCO) respectively as to build a p/n junction necessary to convert the solar radiation in electric energy.

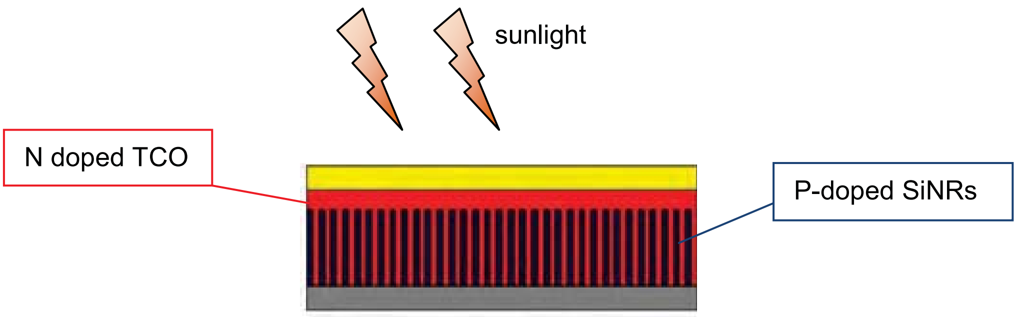

Figure 1 Possible layout of a SiNR based solar cell concept.

For an economically viable concept, SiNR array need be realized on glass of foil substrates. For the generation of SiNR arrays, two processing approaches are looked at in the project. The first is the so-called bottom up approach. In the bottom-up approach, SiNRs are grown by the vapor-liquid-solid (VLS) process on glass substrates. The VLS growth process is based upon a droplet of a metal/semiconductor alloy that catalyzes the local growth of a NR which is a shaft of the semiconductor material (cf. Fig. 1, left). This NR crystallizes with the diameter of the catalyzing droplet and the NR pushes the metal alloy droplet away from the substrate when, upon supersaturation with semiconductor species from the gas phase (e.g. silane, DTBS) the semiconductor shaft crystallizes on the substrate. The position of the SiNRs grown by the VLS process is determined by the position of the necessary metal catalyst particles. Therefore, the first step in a VLS growth process is the patterning of the metal templates. Another possibility for the generation of SiNR arrays is the so-called top down approach. In the top-down approach, NR arrays are etched into silicon by metal assisted chemical etching. A metal catalyst laser is deposited onto a Si surface. Upon immersion into an etching solution, the Si below the metal dissolves. Depending on the pattering of the metal layer, SiNR arrays can be generated. Top-down arrays can either be realized on bulk Si and then depilated, transferred and reintegrated on glass or foil substrates, or the SiNR arrays can directly be etched into crystalline Si thin films.

In order to realize a p-n junction, the possibility of both axial and radial p-n junctions within the SiNRs are investigated in the project. In addition, devices with p-n junctions between the SiNR array and a conformal layer of a transparent conducting oxide (TCO) are realized. The deposition of conformal TCO layers around SiNR arrays for both realizing p-n junctions and for contacting the arrays is a key subject of the project. Three different methods are investigated for this step: magnetron sputtering, atomic layer deposition (ALD) and electrochemical deposition. Different TCO materials are investigated, and the deposition methods and materials are benchmarked against each other. The development of SiNR arrays, p-n junctions and TCO layers are accompanied by numerical simulations, and extensive characterization of structures, materials and defects.

The project is structured in 10 work packages. Empa is involved in 4 work packages and is work package leader in one work package. The main tasks of Empa include:

- The development of metal templates (Au, Al, Cu, Pd, …) for the VLS-growth of SiNR arrays allowing higher density and larger diameter NRs on Si wafer substrates and glass substrates,
- The development of a process for the chemical etching of Si nanorod (SiNR) arrays into Si wafers or crystalline Si thin films as well as a depilation, embedding and reintegration process for embedded SiNRs onto glass or foil substrates.
- The development of a process for the deposition of TCO layers by electrochemical deposition on flat surfaces and on SiNR arrays.
- Structural, electrical, optical and mechanical characterization of individual SiNRs, TCO layers and devices. In particular, this includes the structural characterization of NRs by SEM and EBSD, the measurement of of electrical properties (I-V, EBIC and derived parameters) of individual processed NRs. In addition, the mechanical properties of individual and embedded ensembles of NRs are assessed, and the strength and resistance against delamination of the thin film solar cells are investigated.

D rc gef r e Ar ei en nd erreic e Erge ni e

The development of a process for the chemical etching of Si nanorod (SiNR) arrays into Si

NR arrays can be generated by metal assisted chemical etching. Under the effect of noble metal catalyst particles, an etchant solution dissolves the Si substrate (bulk silicon or crystalline thin film) which is in contact with the metal particle. By patterning the metal catalyst on a Si substrate, ordered structures can be etched into the Si. One task of Empa within the Rod-Sol project is to develop a process route allowing the generation of SiNR arrays having a defined length, inter-rod spacing and rod diameter. The realized process consists of the 7 steps that are schematically visualized on Figure 1.

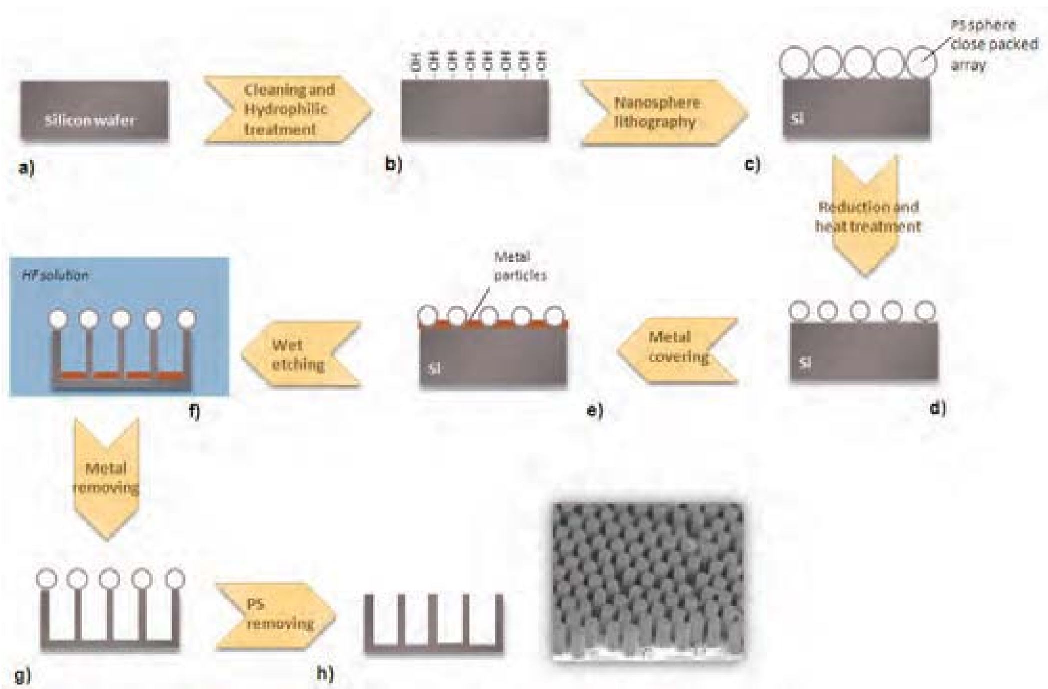

Fig re . process sequence for the etching of SiNRs by templated metal assisted chemical etching.

In this way, ordered Si NR array having tunable rod length, diameter and interdistance can be realized. As an example, Figure 2 shows three samples where different NR lengths have been realized by varying the exposure time to the etching solution.

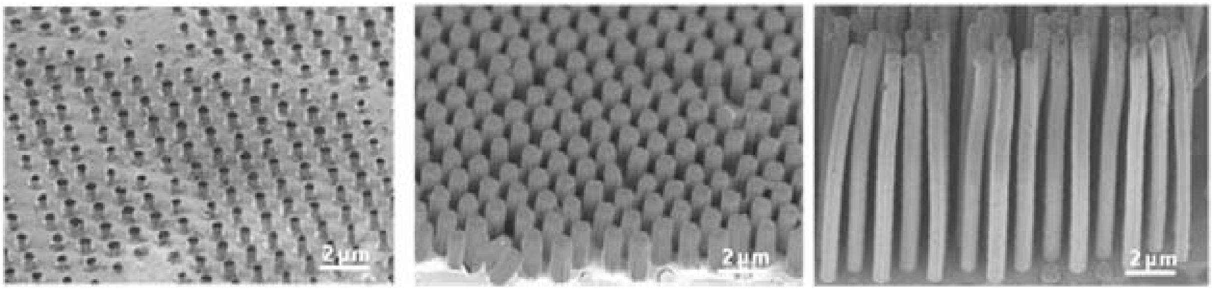

Fig re . NR arrays with different lengths and aspect ratios as a result of increasing etching time.

The development of a process for the deposition of TCO layers by electrochemical deposition

Within the Rod-Sol project, Empa has the task to develop an electrochemical deposition technique for layers of ZnO and Al-doped ZnO (AZO). Electrochemical Deposition (ECD) appears as a judicious choice for ZnO growth, because of its numerous advantages over the other synthesis techniques: *i)* no vacuum system needed, *ii)* low temperature process (<100°C), *iii)* precise control of the film thickness and morphology by playing on the process parameters, *iv)* easy scaling-up, *v)* relatively high deposition rate, *vi)* process less hazardous and environmentally friendly, *vii)* low cost of equipment and *viii)* the possible use of conductive substrates thermally sensitive. Figure 3 schematically shows the setup of the ECD experiment. The depositon process can be divided in three steps, (1) the reduction of the oxygen precursor on the electrode surface, (2) the precipitation of zinc hydroxide and (3) the dehydration and formation of ZnO.

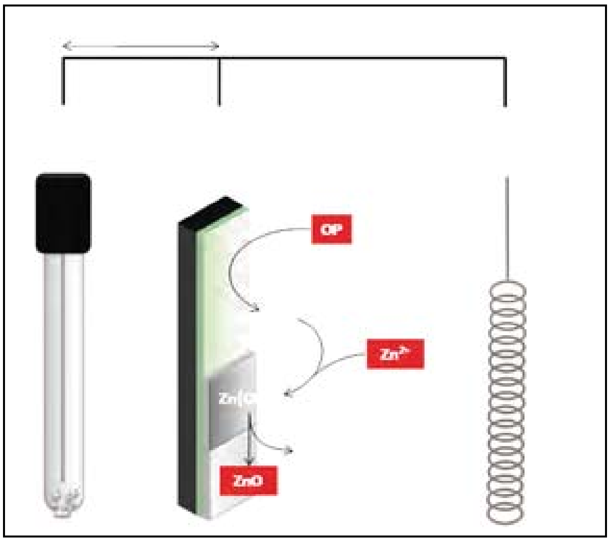

Fig re . Schematic diagram of ZnO growth setup and mechanism by ECD.

Parameters such as precursor concentration, temperature, and especially applied potential were varied in order to obtain good quality ZnO compact layers. Such layers were successfully achieved at 80°C, with an applied potential from -0.9 to -1V and a precursor concentration of 0.1M (Figure 4.a). The control of the charge density allowed controlling very precisely the layer thickness, as it can be seen in Figure 4.b and 4.c (250nm and 1µm, respectively). The deposition time is very fast: less than 1 min and 5 min are necessary to obtain 250nm and 1µm of thickness, respectively. The ZnO layers shown in Figure 4 a to c have been deposited on FTO coated glass substrates, whereas, Figure 4 d to f show that electrodeposition on B-doped Si is equally possible

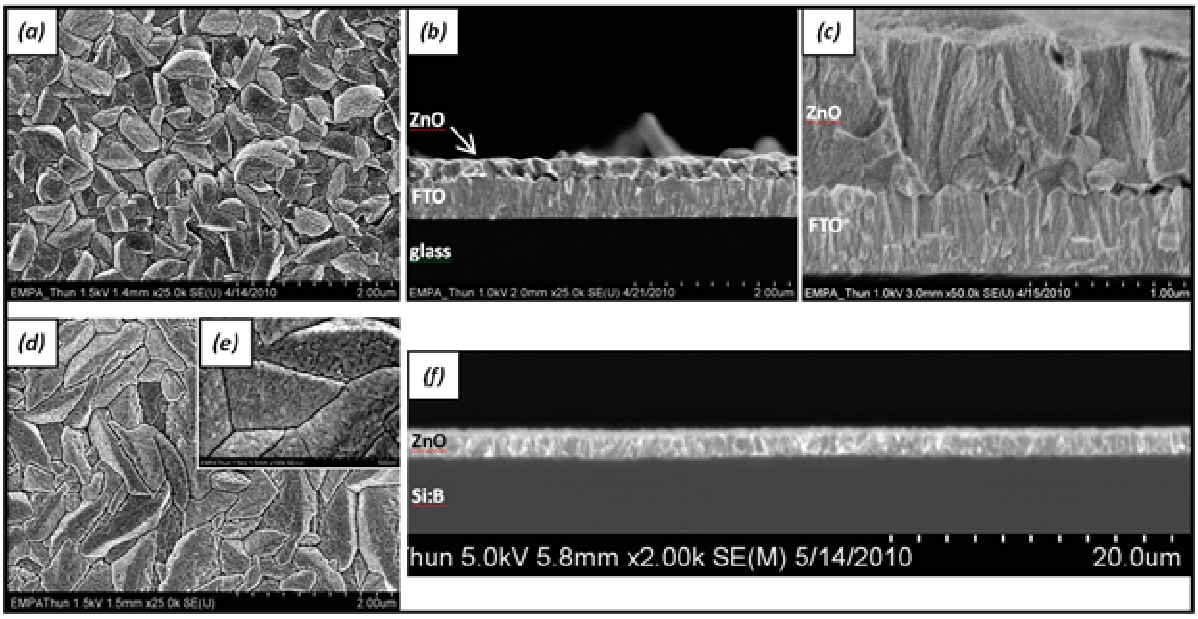

Fig re SEM pictures of ZnO layers electrochemically deposited. ***(a)*** top view, on FTO coated glass. ***(b)*** cross section, on FTO coated glass, with a current density of 150mC/cm². ***(c)*** cross section, on FTO coated glass, with a current density of 1C/cm². ***(d)*** top view, on Si:B, ***(e)*** at higher magnification. ***(f)*** cross section, on Si:B, with a current density of 1C/cm².

Elec rical c arac eri a i n f indi id al SiNR EBIC and I V ea re en

Electrical characterization of individual nanorods (NRs) and nanowires (NWs) has been carried out to characterize NR material. Electron Beam Induced Current imaging (EBIC) is used to characterize the pn-junction depth of individual NRs. In the EBIC method, primary electrons from the electron beam of the SEM induce electron-hole pairs in the semiconductor, just as light in a solar cell does. In the active pn-junction region, the induced charge carriers get separated through the electric field and induce a current. Different currents are represented as different grayscales in the EBIC image. The diffraction limited resolution of light is overcome by the electron beam, which enables to measure the spatial extension of the active region that strongly influences the efficiency of a solar cell. In this way, EBIC is important to identify and locate the active semiconductor device region (pn-junction) and to image its spatial extension. EBIC measurements have been conducted on EBIC equipment setup during and for the project. In this setup, a nanomanipulator inside a scanning electron microscope is used to bring a conductive AFM tip into contact with NRs. In the same way, the setup allows determining the I-V characteristics of individual NWs on their respective substrates and thereby to test the diode behavior of the device. Figure 5 shows the configuration of the EBIC measurements on individual AZO-covered SiNWs. In Figure 5b, a row of AZO-coated SiNRs has been cut in half in order to reveal in cross-section the p-n junction between the SiNRs and the AZO layer. This allows to test the p-n junction and to localize the depletion width in the device.

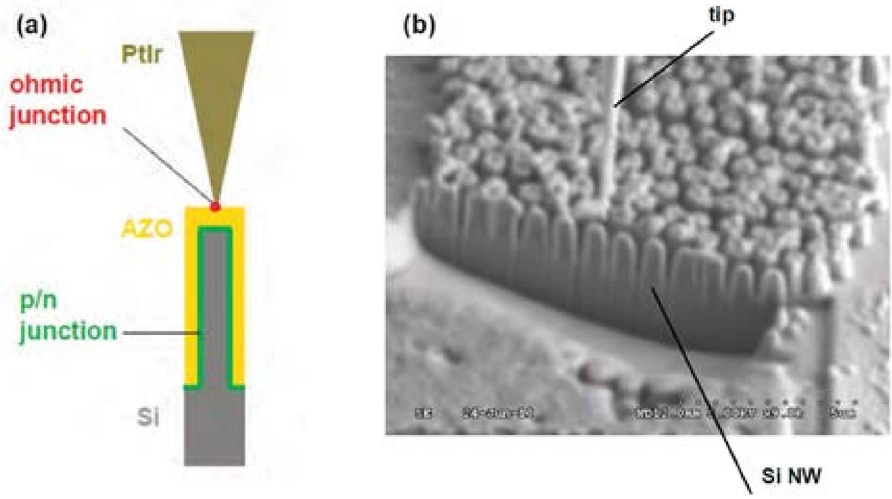

Fig re (a) schematic drawing of the configuration during the EBIC measurements on individual SiNRs covered with an AZO layer. (b) SEM image of the configuration during EBIC measurements.

Na i nale in erna i nale a enar ei

ROD-SOL is a FP7 European Collaborative Project, in which 6 research institutions and 4 industrial partners from 6 European countries are participating, see table 1. The project is coordinated by the Institut für Photonische Technologien in Jena, Germany. Empa collaborated closely with IPHT Jena in the field of metal assisted chemical etching for the generation of SiNR arrays and for the development of a EBIC characterization methods for individual SiNRs. In addition Empa collaborated with ARC (Austria) for the development of metal templates for SiNW growth by the VLS, mechanism, with VTT (Finland) for the characterization of electrodeposited ZnO and AZO coatings and with MFA (Hungary) for the characterization of structures by TEM.

Ta le Project partners in the FP7 European project ROD-SOL

1(coordinator)	Institute of Photonic Technology	IPHT	Germany
2	Friedrich-Alexander Universität Erlangen-Nürnberg Max-Planck Research Group	MPRG	Germany
3	Swiss Federal Laboratories for Materials Testing and Research	EMPA	Switzerland
4	Hungarian Academy of Science Research Institute for Technical Physics and Materials Science	MFA	Hungary
5	ARC – Austrian Research Center GmbH, Nano-System-Technologies	ARC	Austria
6	VTT Micro- and Nanoelectronics	VTT	Finland
7	PICOSUN oy	PICO	Finland
8	Aixtron AG	AIX	Germany
9	BiSOL d.o.o.	BISOL	Slovenia
10	iSupply Deutschland GmbH	iSD	Germany

Be er ng nd A lic

During the last year, an etching procedure to generate ordered large area arrays of SiNRs with controllable length, diameter and inter-rod spacing has been developed. In parallel, a process for the electrodeposition of TCO layers, namely Al-doped ZnO, onto silicon has been successfully developed. These two achievements are promising for NR based solar cell concepts that can be produce in an economic way as both processes are based on wet chemical approaches that do not require vacuum or other expensive process steps. At the same time, an setup to conduct EBIC measurements on individual contacted SiNRs has been realized and demonstrated. It now allows verifying the p-n junction and depletion area in a NR solar cell device. The Rod-Sol project will continue within Empa in 2011. The main focus in 2011 will be on the characterization of solar cell concepts realized within the Rod-Sol consortium. The electrical characterizations (EBIC, I-V measurements) of individual NR elements will continue. In addition micromechanical characterizations of individual NR elements and entire devices will be conducted in order to ensure the mechanical reliability of the realized structures.

THIFIC: THIN FILM ON CRYSTALLINE SI

Annual Report 2010

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Project- / Contract Number	Axpo Naturstrom-fonds 0703
Duration of the Project (from – to)	01.06.2007-31.05.2011
Date	10.12.2010

ABSTRACT

THIFIC (Thin film on crystalline Si) is a project sponsored by the Axpo Naturstrom-Fonds. It aims at developing a new kind of ultra-high efficiency (20-22%) solar cells by depositing very thin silicon layers (typically 5-10 nanometers of amorphous and/or microcrystalline silicon) on top of silicon wafers. These so-called “silicon heterojunction cells” can be fully processed at low temperature (typically below 200°C) and may make use of thin wafers (down to 100 µm), thereby saving Si material. The cells will be integrated into innovative light weight modules with efficiencies reaching up to 20%. These concepts should open the path towards a really competitive production of solar electricity based on high-efficiency crystalline Si products. This wafer-based approach is complementary to the fabrication of solar modules based exclusively on thin films, which should allow the fabrication of lower efficiency modules at lower cost/W_p.

At the Institute of Microengineering (IMT) of the University of Neuchâtel, now part of Ecole Polytechnique Fédérale de Lausanne (EPFL), an activity was started in 2005 in the field silicon heterojunctions. Based on single process step analysis, a better physical understanding of interface phenomena occurring in silicon heterojunction solar cells was obtained. The launch of the Axpo Naturstrom-Fonds project was based on these results, with as main goal the upscaling of the technology both in terms of efficiency and cell size. The past year, we have gradually been more focused on industrialization of our process: Larger sized cells are now fabricated in large area systems, which are industrially compatible. On intermediate-sized solar cells (2x2 cm^2) with random pyramid texture, solar cells with an aperture area efficiency as high as 20.7% have been obtained. Special efforts are made in this project on the topic of screen printed metallization for the front contact grid. By using stencil printing, aspect ratios as high as 1:1 have been demonstrated for fine-line printed fingers.

Introduction / Project Goals

The specific scientific and technological project objectives of this project are to demonstrate:

- the fabrication of ultra-high-efficiency silicon heterojunction solar cells (>20% on "standard" configurations or even higher with novel device structures), based on a combination of amorphous/microcrystalline layers and thin crystalline wafers (down to 100µm).
- that the process is up-scalable to large area solar cells (>100cm^2) which should achieve efficiency over 20%.
- a new metallization/encapsulation process capable to lead to a fabrication of high-efficiency and lightweight (<5kg/m^2) reliable solar modules.
- a roadmap towards the mass fabrication of such modules at very low-cost (<0.7€/Wp) allowing, with suitable module integration, electricity costs down to 12-15 cts.

Project description and approach

The "core" technology for this project is thin-film passivation of crystalline silicon using very high-frequency plasma deposition (VHF-PECVD) with typical frequency from 40 to 70 MHz. The project is divided into four work packages (WP), which address all issues that need to be solved in the 4 years timeframe. In WP 1, interfaces are improved and high-efficiency devices with contacts on both sides are realized. In WP 2, innovative device structures are introduced by putting all the contacts at the back of the devices. This allows, in principle, the achievement of higher efficiencies. In WP 3, the know-how gained in the first two work packages will be transferred to larger deposition reactors and also to larger area solar cells. The goal is to fabricate high-efficiency solar cells on large area. Finally, WP 4, innovative metallization techniques will be tested and will be applied to devices fabricated in the first two work packages. The lightweight encapsulation process is developed also in the last work package.

Results

In this project we focus on the "technology" side of heterojunction solar cells. This comprises the processes for texturing of wafers, large-area deposition, screen-printing, and annealing.

The key-result that we obtained in the past year is a successful transfer from small-area cells fabricated in R&D reactors (which did not feature a metallic front contact), to larger area cells prepared in industry-compatible reactors, with screen printed contacts.

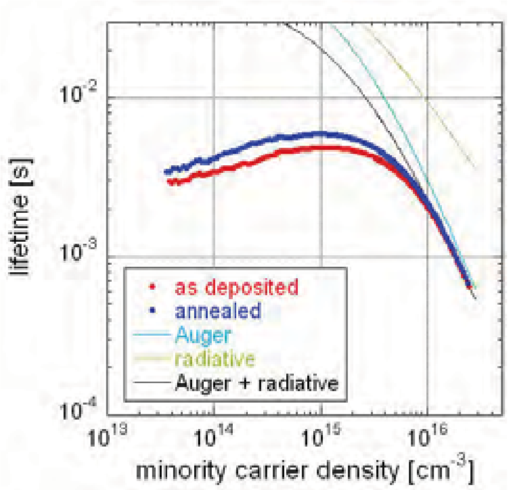
In particular, solar cells of 4 cm^2 area, with screen-printed contacts, with a aperture-area conversion efficiency as high as 20.7 % have been realised on random-pyramid textured wafers, in collaboration with Roth & Rau Switzerland.

This result follows dedicated work on several fronts. For the *a*-Si:H films, a careful optimization study was performed on flat Si(100) surfaces, assuring even with very thin films good passivation in large area reactors, as evidenced in Fig 1.

Next stage, these processes have been transferred onto random-pyramid textured wafers, featuring <111> facets [4,5]. These surfaces, including their chemical pre-deposition preparation, were developed in our new state-of-the-art wetbench, located in our new heterojunction-dedicated cleanroom facilities.

In order to extend the high-efficiencies obtained from small cells (< 1 cm^2) to larger cells, new metallization and cell structuring processes are required. For this good progress has been made by us this year on screenprinting of dedicated low-temperature pastes for front-grid formation on our 2x2 cm^2 devices [6], but also larger-area cells (see Fig. 2). In addition, efforts on stencil printing have been done as well, which has resulted in very fine printed lines, as narrow as 35 micron (see Fig 3), with very good aspect ratios, as high as 1:1 (see Fig 4) [6].

Combining all these developments has allowed us already to reach this year, with the support of Roth and Rau Switzerland for wafer preparation, an excellent 20.7 % aperture area efficiency on intermediate sized (4 cm^2) solar cells.



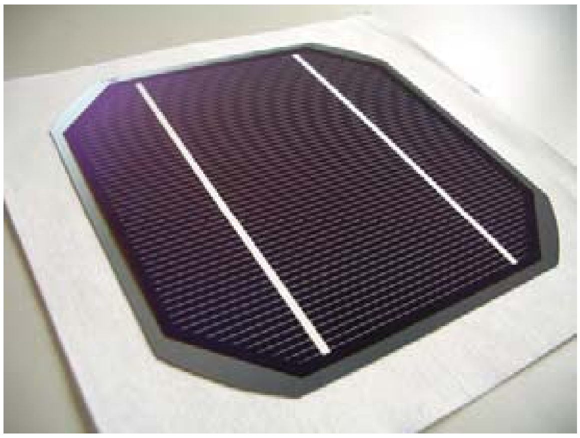


Fig 1. Passivation of a polished float zone wafer with thin intrinsic a-Si:H layers (17 nm). Very high lifetimes are obtained (4.8 ms at 10^{15} cm^{-3} as deposited, and 5.9 ms after annealing at 180°C for 90 minutes).The Auger and radiative recombination limits are also indicated, for c-Si, *n*-type, 4 Ω·cm material

Fig 2. Example of a large-area cell (12.5x12.5 cm^2) fabricated at EPFL.

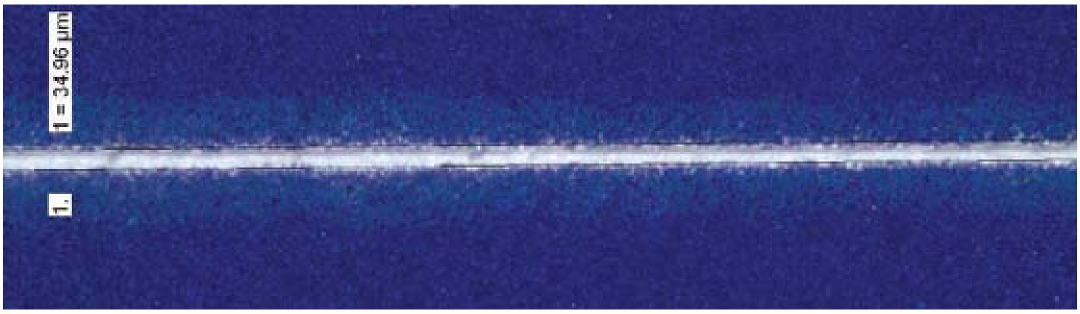


Fig 3. 35 micron traces printed with *EPFL* Stencil

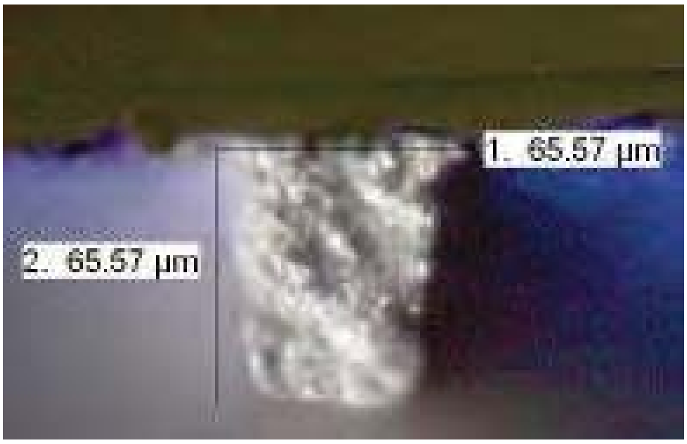


Fig 4. Aspect Ratio printed lines with *EPFL* stencil

Collaborations

IMT is active in collaboration internally with the EPFL for advanced transmission electron microscopy (TEM) sample preparation, supporting the textured heterojunction solar cell improvement. IMT has also an important partnership with Roth&Rau Switzerland (RRS) on the development of industrial processes for heterojunction devices. We acknowledge the technical support of RRS for this project and achieving the 20 % milestones. In addition, IMT is since 2008 also taking part in the European project Hetsi, and since the fall of 2010, in a second European project, 20plµs, focusing on solar cells fabricated on ever thinner wafers. Both projects connect the major European Institutes and Universities working on similar devices.

Evaluation 2010 and Outlook 2011

THIFIC was launched in mid-2007. Crucial parameters have now been identified to fabricate successfully devices on textured wafers, which has been demonstrated successfully in 2010 by efficiencies higher than 20%. For this, an industrial compatible wetbench has been commissioned now in our completely new cleanroom facilities, dedicated for heterojunction devices studies. The same facilities host a fully operational new multi-chamber PECVD system for further device development. A reliable baseline process is now established for larger area solar cells. This baseline includes screenprinted grids, with a special focus on fineline printing. In 2011, the Axpo project enters its final stage, where we want to continue along these lines: For development, increase steadily the cell efficiencies and gradually increase the solar cell size further.

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20 PERCENT EFFICIENCY ON LESS THAN 100 µM THICK INDUSTRIALLY FEASIBLE C-SI SOLAR CELLS

Annual Report 2010

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Project- / Contract Number	20plµs 256695
Duration of the Project (from – to)	01.10.2010-01.10.2013
Date	10.12.2010

ABSTRACT

20plµs (**20 percent efficiency on less than 100 µm thick industrially feasible c-Si solar cells)** is a project sponsored by the European Commission. This project links together world-class EU companies and institutes with experience in the field of crystalline Si solar cells. The guiding principle of this project is to develop new and innovative process steps for wafer fabrication and solar cell and module manufacturing, taking into consideration the transfer of the processes to a pilot production line. The project's goal is to demonstrate the industrial feasibility of high-efficiency solar cells on very thin wafers in Europe. For this, both high- and low-temperature processes will be studied and compared. Our laboratory will focus on amorphous silicon (*a*-Si:H) / crystalline silicon (*c*-Si) heterojunction solar cells processed at low temperatures. Our target is to demonstrate ultra-high efficiency rear-contact cells based on *a*-Si:H/*c*-Si heterojunctions (RCC-HET > 22% efficiency).

At the Institute of Microengineering (IMT) of the Ecole Polytechnique Fédérale de Lausanne, activity was started in 2005 in the field of silicon heterojunction solar cells. Based on single process step analysis and extensive plasma diagnoses, a better physical understanding of interface phenomena occurring in silicon heterojunction solar cells has been obtained. The roles of both intrinsic and doped *a*-Si:H films in deveices are now considered to be relatively well understood. Successful medium-sized solar cells can now be fabricated on textured samples with industrially relevant technology, in particular with PECVD deposition at 40 MHz.

In the current project, that has just been started we will focus on translating these results to much thinner wafers, where a special focus will be put on maintaining high values for the short circuit density. For this, considerable efforts will be put improving the photon management at the rear of the devices.

Goals of the project

The ***overall objective*** of this project is the development of ***20% efficient silicon solar cells*** with thicknesses below 100 µm. The process will be transferred to an ***industrial pilot line*** aiming at a yield that is comparable to the one in standard production and realizing a conversion efficiency of ***19.5% on 100 µm thick 156 x 156 mm² wafers***.

The table below compares the state-of-the-art with the intended innovation in the project.

State of the Art	Breakthrough / Innovation
1. Wafer thickness and efficiency	
Wafer thickness: 160 µm	20-100 µm slicing by advanced wire sawing, wafer separation and cleaning
Efficiency: in production 17% mono-Si, 16% mc-Si	> 20% on mono-Si wafer, > 19% on mc-Si wafer by using pht, bht and nlt processes
2. Solar cell processes	
Emitter: homogeneous, highly doped emitter	Advanced homogeneous emitter, selective emitter, heteroemitter
Surface Passivation: Rear: screen-printed Al-BSF, Front: SiN	Rear surface: dielectric layers and stacks, in particular Al_2O_3, heterojunction BSF
Light trapping : Front: textured, Rear: screen-printed Al	White dielectric reflector, two sides or one side texture schemes as well as Lambertian back diffuser and photonic structures
Metallisation: Screen-printing of Ag (Front), Al (rear)	Aerosol printing, light induced plating, laser groove buried contact, laser fired contact, combination of electroless plating
Handling: batch processes, vacuum “tweezers”, forces applied locally	Horizontal transport and processing, Bernoulli handler, uniform force distribution, contactless handling
3. Solar cell manufacturing	
Cell process: p-type base, high temperature diffused emitter, Front: SiN&Ag-fingers, Rear Al-BSF and contact	Development of cell structures *pht*, *nht* or *nlt*
Handling: Yield 97,5%	Mechanical yield loss below 1.5% at the end of the project by developing available solutions for an application in high volume production
4. Cost savings	
Thinner wafers and high efficiency: 8 g/W silicon consumption	3 g/W silicon consumption

Work performed and results achieved in 2010

This project, which began in October of this year, aims to develop high-efficiency (>20%) solar cells on ultra-thin (<100 µm) crystalline silicon wafers to reduce materials costs during manufacture while simultaneously improving performance. During the kick-off meeting, arrangements were made to obtain high-quality thin silicon wafers—the first step in this collaborative project. Ahead of the wafers’ arrival, we have begun work on our two largest contributions to the project: enhanced light trapping in thin silicon wafers and amorphous silicon / crystalline silicon heterojunction solar cells.

National and international collaboration

Due to the nature of this European Project, IMT is in collaboration with the major European Institutes, Universities and Companies working on crystalline silicon solar cells. These partners include University of Konstanz, Fraunhofer Institut für Solare Energiesysteme, Q-Cells, and PSE AG from Germany; New and Renewable Energy Centre Limited (Narec) from the United Kingdom; Eni S.p.A. fom Italy, Photovoltech NV from Belgium; and Mechatronics Systemtechnik GmbH from Austria. Moreover, in

Neuchâtel, IMT also has an ambitious program running with Roth&Rau on the development of production technology for silicon heterojunction solar cells.

Evaluation of 2010 / perspectives for 2011

The project has started successfully. First experiments have been performed and a successful exchange of samples between partners has been established.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

HETSI: HETEROJUNCTION SOLAR CELLS BASED ON A-SI / C-SI

Annual Report 2010

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Project- / Contract Number	HETSI Grant agreement no.: FP7-211821
Duration of the Project (from – to)	01.02.2008-31.01.2011
Date	10.12.2010

ABSTRACT

Hetsi (Heterojunction solar cells based on *a*-Si:H/*c*-Si) is a project sponsored by the European Commision. This project links, for the first time, world-class EU companies and institutes with experience in the fields of both crystalline Si and thin film silicon. Its short term target is to demonstrate in Europe the industrial feasibility of heterojunction solar cells, by depositing very thin film silicon layers (typically 5-10 nanometers of amorphous and/or microcrystalline silicon) on top of silicon wafers. Based on ultra-thin silicon wafers (100-150 Em, *n*-type silicon, 5-6 g/W, 125 mm PS monocrystalline and 156·156 mm^2 multicrystalline silicon), with very high efficiencies: 21 % for mono and 18 % on multi at the cell level, 20 % at the module level for mono and 17 % at the module level for multi, this should result in a 50% cost reduction compared to mainline production technology. The medium term target is to demonstrate the concept of ultra-high efficiency rear-contact cells based on *a*-Si:H/*c*-Si heterojunction (RCC-HET > 22% efficiency).

At the Institute of Microengineering (IMT) of the Ecole Polytechnique Fédérale de Lausanne (formerly the University of Neuchâtel), an activity was started in 2005 in the field silicon heterojunctions. In this project, we address the more fundamental aspects of the device fabrication. Based on single process step analysis, including the use of photoluminescence imaging, and extensive plasma diagnoses, a better physical understanding of interface phenomena occurring in silicon heterojunction solar cells has been obtained. A key finding is that highly depleted plasmas lead to the best passivation. Both the role of intrinsic film and doping effects are considered to be relatively well understood now. For devices, successful intermediate sized solar cells can now be fabricated on textured samples, with industrially relevant technology, in particular with PECVD deposition at 40 MHz. This is evidenced by aperture efficiencies as high as 20.3% on 2·2 cm^2 devices.

Introduction / Project Goals

The specific scientific and technological project objectives of this European project are:

- To define the optimum device parameters for heterojunction solar cell to reach targeted efficiency (on monocrystalline and on multicrystalline *c*-Si wafers)
- To demonstrate high efficiency solar cells on large area thin wafers at lab scale
- To demonstrate high efficiency of heterojunction concept at module level at lab scale
- To validate the cost reduction of heterojunction concept and the feasibility of industrialization
- To apply heterojunction concept to innovative device : RCC Cells and ribbons

This project unites 12 partners located throughout Europe, based in respectively Belgium, France, Germany, Italy, the Netherlands, and Switzerland.

Project description and approach

The "core" technology for this project is thin-film passivation of crystalline silicon using plasma deposition (PECVD). The project is divided in eight work packages (WP), uniting each time the specialist partners within the project. These WPs address all issues that need to be solved in the 3 years timeframe.

- WP1: Management and innovation related activities
- WP2: Characterization, modelling, roadmap to 25% efficiency
- WP3: Deposited junction and BSF
- WP4: TCO and contacts metallization
- WP5: Cell process integration on large area wafers
- WP6: Heterojunctions applied to rear contact cells and ribbons
- WP7: Module technology
- WP8: Up-scaling and technology assessment

In bold are the WP's involving IMT directly. IMT is coordinating the work in WP5.

Results

In Hetsi, we focus on the fundamental understanding of heterojunction device and processing physics.

In 2009, we have been focused on understanding the precise nature of the *a*-Si:H/*c*-Si interface recombination, when the films are intrinsic [2], but also when they are doped [3]. At present, *in-situ* laserbased plasma-diagnostics [4] have become a well established tool to study of these ultrathin films. A recent key-finding, using these tools, is that for all studied conditions (by varying pressure, VHF power and SiH_4 flow), those films that where deposited under high depletion showed the best passivation. Importantly, the silane depletion fraction can be measured *in-situ* by infrared absorption measurements. In our lab we have developed a detection system for this, based on the use of a dedicated quantum-cascade laser [5]. An example of such time-resolved measurement is shown in Fig 1. As such, this gives an important real-time indicator for the passivation quality.

Next, we have also developed our own photoluminescence imaging tool. By this, we can make images of the implied V_{oc} of our samples, principally throughout the full processing sequence. An example is given in Fig. 2, highlighting that when non uniform passivation is present, this will indeed result in poor values for the V_{oc} in finished devices.

In the near-future, the hydrogen configuration of wafer surfaces and of very thin amorphous silicon

films will be studies as well with our in-house effusion-measurement tool.

These more fundamental studies have been and remain beneficial for further development of devices as well. They allowed us to fabricate solar cell precursors featuring ultra-thin doped films with excellent surface-passivation properties, in large-area reactors [6,7].

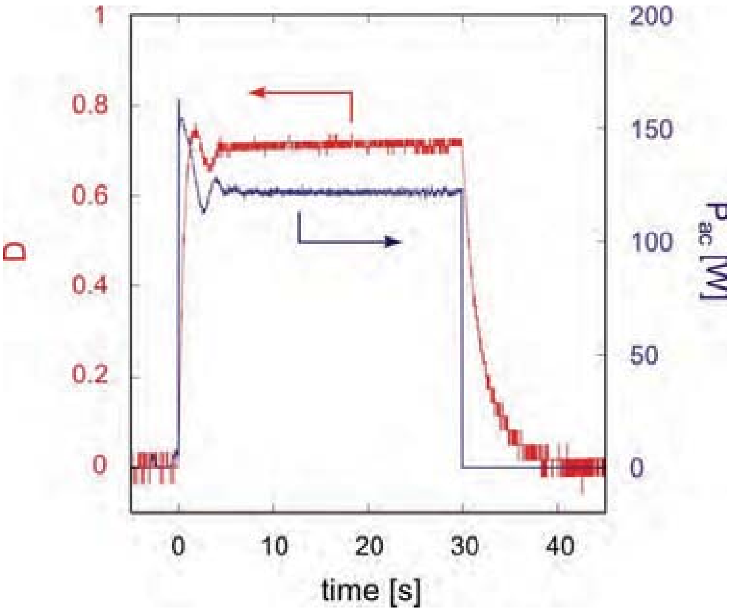

Fig. 1. Example of time-resolved measurements of the silane depletion D and of the active power P_{ac}

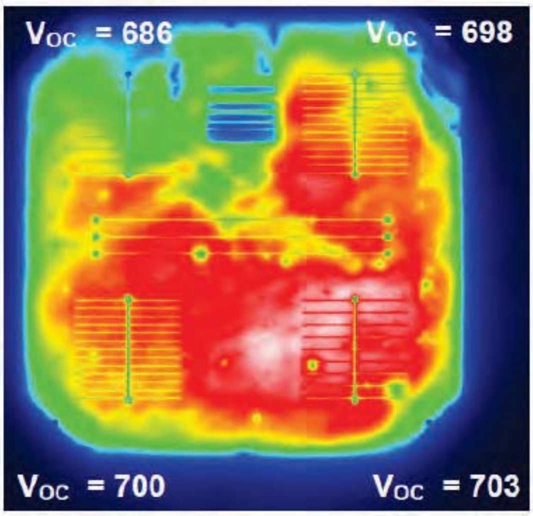

Fig. 2. PL image of a wafer with 4 2x2 cm^2 solar cells defined on it. The displayed values for V_{oc} are from IV measurements, and show that poor PL intensity indeed results in poor values for the V_{oc} in a finished device

From device-point of view, we have increasingly been focused on solar cells on textured substrates. Successful intermediate sized (2x2 cm^2) double-sided heterojunctions are now routinely made in large-area reactors (Kai-M at 40 MHz), with virtually a completely industrial process. Good aperture efficiencies of 20.3% have been obtained on such devices on *n*-type floatzone material. We show the IV characteristic of such a device in Fig. 3.

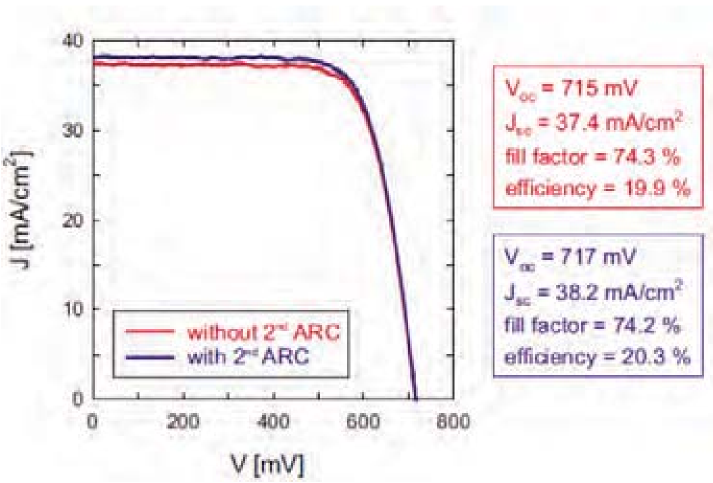

Fig. 3. Illuminated-IV curve of the best 2x2 cm^2 heterojunction solar cell, measured under standard test conditions (in-house measurement).

Collaborations

Due to the nature of this European Project, IMT is in collaboration with the major European Institutes, Universities and Companies working on heterojunction devices. These partners include CEA-INES, CNRS, ALMA and Photowatt from France; ECN and Universiteit Utrecht from the Netherlands; ENEA from Italy; IMEC from Belgium; and Helmholtz Zentrum Berlin, Q-Cells, and Solon from Germany. Moreover, in Neuchâtel, IMT has also an ambitious program running with Roth&Rau on the development of production technology for silicon heterojunction.

Evaluation 2010 and Outlook 2011

Hetsi was successfully launched in early-2008. Critical parameters have been identified for successful device fabrication in this project in 2009. This enabled us in 2010 to fabricate devices with an efficiency higher than 20%. These results have been reported in several journal publications and invited talks at international conferences. Most of our experimental work is now occurring in a cleanroomenvironment, including the wet-chemical processing and *a*-Si:H depositions. A new multi-chamber PECVD system for further device- and layer-*R&D* and new characterization tools (such as plasma diagnostics and photoluminescence imaging) are now fully in use to consolidate these activities. With the project being now in its final stage, we confidently can say it allowed us to establish a solid heterojunction technology in our lab, with good results both on technological as fundamental side. Next, we are confident in the further improvement of the performance of the heterojunction-device in our lab on a processing platform that is industrially relevant.

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FLE IBLE CIGS SOLAR CELLS AND INI- ODULES ON POL ER WITHOUT- OR WITH ALTERNATI E BUFFER LA ER FE-BULAS

Annual Report 2010

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Date	10.12.2010

ABSTRACT

Promising results showing conversion efficiency approaching as high as 75% of that of CdS reference solar cell has strongly motivated us to extend our research on In_2S_3 buffered flexible CIGS solar cells. In order to achieve appreciable performance of flexible solar cells consisting of In_2S_3 as an alternative buffer layer: a) the inconsistency associated with chemical composition of thermally evaporated In_2S_3 buffer layer, b) CIGS growth characteristics, and c) Na incorporation scheme need to be thoroughly addressed. The direct impact of compositional variation in thermally evaporated In_2S_3 buffer layer on the solar cell performance has been studied. The development and installation of a novel Flash evaporation system enabled the control over layer compostion and also it significantly increased the process yield. An in-depth analysis of optical, chemical and structural properties of Flash-In_2S_3 layers has been performed. The maximum conversion efficiency of 12.6% has been measured in low flash rate In_2S_3/CIGS device. Significant improvement in the device performance of flexible solar cell with CdS buffer layer was obtained as a result our optimized CIGS growth recipe in the scope of FEBULAS project and the EU-FP7 hipo-CIGS project. A record efficiency of 17.6% has been achieved on cell level and 12.1% for a mini-module. The role of different schemes of Na inclusion into CIGS absorber was studied. Na inclusion in 3rd state of CIGS growth sequence and post-deposition treatment was found to be most effective amongst other analyzed Na inclusion steps. The influence of different Na inclusion steps on Ga compositional grading in CIGS absorber was analyzed by depth resolved Raman spectroscopy and sputtered neutral mass spectroscopy. In-Se buffer layer prepared within an in-line CIGS preparation system was evaluated as a yet another alternative Cd-free buffer layer. In-Se layers with different thicknesses were prepared on CIGS and an efficiency of 11.2% was obtained.

1. Introduction and Project Goals

The flexible solar cells offer numerous advantages over glass substrate based rigid solar cells. They have immense potential of being developed by low-cost and industrially desired roll-to-roll process. In addition, their easy adaptability to uneven surface of applications site and lightweight significantly adds to its level of acceptance as a future technology [1]. Recently, a world record efficiency of 17.6% has been achieved on CdS/CIGS solar cells [2]. However, from industrial point of view, it is important to preserve the vacuum deposition process for the development of large area solar module which in fact is interrupted by use of chemical bath deposition method to grow CdS layer on CIGS absorber. Hence, the replacement of CBD method by an alternative vacuum based thin-film deposition technique and CdS buffer layer by a Cd-free buffer layer is highly desired and explored worldwide. The efficiency as high as 15.2% for thermally evaporated In_2S_3 buffer layer has been demonstrated by Pistor et al. [3]. Owing to anomalous evaporation behavior of In_2S_3 [4], growth of sulphur deficient layer takes place. The proposed Flash evaporated technique was used to address to problem of non-stoichiometry in the layer. Not only the layer composition of buffer layer plays a critical role in achieving higher cell performance, but also the CIGS composition has its large impact on the functioning of the solar cell.

Following scientific challenges have been addressed in the year 2010:

- Flash evaporation chamber was further upgraded so that mini-modules on substrate size of 10x10 cm^2 can be developed.
- Chemical composition analyses of Thermal- and Flash-In_2S_3 layers were performed.
- In-depth study of growth and properties of Flash-In_2S_3 buffer layer
- Thermal-In_2S_3/CIGS and Flash-In_2S_3/CIGS solar cells performance
- Optimization of CIGS growth
- Investigation of different Na incorporation schemes
- CdS/CIGS mini-module
- Evaluate evaporated In-Se as a yet another Cd-free buffer layer

Background: The Annual Report 2009 discussed the problem of non-stoichiometry in thermally evaporated In_2S_3 buffer layer. The Flash evaporation as a buffer layer deposition technique capable of forming stoichiometric layer was proposed. The current year midterm report presented the compositional analysis of Thermal- and Flash-In_2S_3 layer. The modification to Flash evaporation chamber design were discussed. The layer deposition on large area (10x10 cm^2) was successfully performed and layer uniformity was evaluated by recording the optical transmission. The issues related to CIGS growth were discussed and efficiency a large gain was reported for flexible solar cell.

2. E perimental Details and Results

2.1 Thermal-In_2S_3/CIGS solar cell: Previous year report showed the variation in layer composition (S-loss) with In_2S_3 evaporation runs (Table 1). The S-loss was found to increase successive deposition

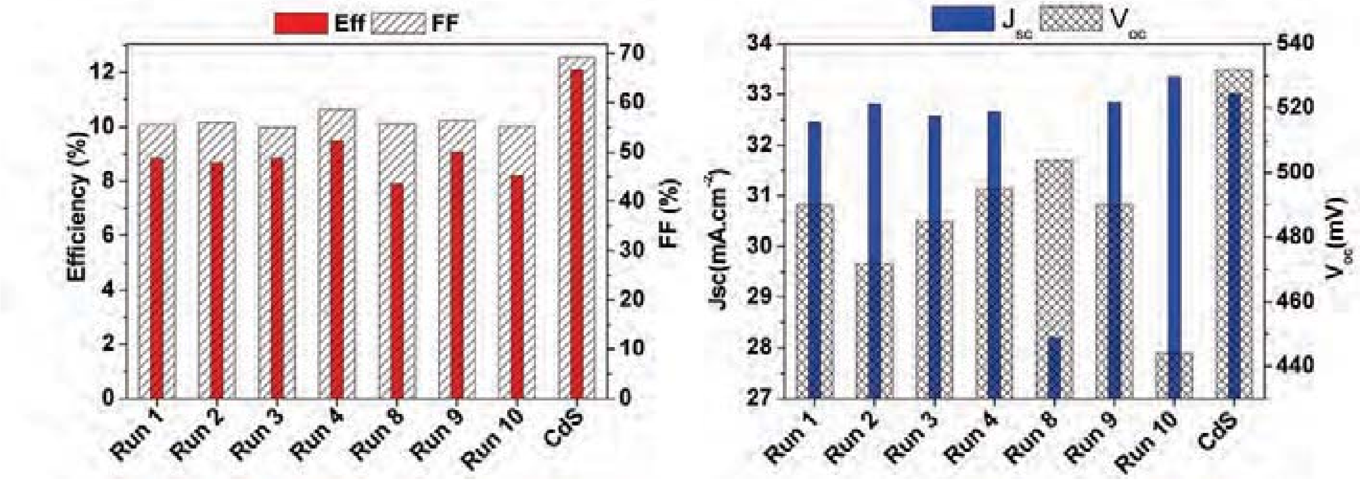


Figure 1: Photovoltaic parameters (average) of Thermal-In_2S_3/CIGS solar cell as a function of buffer layer deposition runs.

runs. The direct impact of S-loss with subsequent evaporation runs on the solar cell performance was evaluated by measuring their current-voltage characteristics. Figure 1 shows the average photovoltaic parameters of solar cells with thermally evaporated In_2S_3 buffer layer as a function of number of buffer deposition runs. It should be noted that the above study was carried out with single filling of the source material in pellet (~ 1 gm) form at the start of Run-1. The average [averaged over 32 sub-cells] conversion efficiency varied from 8.2 to 9.5%. The CdS reference cell yielded an average efficiency of 12.1%.

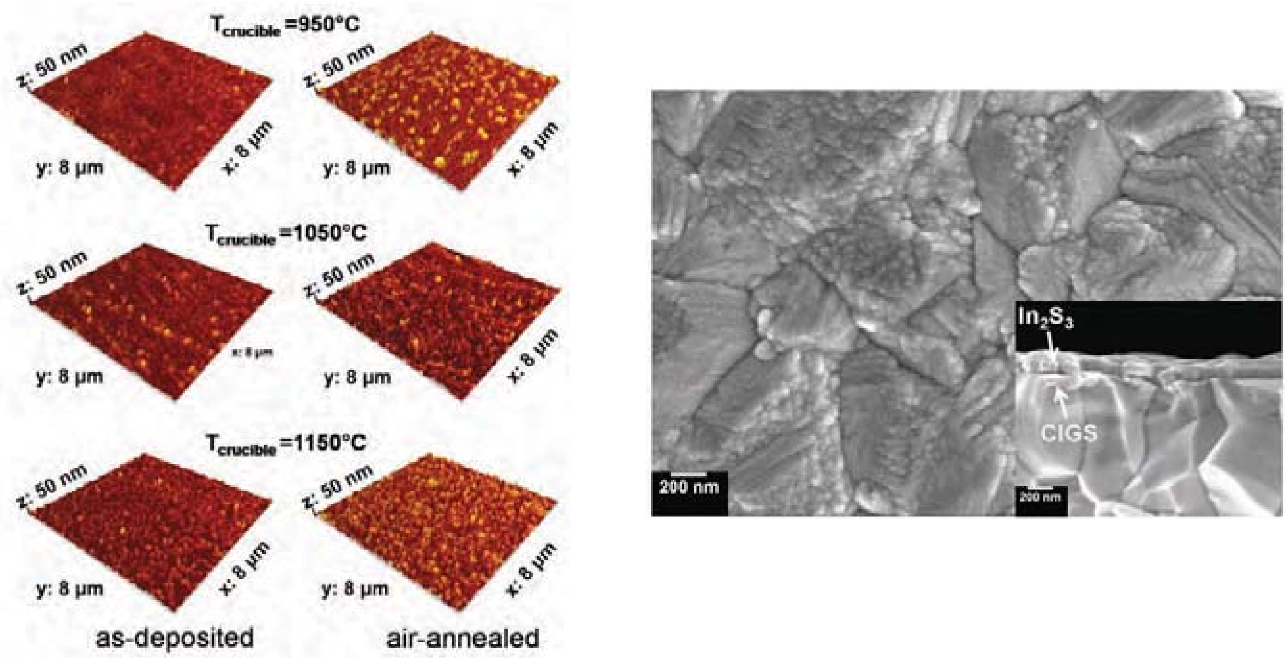
Table 1: Buffer layer composition as a function of evaporation runs.

Evaporation Run	In_2S_Y composition: Y
1	2.75
2	2.74
3	2.71
4	2.74
5	2.7
6	2.49

2.2 Flash evaporated In_2S_3 buffer la er:

2.2.1 La er properties:

It was reported in the midterm progress report 2010 that the flash evaporation also suffered from the loss of sulfur. We further investigated the growth and characteristics of the layers deposited at varying flash rates (corresponding to crucible temperature) and an analytical growth model has been proposed discussing their optical, chemical and structural properties [4]. The growth characteristic of flash evaporated buffer layer deposited on glass substrate at room temperature was studied by atomic force microscopic (AFM) technique. The AFM micrographs of the layers shown in Fig. 2a revealed the continuous growth of In_2S_3 layer with granular morphology. The grain growth due to air annealing (at 200°C, 10min) led to a distinct morphological contrast among layers. Figure 2b shows the scanning electron micrographs (SEM) of the In_2S_3 layer deposited at low flash rate on CIGS surface. Although In_2S_3 layers uniformly covered the rough CIGS surface, infrequent discontinuity at the large CIGS grain edges was distinguishable, indicating poor adhesion between CIGS and In_2S_3 layers.



(a) AFM

(b) SEM

Figure 2: (a) AFM micrographs of as-deposited and air-annealed In_2S_3 layers grown on glass substrate at different flash rates, (b) SEM surface and cross-section micrographs of In_2S_3/CIGS layer stack.

The layers grown on glass substrate were further investigated by x-ray photoelectron spectroscopy (XPS) to determine the presence impurity in the layers. The as-deposited layers were found to be contaminated with oxygen impurity. The oxygen concentration increased with increase in flash rate associated with a further increment after air annealing treatment. Additionally, a trace amount of Na impurity in as-deposited high flash rate layer was also detected which further increased with subsequent air annealing step. These observations implied high concentration of chemically active defect centers present in the layer grown at high flash rate than that existing in low flash rate layer.

2.2.2 Solar cell performance:

Figure 3 shows the solar cell performance PV parameters of the solar cell buffered with Flash-In_2S_3 layer deposited at three different flash rates proportional to crucible temperature. The as-deposited devices yielded lower efficiency and air annealing significantly helped achieving efficiency gain.

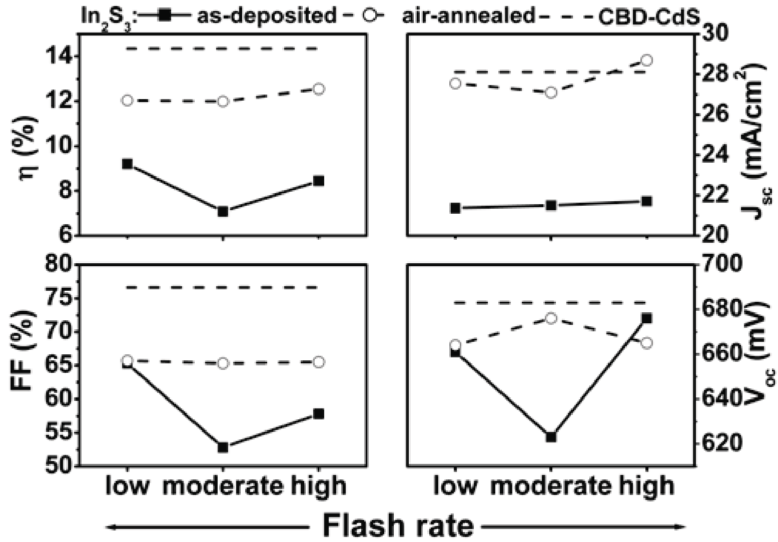


Figure 3: PV parameters of the st CdS reference and Flash-In_2S_3 buffered solar cells before and after air annealing for 20 min at 200°C.

A maximum conversion efficiency of 12.6% has been achieved with buffer layer deposited at high flash rate. A detailed analysis of layer properties and device performance can be found in Ref. [5].

2.3 odified CIGS gro th: In order to improve the efficiency of solar cells on polymer film we investigated several modifications of the evaporation process. This work was done in the scope of Hipo-CIGS and FEBULAS project. The evaporation process investigated here comprises of a 1st stage where an $(In,Ga)_xSe$ precursor is formed at 400°C. In the 2nd stage Cu is evaporated and the substrate temperature is increased to 500°C. In the new process, the Cu rate was increased by a factor of about 2 compared to the old process. At the end of the 2nd stage, when the layer has turned Cu-rich, the Cu deposition is stopped and In and Ga are evaporated again to transform the layer into the desired Cu-poor final composition. In the new process, the In and Ga evaporation rate in the 3rd stage was reduced by a factor of about 4 as compared to the old process. Se is evaporated throughout the whole layer growth in constant overpressure in both processes, the old and the new one. The supply of Na into CIGS was ensured by evaporation of NaF followed by a post-deposition treatment as discussed in Ref. [6]. Figure 4 shows the SEM cross-sections micrograph from devices grown with the old process and the new process. Evidently, the new process leads to significantly enhanced crystallinity, especially near the back contact, where the grains are much larger than in case of the old process. Also many grains extending over the whole film depth are observed, which is not the case for the layer grown with the old process. A flexible CIGS solar cell on polyimide film with a certified efficiency of 17.6% has been developed [7, 8]. The successful transfer of scientific know-how gained at modification of CIGS growth process, on to CIGS/In_2S_3 devices shall pave a solid path towards the development of high efficiency solar cells with In_2S_3 buffer layer.

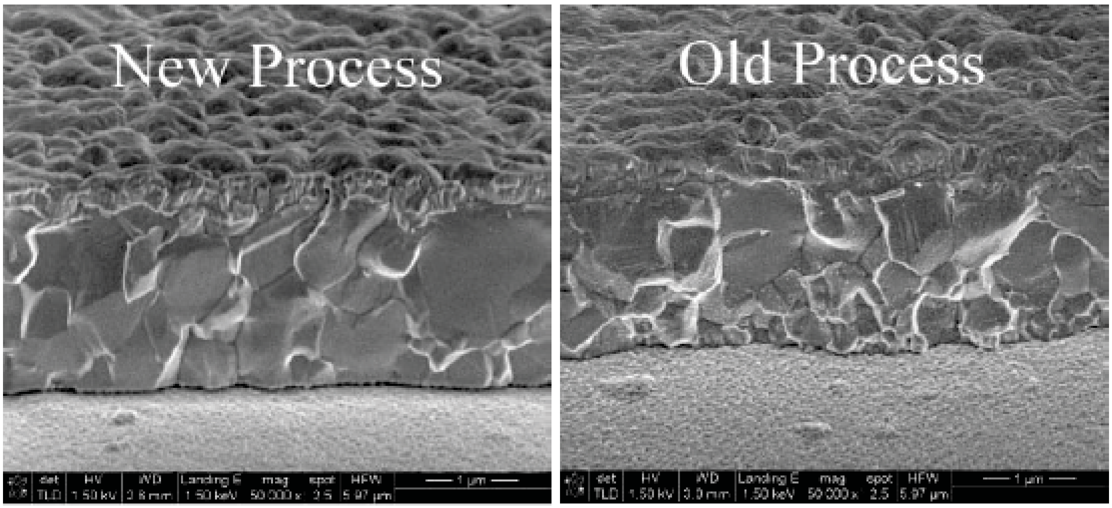
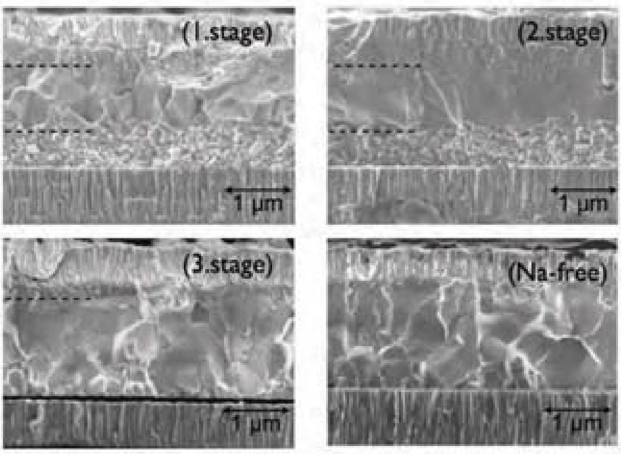


Figure 4: SEM cross-sections comparing the CIGS layers grown with the old process and the new process.

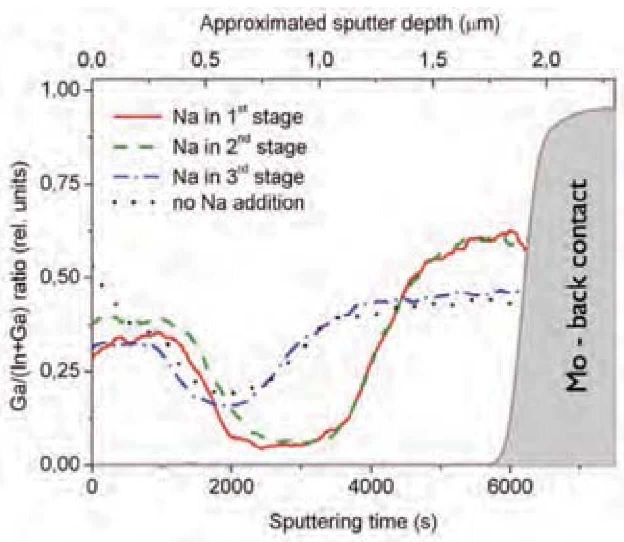
2.4 Na incorporation in CIGS

The incorporation of a small amount of sodium into the CIGS absorber layer is beneficial for performance of solar cell devices [9]. The effects of sodium addition lead to improved conversion efficiencies mainly by enhancing the fill factor (FF) and open circuit voltage (V_{oc}) of the devices. Additionally, increased p-type conductivity is observed for sodium containing devices.

2.4.1 CIGS gro th properties: The effects of sodium incorporation during the different stages of the CIGS deposition on microstructure are shown in scanning electron micrographs (SEM) of the absorber cross-section in Fig 5a. Significant changes in the layer structure can be observed when NaF is evaporated during 1st and 2nd growth stage. A homogeneous layer structure is observed when sodium is incorporated during the 3rd stage of CIGS deposition. The reference sample with no Na comprises a CIGS microstructure typical for low temperature grown CIGS. To investigate the origin of inhomogeneous grain size distributions, sputtered neutral mass spectroscopy (SNMS) measurements are performed.



(a)



(b)

Figure 5: (a) SEM cross-section micrographs of CIGS layers receiving Na incorporation at different stages during CIGS growth (b) Depth profiles of relative Ga/(In+Ga) concentration of CIGS absorbers as obtained from SNMS measurements. Na free sample served as a reference.

The depth profiles of relative Ga/(In+Ga) concentrations are shown in Fig. 5b. The absorber layers exhibit a strongly graded composition across the layer thickness with an intermediate Ga-poor region and Ga-rich surface and back regions. However, the concentration grading is more distinctive compared to the sodium free sample and the position of the Ga/(In+Ga) minimum is shifted towards the molybdenum back contact, when sodium is added during the 1st and 2nd CIGS-growth-stage. Samples Na_1st and Na_2nd exhibit high Ga/(In+Ga) ratios of about 0.6 near the back contact. In contrast, sodium incorporation during the 3^{rd} growth stage results in a concentration profile similar to the sodium free sample with a less graded composition profile, exhibiting a Ga/(In+Ga) ratio near the back contact of about 0.4. The Ga/(In+Ga) value of the absorber surface is similar for all sodium containing samples. However, the reference sample Na_0 has a slightly higher value of about 0.5 near the surface.

2.4.2 Solar cell performance:

To analyze the effect of different Na inclusion schemes into CIGS absorber, the J-V properties of the solar cells were determined. Fig. 6 shows J-V characteristics of CdS/CIGS solar cells processed with the different steps of sodium inclusion. A significant improvement of PV performance is achieved, when sodium is added into CIGS layer. With respect to reference sample, Na_0, all methods of sodium incorporation lead to enhanced FF, V_{OC}, and J_{SC} which increase successively when sodium addition is shifted from the 1^{st} to the 2^{nd} and to the 3^{rd} CIGS growth stage. The parameters of the best devices are summarized in Table 2.

Table 2: PV parameters of the best solar cell devices with sodium addition during different CIGS growth stages. No antireflection coatings were applied.

Na addition	Na-free	1^{st} stage	2^{nd} stage	3^{rd} stage
J_{SC} (mA cm^{-2})	29.5	30.5	30.8	31.8
V_{OC} (mV)	588	605	638	683
FF (%)	61.0	66.2	68.5	75.4
Efficiency (%)	10.6	12.2	13.5	16.4

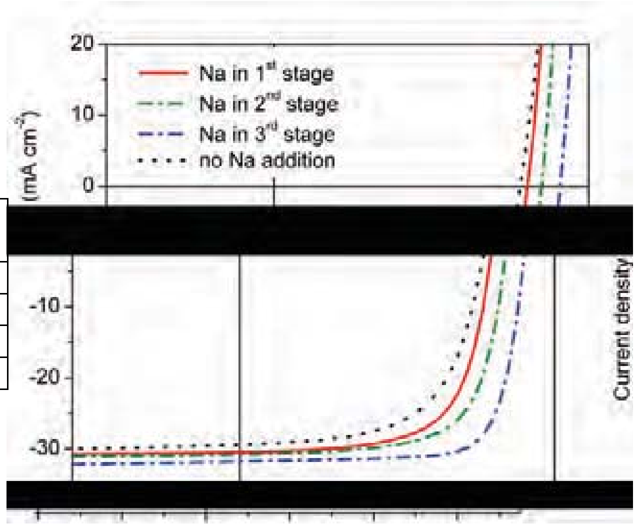


Figure 6: J-V parameters of solar cells on polyimide substrate with sodium co-evaporation during the 1^{st} (red solid line), 2^{nd} (green dashed dotted line), 3^{rd} (blue dashed dotted line), and without sodium (black dotted line), respectively.

The solar cell with CIGS layer having Na inclusion in 3^{rd} stage was found to be the best among other devices with CIGS absorber receiving Na supply in 1^{st} and 2^{nd} stage. After establishing the superiority of Na inclusion step (i.e. 3^{rd} stage of CIGS absorber growth) for CdS/CIGS solar cells, the devices with In_2S_3 buffer layer will be developed and tested.

2.5 Fle ible mini-module:

For CdS/CIGS device, the extensive efforts in process optimization of CIGS growth and Na incorporation steps yielded a mini-module efficiency of 12.1% on 15.8 cm^2 area cells.

2.6 In-Se buffer la er:

In-Se was evaluated as yet another alternative Cd-free buffer layer. The advantage of using In-Se as a buffer layer is the knowledge about its deposition as derived from thermal co-evaporation of constituting element for CIGS layer growth. A relatively narrow band gap of In-Se compounds of as wide as 2.0 eV is a disadvantage. The highest efficiency achieved on In-Se/CIGS solar cell is 13.0% [10].

In-Se layers were prepared on CIGS (CIGS/Mo/soda-lime glass) by thermal co-evaporation following CIGS layers preparation using an in-line deposition system without braking vacuum. In-Se layers with varied thickness were grown on CIGS layers and the device properties were evaluated. Table 3 lists the PV parameters obtained on solar cells with In-Se buffer layer and also presents the reproducibility of the device performance. Compared with the efficiency of the reference cell with CdS buffer, a reasonable efficiency of up to 11.2% was successfully obtained with a layer thickness of about 35 nm.

Table 3 Results of solar cell properties. Best data and the average (in parentheses) for each run on one substrate.

Run	Eff. (%)	V_{OC} (mV)	J_{SC} (mA/cm^2)	FF(%)	In-Se thickness expected
M454	10.2(9.8)	513(512)	32.5(31.6)*	61.2(60.8)	~20nm
M458	10.4(9.7)	487(475)	35.2(34.5)*	60.7(58.9)	~20nm
M463	11.2(10.4)	526(510)	33.9(33.2)	62.8(61.6)	~35nm
M465	10.2(9.8)	513(512)	32.5(31.6)	61.2(60.8)	~50nm
M466	11.1(10.2)	506(496)	34.7(33.4)	63.2(61.4)	~35nm
M468	10.8(10.1)	515(503)	33.2(33.3)	62.9(60.1)	~50nm
M467	12.6(12.1)	540(532)	33.7(33.0)	69.5(69.2)	CdS reference

National and International Cooperation

The research work of FEBULAS project is interconnected with the EU FP7 project "hipo-CIGS" involving 8 European R&D institutes and industries. The research group at Empa is actively collaborating wit project partner Flisom AG based in Dübendorf on source design, laser patterning and module integration.

Be ertung 2010 und Ausblick 2011

The FEBULAS project started on July 1st, 2009. The current year 2010 has seen a wide step forward in realizing its project goals. An extensive analysis of the chemical composition of Thermal- and Flash-In_2S_3 buffer layers generated a wealth of information. The solar cell performance with respect to number of buffer layers deposition runs was determined. A detailed analysis of Flash-In2S3 buffer layer helped us understand the device performance. A highly efficient CdS/CIGS flexible solar cell was developed as a result of our modified CIGS growth process. A successful development of 12.1% efficient mini-module was realized with our optimized CIGS process.

The challenges for the development of flexible solar cells employing In_2S_3 as an alternative buffer layer will be thoroughly addressed in the year 2011. The evaporation source supplied by our project partner will be used for evaporating In_2S_3 buffer layer. CIGS surface and CIGS/In_2S_3 interface properties shall be investigated with the help of suitable (e.g. T-I-V, C-V) thin-film characterization technique. The light soaking experiments will be performed to study the metastabilities in solar cell performance. Flexible mini-module comprising of In_2S_3 buffer layer will be developed.

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Influence of impurities on the performance of CIGS thin film solar cells

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Date	21.12.2010

ABSTRACT

One of the major tasks of this project is to develop a new molecular beam epitaxy (MBE) system for $Cu(In,Ga)Se_2$ (CIGS) deposition, which will be employed to research critical issues in the CIGS solar cells technology, such as influence of impurities, compositional gradients, buffer-free layers, etc. The new system has been planned using the proprietary design, built and successfully installed at Empa, and the first CIGS films were processed during this year.

To investigate the effect of impurities coming from the indium source material on the performance of CIGS thin film solar cells, a baseline process has been defined to make a comparative study of high purity and lower purity source material. The baseline process contains all parameters to make reproducible and high efficient solar cells.

To investigate the effect of additional impurities in the absorber, CIGS device have been processed with two In materials of different purity. The study showed that reduction of the indium material purity did not affect the performance of the CIGS solar cell. With both materials efficiency close to 16% has been achieved. To analyze the impact of the impurities on the electronic properties of the devices in more detail, capacitance measurements (C-V, C-f) have been used.

The effect of impurities diffusing from the substrate through the molybdenum back contact into the CIGS has been investigated as well, using different substrate materials.

1. Objectives

The investigation of the effect of impurities in $Cu(In,Ga)Se_2$ (CIGS) solar cells is interesting in two ways. From the physics point of view, impurities may have beneficial or detrimental effects on the semiconductors electronic properties. The understanding of the underlying processes is essential to further improve the performance of the devices. On the other hand, material cost is a large component of the overall cost of the solar cell, especially when produced on large scale. The standard practice in thin film deposition is to use source materials of a high purity level, typically 6N and higher. These high purity materials are expensive and rather difficult to produce and perhaps even a lower purity material could be adequate or might be even better for cost effective solar cells. Therefore, the aim of this project is to understand to which levels these impurities in the source material are tolerable without affecting the final device performance.
The objectives of this year time frame are to process CIGS solar cells with reduced In source material purity. From the defined baseline process on SLG substrates a comparison of *at ia* with high purity In and *at ia* with lower purity In (<5N) is made. To draw reasonable conclusions an appropriate number of samples had to be produced. In collaboration with the University of Gent the two sets of samples were characterized using quantum efficiency (QE), current-voltage (IV) and various capacitance measurements.

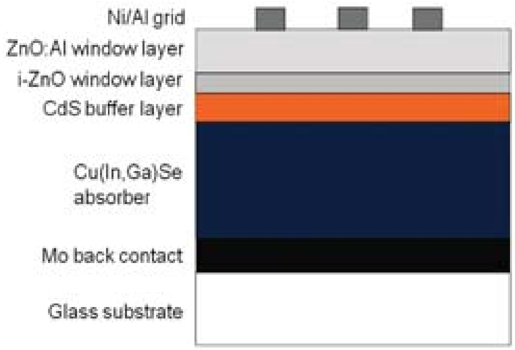
Additional to the use of different In source purities the influence of the substrate material (from which impurities may diffuse to the CIGS absorber as well) on the device properties has been investigated. Polyimide (PI) foils have been used as alternative substrate.

For this project a new MBE system for CIGS deposition has been developed. The construction and installation of the new system has been successfully finished during this period.

2. E perimental Procedure

The CIGS solar cell layer structure as shown in figure 1 comprises of the Mo back contact, the CIGS absorber, the CdS buffer layer and finally a bilayer of intrinsic ZnO and ZnO:Al as the front contact onto which a Ni/Al grid is evaporated for improved carrier collection (see Fig. 1). A 5 cm x 5 cm device is separated into equally sized cells (0.6 cm^2) by mechanical scribing.

In this project the effect of different purity levels of the In source material on the electronic properties of the device is investigated. All the other processing parameters are kept constant as defined in baseline process shown in table 1. Two different types of substrate have been used to investigate the effect of impurities diffusing from the substrate.



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Layer	CIGS		CdS	i-ZnO	ZnO:Al
Parameter	T_{sub} [°C]	Cu-excess [%]	thickness [nm]	thickness [nm]	thickness [nm]
Standard SLG	600	15	100	80	210
Standard PI	450	15	50	80	210

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The investigation of the influence of impurities on the electronic properties requires high efficiency solar cells. In lower efficiency devices other electronic processes might cover the effect of impurities. Furthermore, the samples from high purity and lower purity source material have to be comparable. Therefore, the baseline processing parameters have been developed such that high efficiency (~16%) and reproducibility are possible.

The electrical characterization of the finished devices current-voltage, quantum efficiency and capacitance measurements are used. Especially, the measurement of the capacitance under applied bias voltage and at different frequencies is a useful tool to investigate the effect of impurities on the electronic properties of the device. To understand the underlying electronic mechanisms of impurities the computer based simulation tool SCPAS is used.

3. Results

GD S anal sis of In source material

The In source material has been analyzed for material impurities with GDMS technique. The analysis showed the purity of material B is below 5N (details cannot be published).

CIGS device properties

A reproducible process of the CIGS layer deposition is essential for this project because samples with different source material purity have to be comparable to each other. A series of four samples has been processed from material B as well as a reference sample from material A on SLG with the defined baseline parameters mentioned in section 2.

Sample	Cu	Ga	Se	In	x	y
2	21.9	8.94	53.2	16.0	0.35	0.88
4	22.4	9.04	52.9	15.6	0.37	0.91
ref	22.3	8.84	53.2	15.7	0.35	0.91

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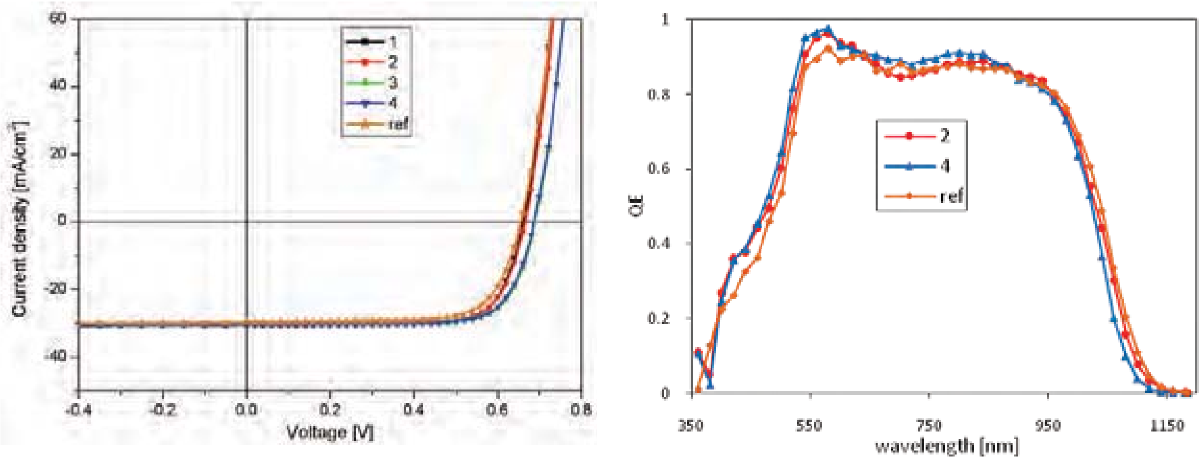
The J-V curve of the best performing cell on each sample is shown in figure 2. The average efficiency on the samples with material B is close to 16%. The short circuit current density is almost identical for all cells. However, in the open circuit voltage slightly different values have been measured. This is partially explained by small variation in the Ga/(In+Ga) ration of the absorber for the different samples (see also table 3). As will be shown in the next section differences in the free carrier concentration are also detected giving rise to differences in V_{oc}.



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A summary of the cell parameters is given in table 4. The small differences in the Ga/(In+Ga) ratio of the absorbers are also reflected in quantum efficiency (QE) curves in figure 2. The shift in the absorption edge in the long wavelength region reflects the minimum band gap of the absorber. In this case a slightly higher band gap is determined for Sample 4 compared to the other samples.

No.	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
1	661	30.9	75.4	15.5
2	665	30.8	74.8	15.4
3	689	30.6	75.5	16.0
4	687	30.3	74.7	15.6
ref	655	30.9	72.7	14.7

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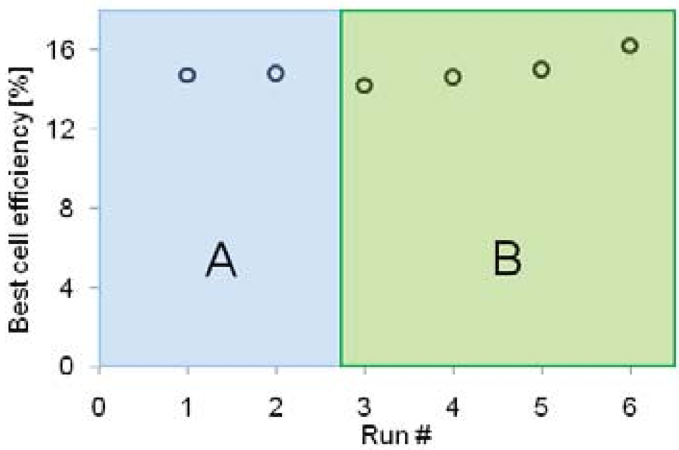
To further investigate the reproducibility as well as possible influences of the long term use of lower purity In on the CIGS device performance, a second series of samples has been produced. Figure 3 shows the evolution of the best cell efficiency on each sample during several CIGS processing runs. On the left hand side, two more reference samples with high purity In have been produced for additional statistics (run 1 & 2) and on the right hand side material B has been used (run 3 - 6).



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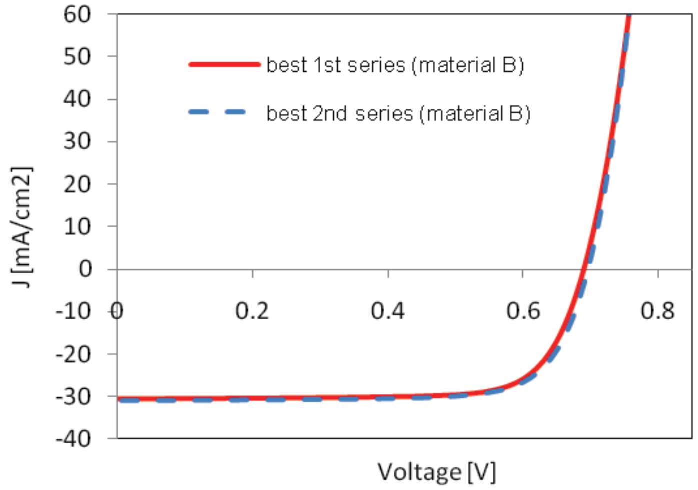
The results shown in figure 3 clearly show that all devices perform similar. The efficiency is in average close to 15%, without the application of an anti reflective coating. The very best cell (Run 6) achieved a cell efficiency of 16.2%. There is no degradation of the device performance due to long term use of material B observable, since the best performing cell is actually the last one of this series.

Figure 5 shows a comparison of the best cell from the first series of samples and the best cell from the second series. This result clearly shows the good reproducibility of the process and absence of long term use effects on the CIGS performance



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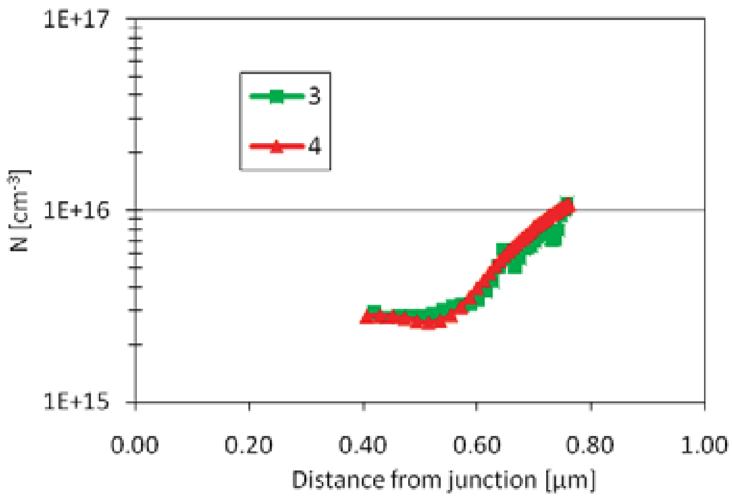
Free carrier concentration

The free carrier concentration in the absorber is an important value for the device simulation. Furthermore, equally processed samples should have comparable free carrier concentration.

To determine the free carrier concentration the space charge layer of the solar cell can be viewed as a plate capacitor with Capacitance C = ε A / W, where ε is the dielectric constant of the absorber, A the area of the cell and W the width of the space charge layer. The width of the space charge layer is linked to the semiconductors doping concentrations forming the p-n junction. The method of C-V profiling makes use of the voltage dependence of the space charge layer width (and therefore of the capacitance) to calculate a depth profile of the semiconductors carrier concentration. Figure 4 shows the free carrier concentration of sample 3 and 4 from the first series of samples, measured at T = 123 K.



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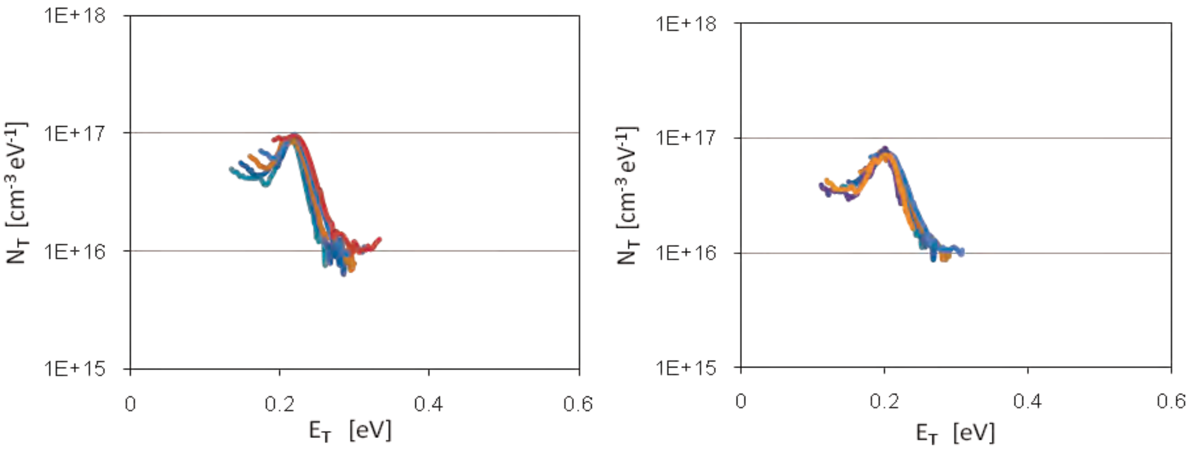
The two free carrier concentration profile curves in figure 4 are almost identical (both with a minimum value of $3x10^{15}$ cm^{-3}), indicating they have similar properties. The minimum free carrier concentration of the reference cell, however, is only $4x10^{14}$ cm^{-3} and therefore almost one order of magnitude lower. This indicates again a different processing of the reference sample compared to the others and the difference in V_{oc}.

Defect levels

Impurities in the absorber layer can form energetic defect levels. Depending on the energetic position of these levels they influence the electronic properties of the device. Admittance spectroscopy and DLTS allow us to asses these defect levels.

The peaks shown in figure 5 determined from admittance spectroscopy, correspond to a defect level that is present in all CIGS devices, no matter what source material is used. This leads to the conclusion of an intrinsic defect instead of a defect from impurities being the origin for this peak.



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All devices in this study including the reference device from high purity In did not show any further peaks in the defect spectrum. This means that either (1) the impurities in the absorber do not form a defect level that is measurable by admittance spectroscopy, but could be detected by DLTS, (2) the impurities in the absorber are not electrically active, i.e. do not act as carrier traps, or (3) there are no impurities (or only in very small quantities) in the absorber.

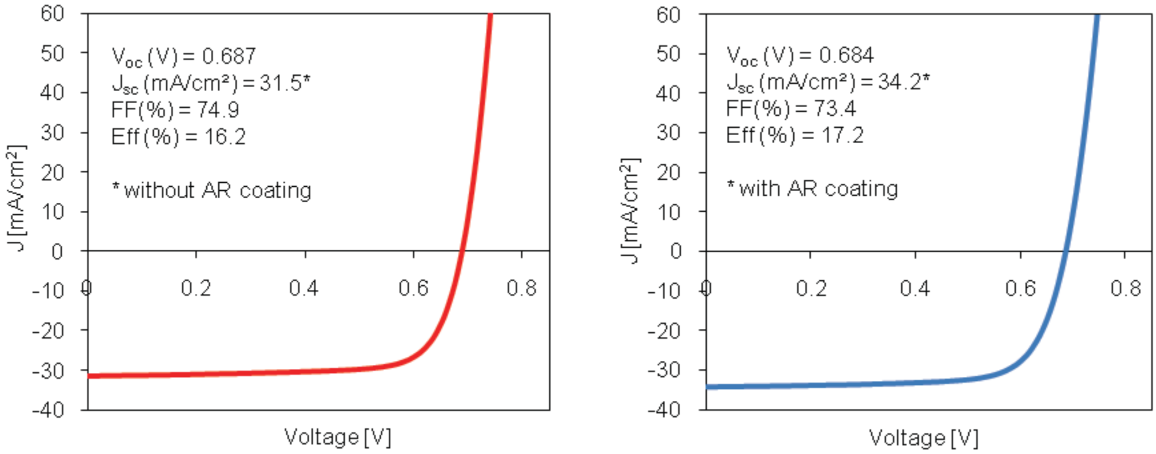
Initial DLTS measurements could not conclusively verify the presence of other defect levels, but confirmed the findings of the admittance measurement peak. Therefore, more experimental data is required from DLTS.

To verify the third conclusion a chemical analysis of the CIGS needs to be done to determine the impurity concentration in the layer based on the findings from the GDMS analysis of the source material.

Alternative Substrate

The possibility for impurities to diffuse from the soda lime glass substrate through the Mo back contact into the absorber motivates extending the investigation of the effect of impurities to alternative substrates. Furthermore, the reproducibility from one sample to another is improved since the incorporation of sodium is more controllable (in case of SLG Na diffuses from the substrate through the Mo layer into the absorber and in case of polyimide foils it is intentionally added during CIGS growth).

Figure 6 shows the current voltage curve of CIGS solar cell grown on polyimide substrate using lower purity In source material. As shown in table 1 the processing parameters had to be slightly changed since the polyimide does not allow higher substrate temperature than 500 °C during CIGS growth. Therefore, a new reference device from high purity In source material has been produced. A detailed discussion of the device processing is given in [1].



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The device shown on the left hand side of figure 6 does not have an anti reflective coating; therefore the current density is lower compared to the device from high purity indium. The V_{oc} of both devices is almost equal. The comparison of these two devices clearly shows that a reproducible process giving high efficiency has been developed for alternative substrates and that reducing In source material from material A to material B does not have any detrimental effect on the device performance.

4. Installation of the BE machine for CIGS deposition

The design as well as the construction of the new MBE machine has been successfully finished during this year. EMPA has recently received the setup and the installation has been completed (see figure 7). During the next year the recipes for the CIGS evaporation will be developed according to our current understanding of the growth mechanisms.

i u n s st

5. National and international collaboration

Investigations of influence of impurities in indium material are complemented by the IWT-supported project with industrial partner Umicore SA. The detailed characterisation of the baseline CIGS solar cell is carried out in collaboration with the University of Gent, Belgium. In particular, the capacitance measurements as well as the analysis and modelling of the defects are assisted by J. Lauwaert, H. Vrielinck, K. Decock and M. Burgelman.

6. Conclusions   Outlook

The reduction of the In source material purity material A (high purity) to material B (lower purity) did not affect the CIGS device performance. Comparable efficiency of ~16% (without anti reflective coating) has been achieved with both materials.

The very promising results using lower purity In source material giving still very high efficiency motivates further reduction of the source material purity. During the next period a chemical analysis of the impurities in the final absorber will be carried out to quantify their concentrations and to correlate them to the electronic properties of the device.

The acquired data of this period will be used to create a theoretical for the electronic properties of the CIGS solar cell. To understand the effect of impurities on the performance more data is needed.

7. References

[1] “Progress towards the development of 18% efficiency flexible CIGS solar cells on polymer film”, A. Chirilă, P. Bloesch, A. Uhl, S. Seyrling, F. Pianezzi, S. Buecheler, C. Fella, S. Nishiwaki, Y. E. Romanyuk, and A. N. Tiwari, Proceedings of the 25th European Photovoltaic Solar Energ Conference and E hibition / 5th World Conference on Photovoltaic Energ   Conversion, Valencia, Spain, 3B   .2.6 , 2010.

NEW CONCEPTS FOR HIGH EFFICIENC AND LOW COST IN-LINE ANUFACTURED FLE IBLE CIGS SOLAR CELLS HIPO-CIGS

Annual Report 2010

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Date	01.10.2010

ABSTRACT

The hipo-CIGS project aims at the development of cost efficient flexible solar cells and modules based on the compound semiconductor CIGS. Efficiency and cost limitations in state-of-the-art flexible CIGS solar cells have been identified and solutions were elaborated for each step in production and each layer of the multilayer structure in order to overcome these limitations. For accomplishing these tasks a European consortium of leading R&D institutes and industries was established.

A key issue for cost reduction is the improvement of efficiency and therefore the output yield in production. An important milestone of the hipo-CIGS project is the achievement of cell efficiency higher than 16% on flexible substrate by optimizing the multistage deposition process for the CIGS layer. Empa focused on this task by investigating a low temperature multistage process during the first year of the project. The deposition process for the CIGS layer was modified in terms timing and of elemental fluxes during the various stages. This leaded to improved grain growth in the polycrystalline CIGS layer. Furthermore, the composition grading of group three elements is flattened and more similar to the high efficiency samples on glass substrate. This reduces recombination losses in the solar cell and hence improves the efficiency. With this certified efficiency of 17.6% has been achieved on flexible polyimide substrate which is a new world record and an important step towards the project objectives.

Further activities during this project are the development of a crack free electrical back contact which provides sufficient adhesion to the substrate and for the CIGS. The sputter parameters of conventional Mo/Mo structure were optimized and a multifunctional Ti/TiN/Mo structure was investigated. Also the doping properties of sodium in the CIGS were investigated by inserting Na during different stages of the CIGS process.

Introduction and Project Goals

The $Cu(In,Ga)Se_2$ (CIGS) on glass technology is already heading towards industrial maturity, but to meet the production cost target of below 0.6 €/Wp in mid-term and below 0.4 €/Wp in long-term, development of highly efficient flexible modules is an attractive option.

The ultimate advantage of thin-film technology is the possibility of monolithically connected flexible modules produced with high speed roll-to-roll manufacturing systems. Partners of this proposal have already demonstrated a record efficiency of 14.1% for cells on polyimide (PI) film and >15% efficiency cells on metal foil using “static deposition” processes. However, transfer of a “static deposition” process to “in-line deposition” on moving substrates brings additional challenges for control of layer composition and interfaces. Choice of appropriate substrate and deposition process to overcome problems of thermal mismatch-related stress are important for high performance and monolithic cell interconnection.

The main goal of the project is to develop innovative flexible substrates and deposition processes suitable for the in-line and/or roll-to-roll production of highly efficient solar modules using thinner (< 1 micron) CIGS absorbers and with potential for production costs below 0.6 €/Wp in future. The objective will be achived by developing novel concepts in growth of “high quality” layers and interfaces for efficiency improvement, aiming a new world record efficiency of 16% on PI and low-cost metal (mild steel and alumina) foils. Also, the implementation of in-line compatible buffer layers, improvements in interconnection technologies and application of multifunctional top layer will lead to an advancement towards roll-to-roll manufacturability of integrated solar modules. This project will help research institutions to maintain a global lead in the CIGS field and will enable the European industries to implement the research excellence in industrial production of low cost flexible CIGS solar modules in future.

In order to achieve the challenging aims and objectives of this project a European consortium consisting of 8 partners from R&D and industry was established and is coordinated by ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Germany).

The project is divided into seven workpackages covering activities on flexible substrates (WP1), back contact and Na supply (WP2), CIGS deposition (WP3), buffer layers (WP4), interconnections (WP5), TCOs (WP6), and assessment of results (WP7). Empa is contributing to WP1-4 with the following goals for the reporting period:

- Crack-free back contacts with sufficient adhesion on various flexible substrate materials.
- Investigation of influence of NaF doping during different growth stages on the CIGS morphology and device performance.
- Find optimum low-temperature CIGS growth procedure for solar cell efficiency above 16% on flexible substrate.

These tasks for achieving high efficiency CIGS flexible cells are complemented by research activities within BFE project Febulas (103317) and CTI project on Multifuncional back contacts (CTI-10245.1).

Work and Results

1. Crack free back contact

The preparation of the multilayer CIGS thin film solar cell starts with the deposition of the electrical back contact. A bilayer of molybdenum is commonly used, however, the adhesion both of the Mo on the flexible substrate and the CIGS layer on the Mo are not satisfying with standard sputter parameter. These sputter parameters were modified in order to achieve maximum adhesion and minimum residual stress in the layer stack. Furthermore, multilayer back contact stacks of Ti/TiN/Mo for flexible CIGS solar cells were compared to a conventional Mo/Mo design. The residual stress of individual layers was investigated, where Ti showed low and tensile, TiN and Mo high and compressive stress. It was found that a combination of these layers with different stress contributions lead to an overall residual stress compensation in the back contact stack. The adhesion of the CIGS was improved by applying this alternative multilayer back contact.
Conversion efficiencies of 13.4% were obtained with the Ti/TiN/Mo back contact and 14.9% for the Mo/Mo reference. The lower solar cell performance with alternative back contacts apparently stems from smaller average CIGS grain size and rough morphology. This is a result of higher surface roughness of these contacts and/or lower substrate temperatures during CIGS growth, caused by higher heat emissivity of the contacts. It is expected that both, an improvement in the alternative back contact growth structure, and an adaption of the CIGS deposition process could lead to comparable solar cell performance regarding the conventional design.

2. Influence of NaF incorporation during CIGS gro th on microstructure and photovoltaic performance

The sodium supply via thermal evaporation of NaF during different stages of a three-stage CIGS evaporation process has been investigated. Solar cells were processed on soda lime glass (SLG) with Si_3N_4 diffusion barrier and on PI foils at low substrate temperature of <500°C compatible with the stability of the PI foil.

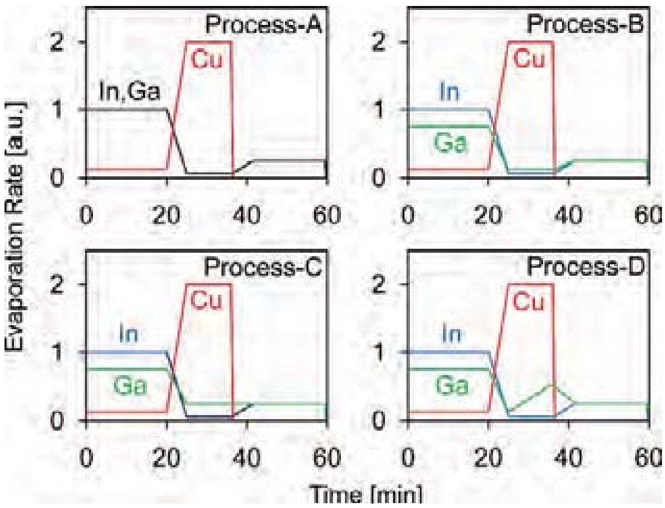
Secondary electron micrographs of CIGS layers show inhomogeneous microstructure containing regions of small grains near the back contact when sodium is evaporated during the 1st or the 2nd CIGS growth stage. The CIGS layer structure is affected only to a minor extent if sodium is incorporated in the 3^{rd} stage. In order to correlate the layer inhomogeneities with the composition profiles, the CIGS layers were investigated with depth resolved Raman scattering and sputtered neutral mass spectroscopy. Both analyzing techniques reveal a strongly graded composition across the CIGS absorber, with an intermediate Ga-poor region and Ga-rich surface and back regions.

The performance of resulting solar cells was characterized by means of current-voltage and external quantum efficiency measurements. It is found that the photovoltaic performance of the cells depends significantly on the NaF incorporation method. Cells developed with a low temperature growth process yielded high efficiencies of up to 16.4% without antireflection coating when NaF was supplied during the 3^{rd} stage of the CIGS growth process. This task has overlap with the BFE-Febulas project and results are published in more detail in [1].

3. Lo temperature gro th procedure

Devices were prepared with conventional process steps commonly used for CIGS solar cells. First a Mo back contact (600 nm for PI, 1 µm for SLG) was deposited by dc-sputtering. The CIGS absorber layer was grown by elemental co-evaporation and various deposition profiles were used in modified three-stage processes. The evaporation rates of different elements were controlled by regulating the temperatures of the respective effusion cells. Subsequently, the CIGS layer was covered by an approximately 100 nm thick CdS layer grown with a chemical bath deposition method. The front contact window layer consisted of a 70 nm / 250 nm thick i-ZnO / ZnO:Al bilayer deposited by rf-sputtering. For single cells, Ni/Al grids grown by e-beam evaporation were applied. No anti-reflection coatings were applied, except for the best cell presented below.

The CIGS growth recipes investigated (Process A-D) are schematically depicted in Figure 1. In all processes Se was provided throughout the deposition in constant overpressure. During the 1st stage, when mainly In and Ga were deposited, the substrate temperature was kept at a nominal value of 400°C, as measured with a thermocouple behind the substrate at a fixed reference position. The actual substrate temperature could be lower than the values mentioned here. During the 2nd stage, the substrate temperature was increased to 500°C and then kept constant until the end of the deposition. The transition from Cu-poor to Cu-rich towards the end of the 2nd stage was monitored by an end-point detection method [2] and was used to control the maximal Cu content and final Cu content.



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Various growth recipies that aimed at modifying the composition profiles were investigated and are shown in figure 1. In case of Process-A the Ga/In ratio was kept constant throughout the whole deposition. For Process-B a lower Ga/In ratio was applied during the 1st stage and a slightly higher amount of Ga was deposited during the 2nd stage. Process-C differs from Process-B only by a higher amount of Ga deposited during the 2nd stage. Finally, Process-D comprised of an asymmetrical Ga deposition during the 2nd stage and the beginning of the 3rd stage.

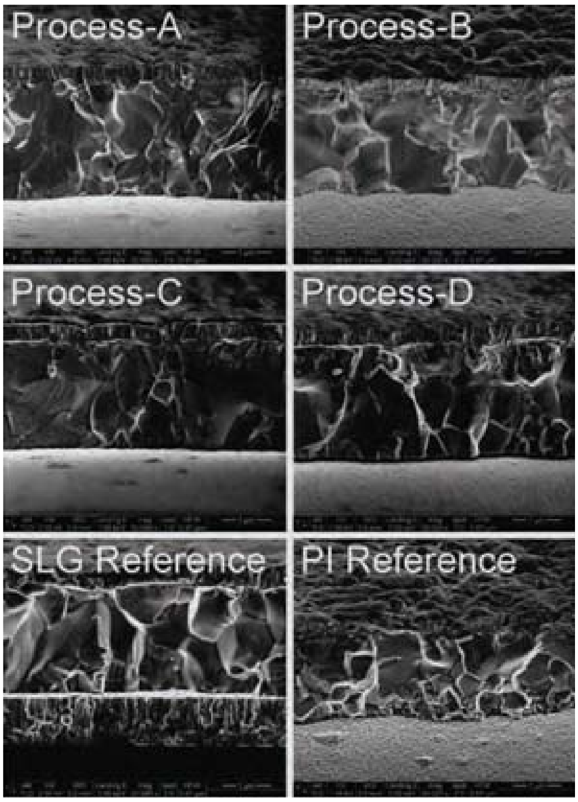
The main difference between Process A-D and previous baseline processes (denoted as "Reference" below) is mainly the overall changed deposition rates during the process. While in the reference processes the same deposition rate during the 1st stage and the 3rd stage were applied, in process A-D the 3rd stage was much slower than the 1st stage. Also the 2nd stage for process A-D was done about double as fast as in case of the reference processes. Further experimental details about the reference processes can as well be found in [3,4].

In case of the SLG reference sample, Na was incorporated by diffusion from the substrate. For the PI reference sample, Na was provided by a post-deposition treatment that has been previously developed [5]. However, in Process A-D NaF was co-evaporated during the CIGS growth process in the 3rd stage.

Structure of the CIGS

Scanning electron microscopy (SEM) was used to characterize the structural properties of the CIGS layers. Figure 2 shows the images of the cross-sections from devices grown with different growth recipes.

The images were taken at different tilt angles distorting the actual layer thicknesses. Hence, no conclusion should be drawn about the layer thickness from these images. Typical CIGS layer thickness was in the range of 2.0 - 2.5 µm for all devices presented here. The Process-C device has an additional MgF_2 antireflection coating. Due to the different sample preparation methods for SLG and PI, the Mo cross-section is only visible in the image taken from the SLG reference sample.



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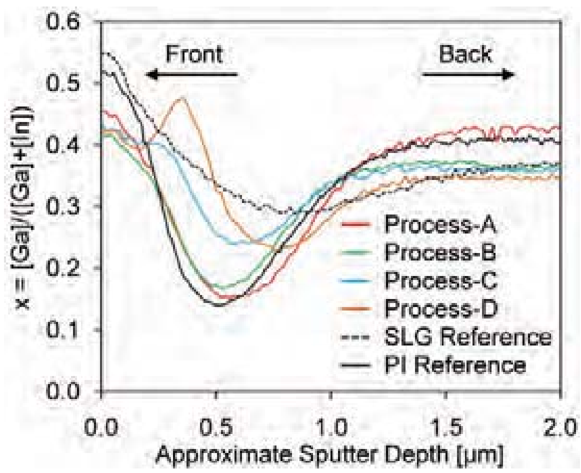
Comparing Process A-D with the PI Reference reveals a significantly enhanced grain size towards the back contact and the overall structure resembles the one grown on SLG at significantly higher substrate temperature. Previous work has revealed that the deposition rate in the 3rd stage of the growth process has a critical impact on crystal size throughout the whole layer [3,4]. Therefore, we attribute the improved film structure predominantly on the low growth rates of Process A-D during the 3rd stage of the CIGS growth and not a slightly higher substrate temperature.

Within Process A-D only minor differences are observed. In case of Process-D the upper third of the CIGS layer appears to have a distinct structure that is clearly separated from the underlying CIGS.



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Composition

The composition of the CIGS layers is characterized with x-ray fluorescence (XRF) and secondary ion mass spectroscopy (SIMS). Main focus is on the influence of the modifications of Process A-D (see Figure 1) on the Ga grading profile as compared to the reference processes.

Figure 3 shows the depth profiles of relative Ga contents x = Ga/(In+Ga) obtained from the SIMS measurements. The data is normalized according to the x values obtained by XRF measurements which can be assumed to yield average composition values.

The most pronounced grading profile is obtained with the baseline process for polyimide (PI Reference). Apparently, the shallowest profile is obtained with the high temperature grown SLG reference process. Application of Process-A only slightly alters the grading profile compared to the PI reference. Process-B mainly reduces the Ga content towards the back contact but has no significant impact on the profile in the front part. The increased Ga evaporation during the 2nd stage of Process-C on the other hand changes the profile in the front part significantly by increasing the Ga content at the Ga dip in a depth of about 600 nm. In case of Process-D the grading profile consists not only of a Ga dip but as well an additional spike in a depth of about 400 nm.

Photovoltaic Properties

Solar cells were prepared with CIGS grown with the different recipes and the impact of the altered Ga grading profiles on optoelectronic properties was investigated. All solar cell devices presented in this work were finished with identical buffer and window layers.

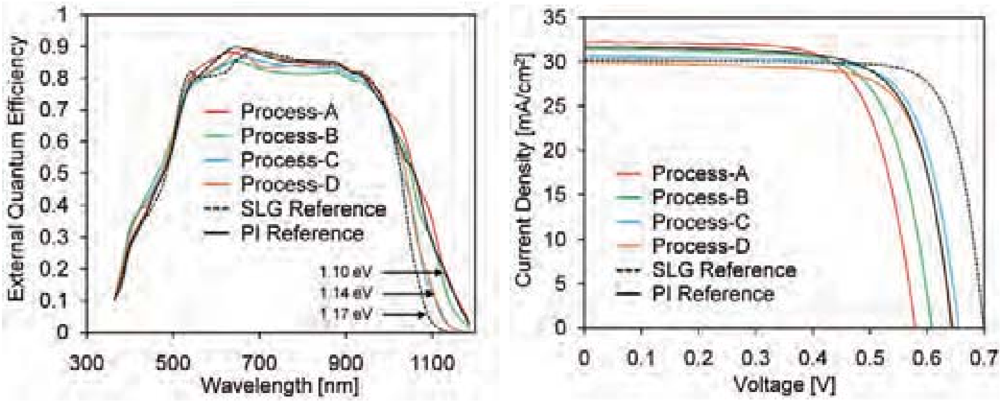

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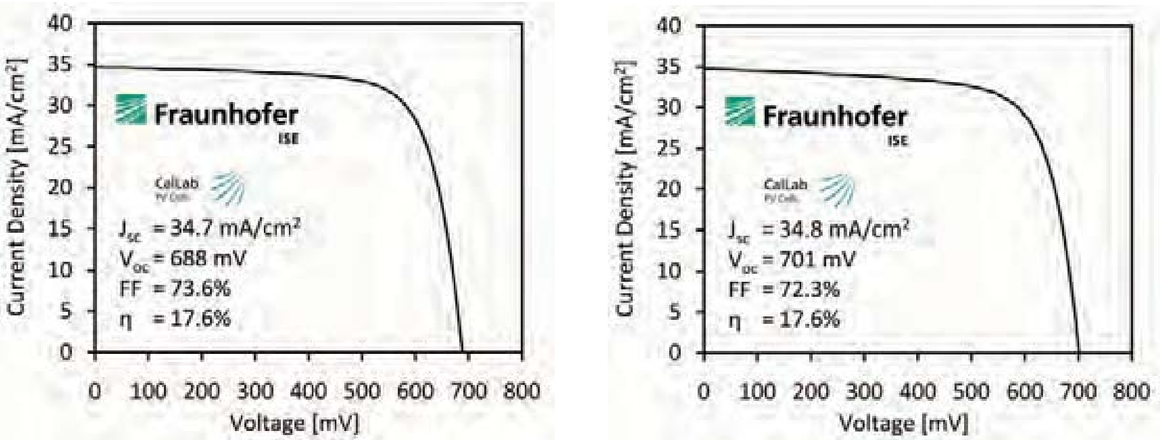
Figure 4a shows external quantum efficiency measurements of solar cells obtained with the different processes. The low response in the short wave length below 500 nm is due to the relatively thick CdS buffer layer. The response in the main part from 500 nm to 1000 nm is high in all cases with only slight indications for recombination of carriers generated deep inside the absorber layers. Differences in this region could also be attributed to slight variations of layer thicknesses as well as slightly different grid obscuration of the different solar cells. The main impact of changing the Ga grading profile is visible in the near-infrared region > 1000 nm. The cut-off wavelength in this region corresponds to the region of lowest Ga content, e.g. the minimum band gap. As indicated by arrows in Figure 4a, minimum band gaps of about 1.10 eV for Process-A and -B and the PI Reference, 1.14 eV for Process-C and -D, and 1.17 eV for the SLG reference can be derived, corresponding well with observations made with SIMS (see Figure 3).

Table 1: Photovoltaic parameters of solar cells obtained ith the different processes.

Process	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
A	579	32.2	70.2	13.0
B	608	31.5	71.5	13.7
C	655	30.6	74.0	14.9
D	645	30.0	73.5	14.2
SLG-Ref.	698	30.2	78.9	16.6
PI-Ref.	643	31.7	71.9	14.6

The current-voltage characteristics of the solar cells developed with different processes are shown in Figure 4b and the photovoltaic parameters are given in table 1. The best trade-off between J_{sc} and V_{oc}, as well as highest FF for cells on PI is achieved with Process-C yielding an efficiency of 14.9% without antireflection coating. While Process-A and –B are found to have a pronounced Ga grading profile, and Process-C and –D a profile closer to the SLG Reference (see Figure 3), we assume that the superior performance is likely related to the modified Ga profile. However, the solar cell obtained on PI with the reference process is as well strongly graded similar to Process-A and –B, but the V_{oc} is significantly higher. A possible reason for this behavior could be the increased Ga content towards the surface. The inferior performance of solar cells grown on PI, compared to those grown on SLG, is due to lower V_{oc} and FF, and this is related to the significantly lower deposition temperature. This investigation suggests that further improvements in device performance on PI can be expected by further process modifications that aim at obtaining a Ga grading profile on PI similar to the one on SLG.

This was tested by increasing the maximum Cu-content during a process, which allows more intensive interdiffusion of the group three elements in the CIGS absorber. More details about processing of these devices can be found in [6]. Two such solar cells, covered with anti-reflection coating, were measured independently at the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany. Figure 5 show the corresponding J-V curves with photovoltaic parameters.



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A new record efficiency of 17.6% on flexible PI film has been achieved, which is the highest reported value of any type of solar cell grown on polymer film. Main factors in achieving such high efficiencies lie in systematic modifications of the CIGS growth process, which are required at the low substrate temperature applicable for PI films. Most importantly, a significant enhancement in grain size and optimization of the composition grading profile has been achieved.

Based on the best values of J_{sc}, V_{oc} and FF of the two presented individual devices, it is feasible that efficiencies exceeding 18% can be reached on flexible substrates in the near future.

National / international Cooperation

The consortium of the EU-FP7 hipo-CIGS project consists of four R&D partners ZSW (Germany) TNO (Netherlands), Technical University of Warsaw (Poland), and Empa (CH) and four industrial partners Flisom (CH), Corus (Netherlands), Pemco (Belgium), and Würth Solar (Germany). Some of the tasks in this European project overlap with activities in complementary BFE project Febulas (103317) and a CTI project on Multifuncional back contacts (CTI-10245.1), where direct partners are companies FLISOM AG and W. Blösch AG, respectively.

Appraisal 2010 and Outlook 2011

With the achievement of 17.6% efficiency on flexible PI substrate an important milestone of the hipo-CIGS project was accomplished by Empa already in the first year. This result shows the high potential of low temperature processed CIGS devices. It was obtained by combining efforts on the development of crack free back contacts for reduced residual stress and improved adhesion of the CIGS layer, on the investigation of the optimum Na treatment procedure, and ultimately in reducing recombination losses by modified band gap grading in the low-temperature CIGS absorber.

The results and findings of 2010 are an ideal basis for the challenging tasks of thickness reduction and increased deposition speed of the absorber which are planned for 2011. In collaboration with ZSW and the Technical University of Warsaw an important aim for 2011 is to gain deeper understanding on relevant critical stages of the growth process for low substrate temperature on various substrate materials including mild steel and alumina foil. Further on, the issue of in-line buffer layer deposition and the development of modules by laser scribing will be important activities.

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NO A-CI G S: NON- ACUU PROCESSES FOR DEPOSITION OF CI G S ACTI E LA ER IN P CELLS

Annual Report 2010

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Duration of the Project (from – to)	01.01.2010–30.06.2013
Date	10.12.2010

ABSTRACT

Current production methods for thin film photovoltaics typically rely on costly, difficult to control (over large surfaces) vacuum-based deposition processes that are known for low material utilisation of 30-50%. NOVA-CI(G)S proposes alternative, non-vacuum deposition processes for thin film Cu(In,Ga)Se_2 (CIGS)photovoltaic cells. The low capital intensive, high throughput, high material yield processes will deliver large area uniformity and optimum composition of cells.

The overall project goal is to develop an ink based, simple and safe deposition process of the CIGS absorber layer for highly efficient low cost solar cells. Major scientific breakthroughs of the project include improved materials control in novel precursor materials by using nano-sized precursors of specific chemical and structural characteristics and innovative ink formulation, to enable coating by printing processes while avoiding the use of toxic gases or solvents in subsequent process steps.

Specifically, research work at Empa is focused on the deposition and activation of CIGS layers from formulated precursor suspensions and solutions, providing a feedback to the project partners engaged in precursor materials and ink formulation, and preparing background for large area solar cells and industrial implementation.

During the first project year, Umicore suspensions of oxide and selenide nanoparticles in organic solvents were received from projects partners, deposited on rigid glass substrates by means of doctor-blading or printing and activated to yield the CIGS absorbers. Promising results were obtained with the oxide ink, which could not be matched for the moment when utilizing selenides because of poor sintering (due to small volume expansion) and crack formation. Optimized conversion with selenium as a fluxing agent facilitated sintering and promoted the growth of large CIGS grains. Further experiments are planned to improve the sintering of deposited inks by adjusting copper content and employing mixtures of nanoparticles. An effect of the rapid thermal processing (RTP) on the CIGS phase formation and layer uniformity will be studied.

Introduction and project objectives

Concept

Photovoltaics (PV) is a key technology option to meet the rising demand for energy and counter rising energy prices whilst reducing CO_2 emissions and encouraging energy independence in Europe. However, the dominating crystalline silicon (c-Si) technology remains expensive with a module cost in excess of 2.5 €/Wp (peak power in Watt). It is also comparatively energy intensive to manufacture and results in rigid and heavy devices. A radically different step-change concept is required to become competitive with fossil-based energy.

With 100 times thinner absorbers, the emerging inorganic Thin Film (TF) PV technology uses only small quantities of semiconductor material to achieve viable cell efficiencies, allowing light weight and flexible modules. There are three major families of inorganic TF PV: i) amorphous / micro crystalline silicon (a-Si/micro-Si), ii) Cadmium Telluride (CdTe) and iii) Copper Indium (Gallium) Diselenide (CI(G)S) and Copper Indium Sulfide (CIS).

The current deposition process for TF PV relies on well-known vacuum-based sputtering or co-evaporation technologies. Whilst allowing controlled deposition of high purity thin layers, these techniques experience limitations such as high investment and operating costs, low throughput, low materials yield and high energy consumption, amongst others. This leads to TF PV module costs of about 2-2.5 €/Wp.

However, TF PV has significant cost reduction potential. Thin layers can be applied by wet deposition processes such as printing, which are low capital intensive, exhibit high throughput, high material yield and are suitable for roll-to-roll processes that deliver large area uniformity and optimum composition. The EU PV Technology Platform suggests that development of such technology should lead to medium term (2013-2020) TF module cost of around 0.8 €/Wp.

The feasibility of this method was shown by companies ISET and Nanosolar that reported CIGS solar cells with 13.6% and 14.5% efficiency, respectively [1,2] by printing pastes containing oxide nanoparticles. Kaelin et al. reported 6.7% efficient cells in 2005 [3] by selenization of metal salt solution pastes. Recently, Mitzi et al. utilized hydrazine as a solvent reaching an efficiency of 12.8% [4], but the industrial implementation might be hindered due to the toxic and explosive nature of hydrazine.

Global project objectives

The goal of NOVA-CI(G)S is to develop an ink based non-vacuum, simple, and safe deposition process of the CIGS absorber layer for highly efficient low cost solar cells. The CIGS absorber is the core of the solar cells, and also the most scientifically challenging and most cost intensive layer to produce. The project aims to demonstrate the following:

1. Non-vacuum deposition of the CIGS layer is possible whilst maintaining high efficiency.
2. Non-vacuum deposition of CIGS layers can be realized at high speed on rigid and flexible substrates whilst maintaining acceptably high efficiency on assembled cells.

The overall aim being to make a significant impact on reducing the cost of the CIGS layer and pave the way to future development addressing the device's adjoining layers with a similar fully integrated low cost deposition process ultimately achieving a CI(G)S TF module cost of below 0.8 €/Wp.

Specific research objectives at Empa

Research work at Empa is focused on the deposition and activation of CIGS layers from formulated precursor suspensions and solutions, providing a feedback to the project partners engaged in precursor materials and ink formulation, and preparing background for large area solar cells and industrial implementation. Three specific work packages at Empa are:

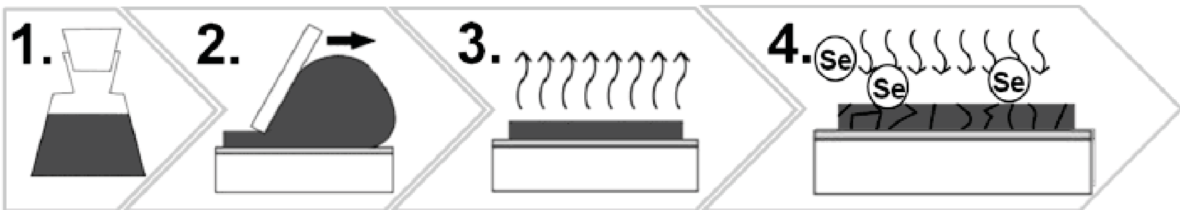
1. layer deposition
2. layer activation
3. solar cell processing and characterization

The layer deposition will be optimized individually for each precursor material for a good adhesion of the precursor layers and homogeneous film formation. This work is important for large-area deposition and the development of solar modules. The starting point is the raw precursor material which has to be converted effectively into an efficient photoactive layer upon thermal annealing, with or without addition of chalcogen. The deposition process is a means to transfer the precursor to the substrate to achieve a thin precursor layer. By nature printing processes are likely to introduce potential contaminants, which need to be accounted for. Therefore, an intensive iterative process will take place throughout the project for the materials synthesis, ink formulation layer conversion and deposition process to ensure that the layer is correctly applied, that there is minimal interference by ink formulation chemistry, the layer has adequate adherence, has optimal chemistry and crystallography / phase structure.

The layer activation via thermal treatment is required in order to transform printed precursor layers into crystalline CIGS absorbers with correct composition, homogeneity and morphology. Usually a two-step method is applied to first sinter the precursor at 200-300°C in order to remove solvent and binder material and to densify the precursor. In most cases an additional selenization/sulfurization step at higher temperatures (500-600°C) in a closed reactor furnace with Se/S atmosphere will be necessary. The selenization conditions (partial pressure of Se, temperature ramps, annealing time, etc) must be optimized to obtain single phase CIGS layers of optimum structural and opto-electronic properties. Depending on the precursor material, especially depending on its selenium content (pure metals without selenium or binary selenide compounds) the selenisation or conversion process has to be adapted. Rapid thermal processing (RTP), which offers fast heating rates, will be tested in order to avoid detrimental reaction pathways during layer activation and increase processing speed.

ethodolog

The non-vacuum deposition of CIGS absorbers can be divided into four steps (see Figure 2). A suitable precursor paste is formulated from either true metal solutions or particle dispersions. The paste is then transferred on a molybdenum coated substrate by means of a non-vacuum technique, i.e. doctor-blade, screen printing, slot-die, ink-jet or spray-coating. Consecutive drying on a hotplate or drying lamp in ambient or inert atmosphere facilitates the evaporation of solvents and chemical additives. In a last step CIGS phase is obtained via a heat treatment at 500-600°C in selenium atmosphere. While all steps are important for a successful absorber deposition this work will mainly focus on the paste formulation and optimization of the CIGS conversion.



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Performed ork and results

Characteri ation of nanoparticulate inks

Five different suspensions were obtained from project partners, which consisted of two nanoparticle types A and B in two different solvents with high and low boiling points, respectively (Table 1). The material load was adjusted to obtain stable suspensions without particle aggregation.

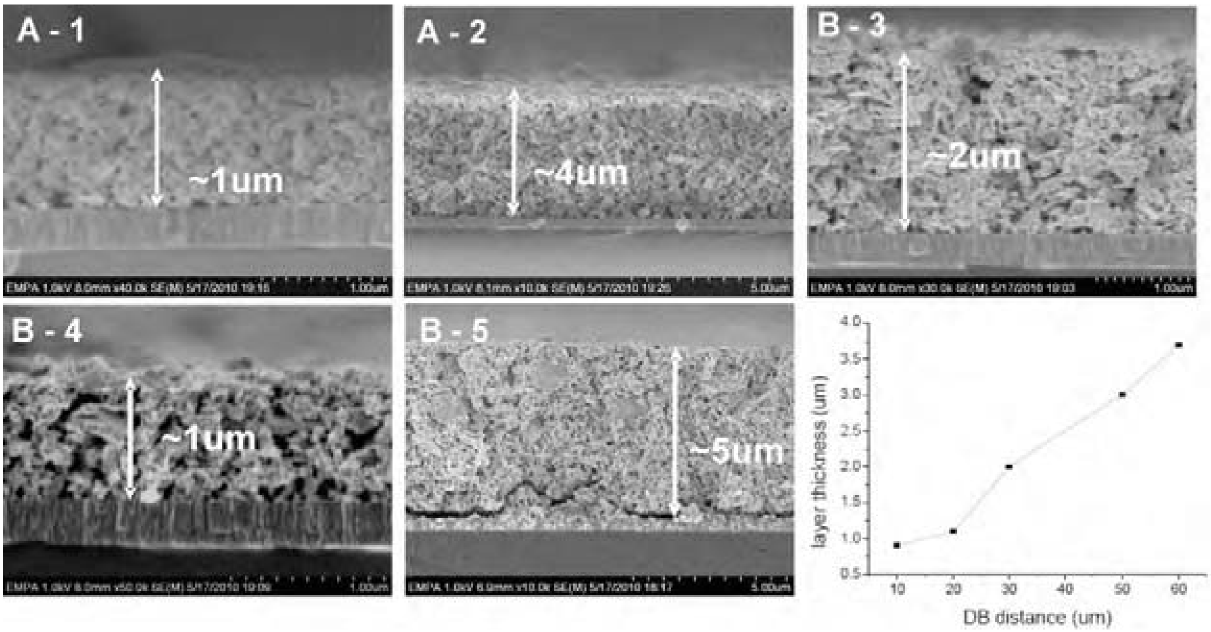
Table : ist nan a tic sus nsi ns in sti at u in t i st ct i

Suspension	Nanoparticle compound	Weight load	Solvent
1	oxide (A)	Low	High boiling point
2	oxide (A)	Low	Low boiling point
3	selenide (B)	Low	High boiling point
4	selenide (B)	Low	Low boiling point
5	selenide (B)	High	Low boiling point

Material characterization by laser diffraction method determined particle size below 500 nm. Dried precursor powder was probed by EDX and XRD to elucidate composition and crystalline structure of the powders.

La er deposition

Dispersions were applied on molybdenum coated SLG glass by doctor blade method and dried at room temperature. As seen in SEM cross-section micrographs (Fig. 2) films are homogeneous, have good adhesion and exhibit thicknesses around between 1-5 µm depending on the solid load and doctor-blading spacing. An important observation was that the thickness of the dried layer could be controlled by varying the doctor-blade (DB) spacing, thus tailoring required thickness (Fig. 2 bottom right).



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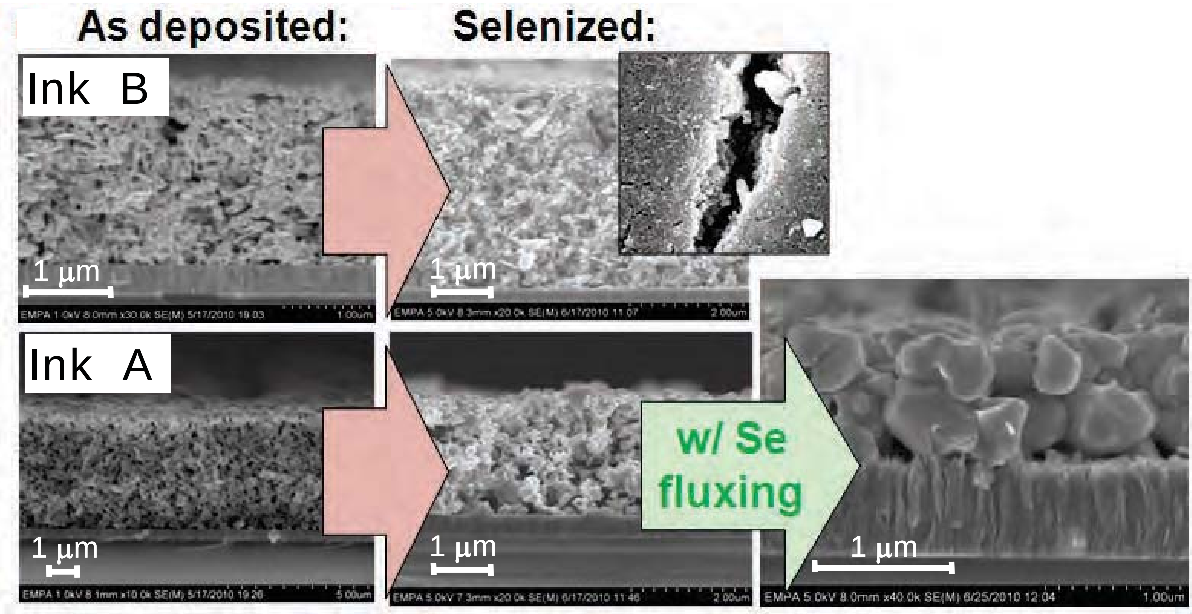
La er activation

Selenization was carried out under standard conditions in a two temperature zone tubular furnace. XRD of selenized films could confirm CIGS phase with only minor additions of In_2O_3 secondary phase for all particle dispersions A. The difficulty of In_2O_3 conversion to CIGS requires harsh selenization conditions in H_2Se or H_2S gas and/or reducing steps in H_2 and was expected from previous results with true solutions. Cross-section SEM pictures of selenized films showed poor sintering as compared to precursor films (Fig. 3). Large micrometer wide cracks were seen in top-view pictures for precursor B. A volume expansion during selenization can overcome this problem and is expected to be the reason for reduced cracks for oxide particles. Enhanced supply of selenium during annealing could drastically improve sintering (Fig. 3, right). Large grains of CIGS with only minor incorporation of pinholes could be obtained by these adjustments. It is expected that selenium or selenium rich copper binaries can act as a fluxing agent to facilitate CIGS grain growth. Large inhomogeneities on the substrate and crevices through the absorber prohibited measurements of the photoelectrical response of such films. Future improvements and systematic work will further optimize obtained results.



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National and international collaboration

The project Consortium includes four academic-research partners and four industrial partners:

* Umicore S. A., Brussels, Belgium (coordination)
* Eidgenössische Materialprüfungs- und Forschungsanstalt (Empa), Switzerland
* FLISOM AG, Switzerland
* Zentrum für Sonnenenergie und Wasserstoffforschung (ZSW), Stuttgart, Germany
* Würth Elektronik Research GmbH, Stuttgart, Germany
* VTT Technical Research Center of Finland
* Technische Universität Chemnitz, Germany
* Xennia Technology Ltd., Letchworth, UK

Empa is collaborating intensively with ZSW to elaborate different routes for post deposition annealing and selenization, as well as concepts of defining optimum structural, compositional and electronic properties of absorber layers.

Conclusions 2010 and Outlook 2011

Systematic investigations of deposition and activation parameters of two sets of dispersions with oxide and selenide nanoparticles has led to the identification of several important criteria that must be fulfilled for the successful deposition of CIGS absorber films from a fluid or paste (ink). They can be divided with regard to coating, chemistry, and morphology. Electronic properties and interfaces also play an important role, but will be considered at later project stages.

- Coating: the ink with homogeneously distributed components must wet the substrate and evenly coat it. The film should not form cracks and porosity should be minimized, which also depend on the particle size and shape.
- Chemistry: the resultant activated film should be the chalcopyrite phase $Cu(In,Ga)Se_2$ without inclusions of indium and/or gallium oxide phases. Residues and oxidation from solvent and/or any additives should be minimized. Selenide inks require high temperature and selenium pressure to recrystallize. Better sintering is observed for oxide particles because of their higher reactivity and volume expansion during selenization. Optimized conversion with selenium as a fluxing agent facilitated sintering and promoted the growth of large CIGS grains.
- Morphology: cracks, voids and pinholes in the final absorber layer must be absolutely avoided because the cause short circuits in solar cells.

In 2011 several new sets of pre-formulated inks will be received from the project partners. Future experiments will focus on better sintering of inks. A new rapid thermal annealing (RTP) set-up will be installed in order to study the effect of rapid heating on the CIGS phase formation and the absorber uniformity. Fabrication and characterization of CIGS solar cell devices will be done.

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ULTIFUNCTIONAL BAC ELECTRICAL CONTACT FOR FLE IBLE THIN FIL SOLAR CELLS

Annual Report 2010

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Duration of the Project (from – to)	6. 2009 – 6. 2011
Date	14.12.2010

ABSTRACT

Flexible $Cu(In,Ga)Se_2$, called CIGS, solar cells provide high efficiencies with low cost potential. The aim of this CTI project is to develop concepts and optimize deposition processes for multifunctional back electric contact layers suitable for roll-to-roll manufacturing. Low electrical resistance, thermal and mechanical stability, impurity barrier properties for long-term solar cell performance stability, and suitable film stress comprise the multifunctional contact.

In the year 2010 the alternative back contact design has been optimized, while first single layer experiments of Ti, TiN and Mo were done and afterwards the multilayer stack was adjusted. A comparison study with CIGS solar cells on the alternative and conventional back contact on polyimide foils was performed. Results showed an improvement in CIGS adhesion and residual stress, whereas the conversion efficiency was lower compared to the conventional design. It is believed that the smaller grain-size of the CIGS microstructure is mainly responsible for this decrease in efficiency.

Further a study of ZnO:Al deposition with an inline pulsed-DC magnetron sputtering system was accomplished and compared to the conventionally used RF magnetron sputtering (reference). Results showed a strong dependency on substrate temperature. An optimization of process parameters was performed at 150°C, which was chosen to prevent inter-diffusion of the CIGS absorber and CdS buffer. A resistivity of 10.6 µΩm with comparable transmittance to the RF reference was achieved.

On stainless steel foils different back contact structures were tested. Two different CIGS processes were applied on these contacts: a low and high temperature three-stage process, both with a sodium post deposition treatment. Results showed that a Mo back contact showed similar solar cell performances compared to contacts with either TiN or Si_3N_4 additional impurity diffusion barrier layers.

Laser scribing experiments were done on different back contact designs at two scribing wavelengths and modes. Samples scribed with laser mode 2 showed good quality at high scribing speeds.

Introduction / Project Goals

Production of flexible thin film solar cells and modules with roll-to-roll deposition methods offer several advantages for potentially low cost manufacturing. However suitable equipment for web (roll-to-roll) coating including relevant processes are not commercially available. Appropriate web coating equipment together with a baseline deposition process is essential to facilitate manufacturing of next generation of high performance $Cu(In,Ga)Se_2$ (called CIGS) thin film solar modules. The project will demonstrate development of next generation of high efficiency CIGS flexible thin film solar cells and monolithically connected modules based on “alternative multilayer electrical back contact” that provides multi-functionality and overcomes the problems of conventionally used electrical back contact. Sputtering processes will be used to grow these stacked layers and based on a specific process know-how a proprietary design will be developed to configure a roll-to-roll coating system with rotatable cylindrical magnetron sputtering targets appropriate for cost-effective industrial production in future.

Short Project Description

This Project is structured in four work packages:

- WP 1: Deposition and characteri ation of the multila er back contact An inline sputtering deposition system with four cathodes is used to deposit metals, nitrides, and transparent contacts for thin films solar cells using DC or pulsed DC magnetron sputtering technology. Multilayer contacts are deposited and optimized in conductivity, film stress, and long-term stability. For metal substrates, contacts with impurity diffusion barrier properties are deposited. Investigated materials are Mo, Ti, TiN, SiN, ZnO, and ZnO:Al.
- WP 2: Processing of fle ible solar cells Solar cells with alternative multilayer back contacts will be processed on various flexible substrates. The back contact needs to fulfill the above mentioned demands for these different substrate materials. It was found that sodium, which is present in the commonly used soda lime glass, acts as dopant material when diffusing from glass substrate into CIGS. Since our flexible substrates do not contain sodium, a suitable method for sodium doping needs to be tested and applied. [1]
- WP 3: Laser scribing and patterning for modules The development of monolithically connected solar cells requires a process with several sequential steps of layer deposition and selective layer removal by laser scribing. In this project, the laser scribing behavior of the alternative multilayer back contacts on flexible substrates will be investigated. The principle is shown in Fig. 1.

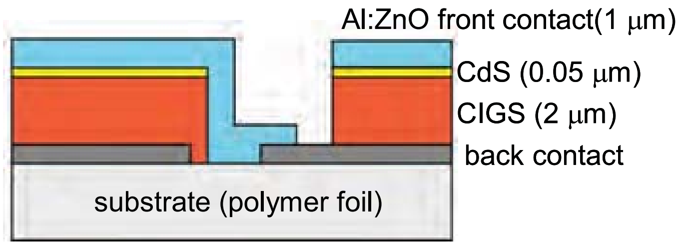

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Figure 1: *c atic a n it ic int at s a c ac c ntact is c nn ct t t nt c ntact s ia c nn cti n c s*

- WP 4: Design and testing of the rotatable c lindrical magnetron sputtering s stem A rotatable cylindrical magnetron will be tested in the same sputtering chamber to compare the sputtering behavior to the generally used planar magnetrons. These tests will be performed by sputtering Ti and TiN.

Accomplished Project Tasks and Results

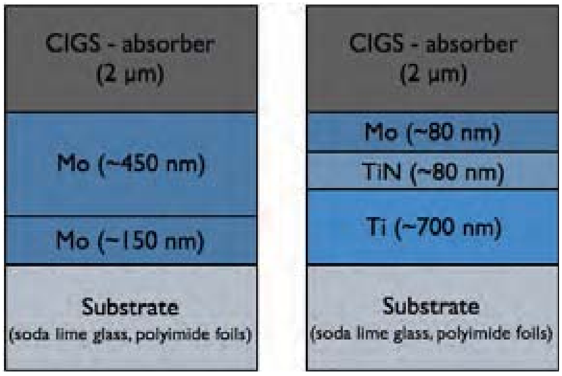
WP 1: Deposition and Characteri ation of Alternative ultila er Back Contacts

In this work package the back contact of a CIGS solar cell on polyimide substrates is replaced by an alterative multilayer structure. The deposition process of all back contacts was done with magnetron sputtering, where in case of Si_3N_4 and TiN reactive sputtering was used [2].

1.1 Combinatorial Design of Alternative Back Contact

The designs investigated in this project are summarized in Fig. 2. The Figure shows the conventionally used back contact structure at Empa, which is a Mo bilayer structure (left) and the alternative structure tested at Empa (right) consisting of a multilayer Ti/TiN/Mo stack.

The designs were developed parallel to single layer experiments with Ti, TiN and Mo. For the optimization of the multifunctional back contact not only the contact structure itself but also the subsequent process steps (mainly the CIGS growth) have to be considered. This is due to the high temperatures applied during the CIGS deposition (>450°C), which can induce thermal stress as well as inter-diffusion of elements from the substrate or back contact to the CIGS and vice versa.



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The following back contact properties have to be optimized:

- *n ucti it ac c ntact* The conductivity of the back contact is given by the sum of each single layer (Ti, TiN, and Mo) of the stack. Due to higher bulk resistivity of Ti compared to Mo, a thick Ti (~700 nm) layer is required to provide <0.6 Ωsq of sheet resistance.
- *R si ua st ss ac c ntact* Residual stress management is important because stress can result in cracking of the films and, especially on polyimide foils, leads to deformation of the substrate (the foils bend to a cylindrical shape). The thermally induced stress is also important due to the subsequent high temperature CIGS process (>450°C) and can be optimized by the choice of material. The use of Ti and TiN leads to lower thermal stress because of their similar thermal expansion coefficient (CTE) in comparison to both CIGS and the polyimide foil, which is not true for Mo (much lower CTE).
- *nt ac ati n ac c ntact t a s* During CIGS growth, Mo is partially transformed to $MoSe_2$, which forms a quasi-ohmic electrical interface between the back contact and CIGS. Therefore, a (thin) Mo top layer is required in the multilayer back contact stack.
- *ta i it an ac c ntact* An impurity diffusion barrier can be used to improve the stability of both the back contact and CIGS absorber. TiN has been identified to be an appropriate candidate as it is a well-known impurity diffusion barrier and a good conductor.

1.2 Single La er E periments

The trends observed for an increase in sputtering parameters (power, pressure, substrate bias and temperature) to the film properties (residual stress, resistivity, average reflectivity and stoichiometry) of Ti, TiN and Mo are shown in Tab. 1. Ti shows low and mostly tensile residual stress due to its low-density microstructure. The application of a substrate bias leads to compressive stress and a decrease in film resistivity. In case of TiN a significant improvement in stoichiometry was obtained when applying a substrate bias and elevated substrate temperature (e.g. 200°C). Mo is generally under compressive stress with nicely defined columnar and dense microstructure. Changing both the power and pressure of the sputtering process can control the residual stress of the Mo film, whereas the resistivity increases strongly with increasing pressure. The low residual stress of Ti can be used to relax the compressive stress of TiN and Mo in the multilayer back contact design.

	Increase in	Stress	Resistivit	Reflectivit	Stoichiometr
Ti	P	↓ (t)	↓↓	↑	-
	P ssu	→	↑	↓	-
	u ias	↑↑ (c)	↓↓	↑↑↑	-
	atu	↓ (c)	(↑)	(↓)	-
TiN	P	↓↓ (c)	→	→	-
	u ias	↑↑↑ (c)	↓↓	↑↑	↑↑
	atu	→	↓	↑	↑
o	P	↑↑ (c)	↓	↑	-
	P ssu	↓↓ (c)	↑↑	↓	-

Table : u a sin a i nts ta s s t i act an inc as in t s cti s utt in a a t t st ss, sisti it , a a cti it an st ic i t t i s a - s s t t n nc t c an in i a a t s, ↓ s a c as , ↑ s a inc as , ↑↑ at inc as , ↑↑↑ st n inc as , → sta s c nstant a u s in ac ts a n initi t n s t si ua st ss, t n t s t nsi , c c ssi st ss

1.3 Optimi ation of Alternative ultila er Back Contact Design

The multilayer back contact optimization was performed applying the knowledge acquired in the single layer experiments discussed in section 1.2. In Tab. 1 the influence of sputtering parameters to film properties of Ti, TiN and Mo are summarized. Important factors for the optimization of Ti/TiN/Mo alternative back contacts have already been discussed in section 1.1. In Tab. 2 a summary of the different back contact structures is shown.

Back contact process parameters and film properties	o/ o (A)	Ti/TiN/ o (B)	Ti_{Bias}/TiN/ o (C)
Thicknesses [nm]	150/450	700/80/80	700/80/80
Pressure	low/high	low/medium/high	medium/med./med.
Bias [W]	0/0	0/80/0	30/80/0
Temperature Heater [°C]	-	200	200
Sheet Resistance [Ωsq]	0.2	0.8	0.57
Residual Stress [GPa]	-0.91	-0.12	-0.11
Av. Surface Roughness [nm]	4.7	15.3	14.3

Table : i i nt u ti a ac c ntact ti s a a su ac u n ss as n ca cu at it t an s ua t

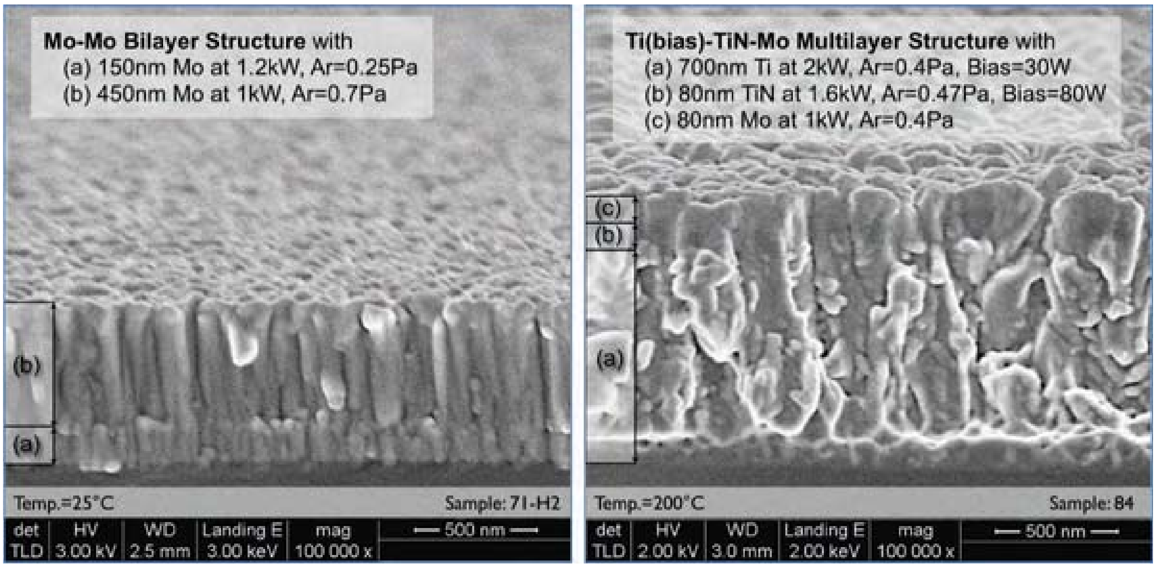

Figure 3: c ss-s cti n , t an i ias i u ti a ac c ntact , i t i nc in ic st uctu is c a isi s s a ns an c u na st uctu as i as uc a c u na ains, ic su t in i nsit an i su ac u n ss

The conventional design (A, Tab. 2) shows high conductivity and low surface roughness, but high compressive stress. The alternative back contacts show higher sheet resistances and surface roughness, but they have significantly lower residual stress. Design C in Tab. 2 was identified as the best alternative back contact structure. The differences in microstructure and topology of the conventional design (A, left) and the alternative design (C, right) are shown in Fig. 3.

1.4 Deposition of nO:Al b Inline Pulsed-DC agnetron Sputtering

ZnO:Al (also called AZO) is a transparent and conductive oxide (TCO) used as the front contact material for CIGS solar cells. In this project, the conventionally used RF magnetron sputtering process is replaced by a pulsed-DC sputtering process, which is better suited for industrial production at large scales. Due to the high sensitivity of CIGS to sputter damage and heat, the AZO process has to be done under special conditions, which will be evaluated during the project.

In Fig. 4 the resistivity versus the transmittance quality factor (TQF) for single AZO layers are shown. The TQF represents a measure for the transparency weighted by the spectral response of a typical CIGS solar cell. Additionally, the RF reference conventionally used by Empa is shown in the graph. The resistivity of the RF reference is much lower compared to the pulsed-DC samples, which is both an effect of the RF process and the fact that the reference has been coated in stationary and not in an inline mode. [3]

Both the resistivity and TQF was improved by increasing the substrate temperature. Due to the sensitivity of the CIGS absorber, a maximum deposition temperature of 150°C was chosen. At 150°C a film resistivity of 10.6 μΩm with comparable TQF to the RF reference was achieved.

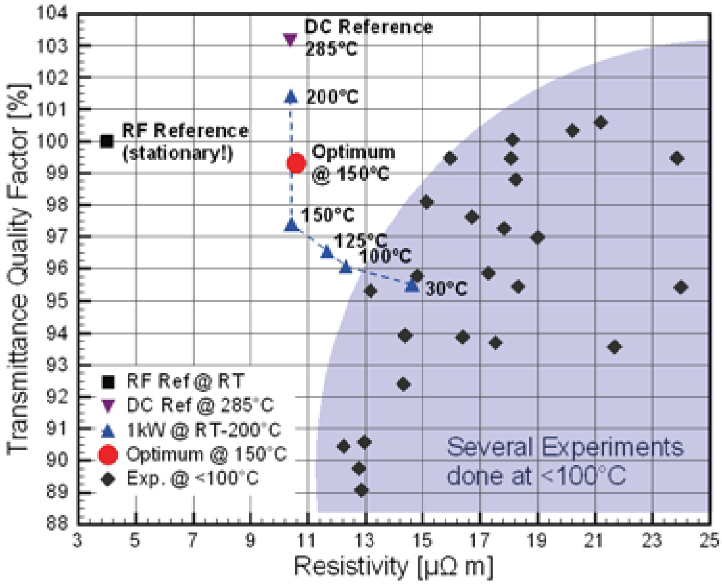

Figure 4: u a sin a su ts n ass siti n t atu s a si ni icant ct n t t c n ucti it an t ans a nc

Further improvements of the AZO process as well as an investigation of sputter damage to the CIGS absorber will be done in the future to ensure the compatibility of this technology for high efficient CIGS solar cells on polyimide foils.

WP 2: Processing of Fle ible CIGS Solar Cells

The CIGS absorber is deposited with a three-stage process done by co-evaporation of the elements (see Fig. 5). Due to the lack of sodium in the polyimide and stainless steel foil, a post deposition treatment with NaF was used to improve the solar cell efficiency [4].

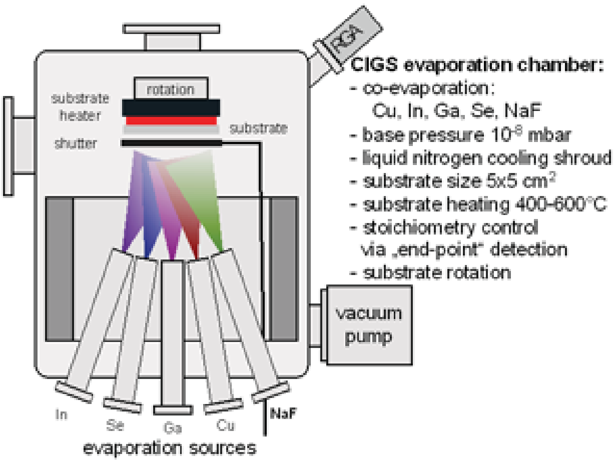

Figure 5: siti n s st a s - insta at a c su st at si

Empa has developed two different CIGS processes: a low and high temperature process. The low temperature process (~450°C) is suitable for various substrates, where Empa recently published a new world record in efficiency of 17.6% on polyimide foils [5]. This CIGS process was developed within several projects financed by CTI, BFE and EU-FP7. The high temperature process (~550°C) can be used on either stainless steel foils or soda-lime glass.

2.1 Performance of CIGS Solar Cells ith Alternative Back Contacts on Pol imide Foils

The performance of CIGS solar cells processed on polyimide foils with the conventional and alternative back contact designs (see section 1.3) were investigated. Results of this comparison are summarized in Tab. 3. The solar cell with the alternative back contact showed lower residual stress and improved adhesion of CIGS, but the cell efficiency and fill-factor was lower.

Properties	Conventional Design o / o	Alternative Design Ti bias / TiN / o
Back contact sheet resistance	0.2 **Ωsq**	0.6Ωsq
Residual stress of back contact	-0.9 GPa (compressive)	-0.1 GPa compressive
Residual stress after solar cell process	High (compressive)	oderate compressive
Adhesion of CIGS on back contact	Moderate	High
Best solar cell performance (equal CIGS process)	Efficienc : 14.9 Fill-Factor: 73.7	Efficiency: 13.4% Fill-Factor: 70.8%

Table 3: a is n s a c anc s it c n nti na in a an a t nati ac c ntact in a si ns s it a t nati ac c ntact a st ss an i a si n , ut ac c ntact c n uctanc , c ici nc an i - act

The reasons for the decrease in solar cell performance are not yet fully understood. It is assumed that the microstructure of the CIGS, shown by SEM cross-section images in Fig. 6, is responsible for the lower performance. The CIGS microstructure of contact (C) (image b) shows smaller grain-sizes, especially near the back contact. This change in microstructure could result from the higher surface roughness (see Tab. 2) and lower substrate temperature (differences in heat emissivity due to back contact materials).

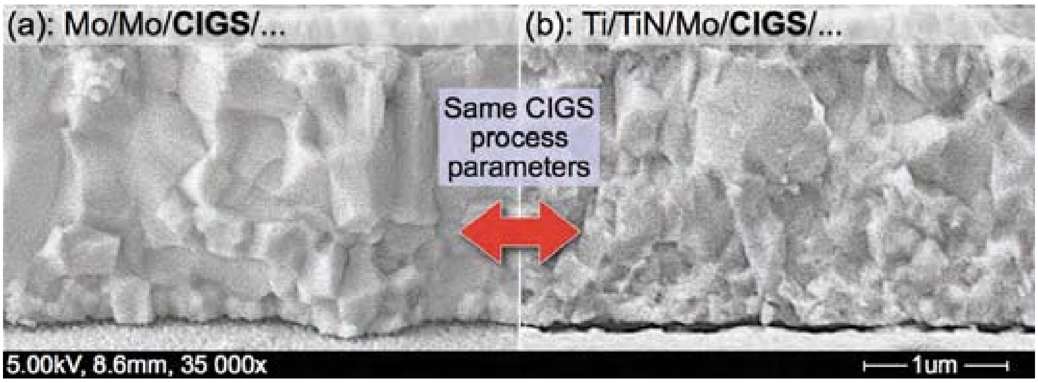

Figure : i a s a s c ss n a an i ias i ac c n- tact ic st uctu s s s a ain si s n a t ac c ntact c a t a

2.2 CIGS Solar Cells on Stainless Steel Foils

On stainless steel foils, different back contact designs were tested with both low and high temperature CIGS process. For both processes a NaF post deposition treatment was done. Contact 1 (reference) and contact 2 have no impurity diffusion barrier layer, where contact 3 uses a Si_3N_4 and contact 4 a TiN diffusion barrier. Barrier layers are important because the diffusion of Fe and Cr from the steel substrate to the CIGS leads to a reduction in solar cell conversion efficiency.

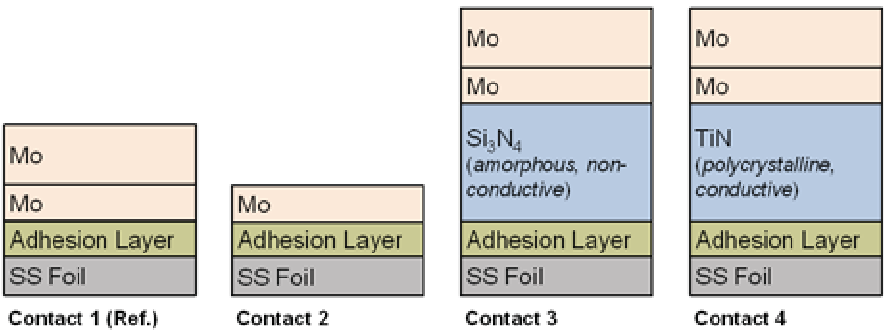

Figure 7: ac c ntact si ns n stain ss st i s ntact an a it ut, c ntact it i an c ntact it i i usi n a i

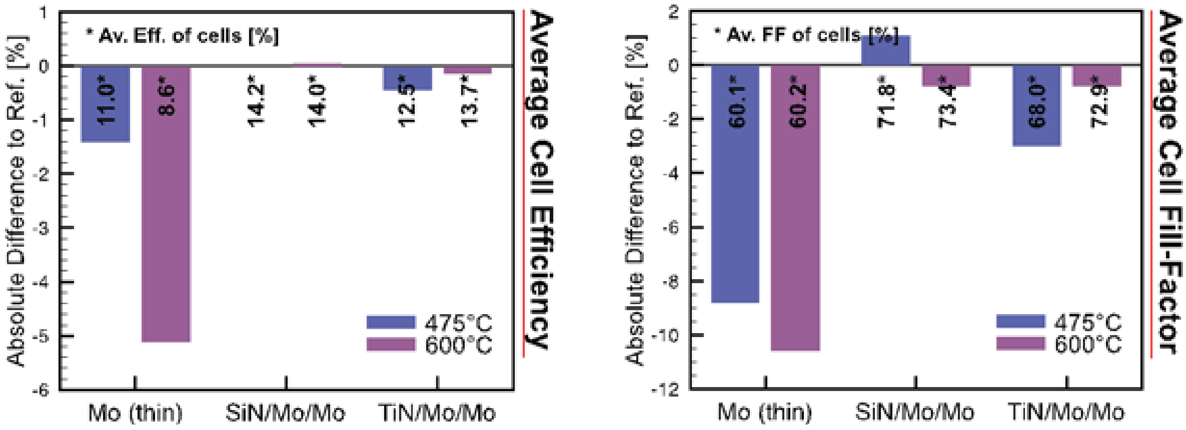

Figure : a c su ts s ut i nc c ici nc an i - act sa s it i nt ac c ntacts c ntact - t t nc c ntact a u s it s nt t a a ici n- c t sa s st c ici nci s tain it ut anti- cti n c atin

In Fig. 8 the absolute difference in efficiency and fill-factor of the solar cells with back contacts 2-4 to the reference contact 1 is shown. Solar cells with additional impurity diffusion barrier of Si_3N_4 and TiN showed no significant improvements to the reference. However, cells processed on back contact 2 (thin Mo) had both lower efficiency and fill-factor, where the loss in efficiency was much stronger in case of the high temperature CIGS process. We believe that the impurity diffusion from the steel substrate to the CIGS is responsible for the loss in performance.

WP 3: Laser Scribing and Patterning of odules

The P1 laser scribe, where the back contact is divided in electrically isolated lines, was tested with different back contact designs. Additionally, two different wavelengths (A and B) and laser ablation modes (1 and 2) were applied to the samples. It was found experimentally that the application of laser mode 2 resulted in far superior scribe quality and higher achievable process speeds. Laser mode 1 lead to more or less pronounced delamination at the scribe borders for all process parameters and for all utilized laser wavelengths (A or B). However, this tendency was less pronounced for stacks containing a Ti underlayer (see Fig. 7 for some representative examples). Therefore, the ongoing work focuses on ablation experiments with laser mode 2. It was found that good quality scribes can be achieved for Ti single layers as well as for Ti/Mo stacks deposited on polyimide film. TiN or Si_3N_4 in direct contact with the plastic substrate showed ablation in good quality as well. However, when Ti was deposited at elevated temperature, an increased laser threshold fluence for ablation was observed probably due to enhanced adhesion. For Ti deposited with RF bias, no ablation was observed up to the highest reachable laser fluence.

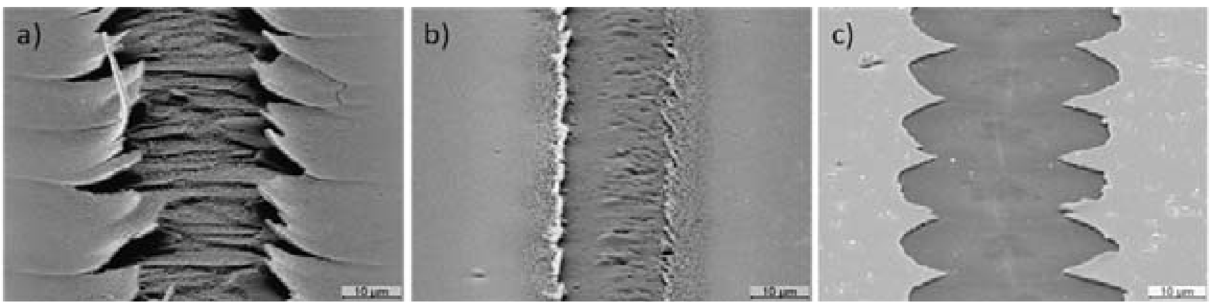

Figure 9 i a s ti t P in s a ac c ntact a n t it as , i ac c ntact a n t it as , c i ac c ntact a n t it as t a ius as - μ n in n t a n t

WP 4: Integration of Rotatable C lindrical agnetron Sputtering S stem

The design of the rotatable cathode including its integration chamber (will be flansched to the sputtering machine at Empa) was developed in close corporation with our industry partner W. Blösch AG. The design is completed and the rotatable cathode will arrive at the beginning of next year. First tests with Ti and TiN sputtering will be done in February 2011.

National / International Cooperation

There are three parties in this CTI project: The academic partner is the Laboratory for Thin Films and Photovoltaics at EMPA in Dübendorf, the main industry partner W. Blösch AG with its headquarter in Grenchen, and the second industry partner Flisom AG located in Dübendorf. EMPA works close with both industry partners to ensure good coordination and project advances.

Furthermore, this project has overlap with EU-FP7 hipoCIGS project, where six additional European R+D and industrial partners are involved.

Appraisal 2010 and Outlook 2011

In 2010, an alternative back contact design was created and tested on polyimide with the low temperature CIGS process of Empa. An improvement in residual stress and adhesion was achieved. However, the conversion efficiency of the solar cells was about 10% (relative) lower compared to the conventional design of Empa. Further, ZnO:Al was sputtered with pulsed-DC magnetron sputtering at various temperatures. An optimization at 150°C showed 10.6 µΩm at comparable transmittance with the RF sputtered reference. The degradation of CIGS performance on stainless steel foils was evaluated by different back contact designs, where it was found that the back contact has a significant influence on the solar cell performance, which is expected to be due to different Fe and Cr diffusion to the CIGS absorber. Additionally, laser-scribing experiments showed that it is possible to ablate e.g. Ti/Mo back contacts with two different techniques.

In June 2011 the project will end. Further investigations will be done with the alternative back contact designs, where an optimized structure will be tested and compared to the conventional design. The goal is to improve the conversion efficiency without loosing the good CIGS adhesion and low residual stress. On stainless steel foils the elemental diffusion will be quantified by SIMS measurements, which is important to fully understand the degradation of the solar cell efficiency with different back contacts. Additionally, more investigations of ZnO:Al are planned in terms of sputter and heat damage of the CIGS solar cells during the pulsed-DC process. The rotatable magnetron will be installed to the sputtering system at Empa and will be tested with the deposition of Ti and TiN in February 2011.

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APOLLO

EFFICIENT AREAL ORGANIC SOLAR CELLS VIA PRINTING

Annual Report 2010

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Duration of the Project (from – to)	1.11.2008 – 1.4.2011
Date	1.12.2010

ABSTRACT

This project aims to combine plastic electronics expertise in Europe for realising organic solar cells for empowering printed electronics applications. Existing solar cell technologies cannot provide the potential attributes such as printability in ambient conditions, flexibility and low cost. These research topics carry high innovation potential and unique selling points for Europe. If successful they open up new markets for the European high-tech industry allowing for Europe to take a leading position in printed electronics and solar cells.

So far, the development of organic solar cells was to a large extent a semi-empirical trial-and-error process, in which organic semiconducting materials were selected on the basis of their known or partially known separate properties. It has recently become clear that this provides an insufficiently sound basis for a further development. For further progress, an interdisciplinary approach with new materials, device concepts, models and characterisation methods is critical.

The focus of this project is on single cells and tandem cells with record efficiency that feature ease of production and proof-of-principle for the interdisciplinary research approach. The detailed understanding of device operation allows for steady improvements in efficiency.

INTRODUCTION

Polymer solar cells convert sunlight directly into electricity via a complex sequence of events (cf. figure 1), starting with the absorption of light (1), followed by creation of an exciton (2), dissociation of the exciton (3), transport (4,5) and collection of charges. The expectation that lightweight, flexible, and large area polymer solar cells can be produced at low cost, in combination with high energy efficiencies spurs a worldwide fast growing interest in this area. Not all of these attractive properties have materialised and although evidence is building up that polymer solar cells may live up to this appealing scenario in the future, new inventions have to be made. Presently, state-of-the-art polymer solar cells have reached power conversion efficiencies of 8% [1]. Projected efficiencies of 10% seem within reach and expectations for the future are even higher.

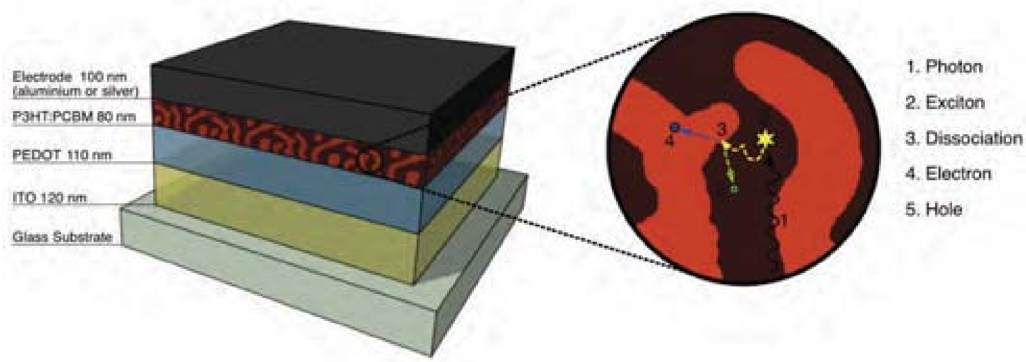

Figure 1: Standard device setup of a polymer bulk heterojunction solar cell. The active layer is the P3HT:PCBM layer.

Most polymer solar cells rely on a photo-induced charge transfer reaction at the interface of an acceptor and a donor type organic semiconductor which are combined into a bulk heterojunction to generate charges in a process that mimics natural photosynthesis. Following this event, charges must escape from recombination, separate spatially, migrate to the appropriate electrode and finally be collected. Each of these processes poses intriguing scientific questions and exciting challenges to materials design to make the overall conversion both quantum and energy efficient. With the continuing increase in power conversion efficiency, it is clear that the field of polymer solar cells has progressed in the last five years from a scientific curiosity to a stage that it is now on the brink of a breakthrough technology for the future. Yet, the transfer from test type devices that are typically 5-100 mm^2 in size to real large areas (1 m^2) does require new concepts in cell design and large area processing.

The power conversion efficiency of any polymer solar cell depends critically on the quantum efficiency of photon to electron conversion that determines the current and the potential energy efficiency that describes how much of the initial photon energy (eV) is preserved at the operating voltage of the cell.

The past years we have witnessed a strong innovation in the development of polymers that have a small band gap and are able to absorb up to the near infrared. Despite their high and promising efficiencies, the maximum EQE of these cells is still lower compared to the cells that absorb light in the visible region only. If for these low band gap cells the quantum efficiency could be improved, cells with 10% efficiency or more are within reach.

TAS S OF THE COLLABORATION PARTNERS

New materials (BASF, TUE): BASF competence in synthesising tailor-made materials for a variety of dye applications is crucial for this project. The challenge in the design of synthetic organic semiconductors for solar cells is to optimise the absorption spectra (for matching the illumination), the transport energy levels and mobilities (for low electrical losses) as well as the electron-hole binding energy (for efficient dissociation). Solubility and printability concerns add additional constraints.

A new series of small band gap donor-type polymers with high intrinsic charge carrier mobility and energy levels that are optimised for charge carrier generation in combination with PCBM need to be synthesised. Of the most promising materials multi-gram quantities will be available for further studies and printing at the other partners.

Cell optimisation and new concepts (TUE, CSEM): Even though the excited state energy of the absorbing solar cell material can be as high as 2 eV, the open-circuit voltage is typically as low as 0.6V. This represents a loss by a factor of 3 and is one example of the room for improvement. While high efficiencies and innovative concepts were demonstrated with multi-cell stacks at TUE, in this project we will focus on low-complexity cell concepts that are feasible for printing. Solution-processed organic solar cells rely on bulk heterojunctions that must separate the charges effectively. These blends must be optimised for high efficiency, open-circuit voltage and fill factor. Combinatorial device fabrication by use of a high-throughput pipetting robot (cf. figure 2) and automatic characterisation has proven highly useful for OLED research and development at CSEM and shall be explored for solar cells.
The active layers need to be fully characterised with respect to their morphology and optical absorption. The IQE, EQE, and J-V characteristics of the devices will be characterised to determine the major loss mechanisms and –hence – identify opportunities for further optimisation.

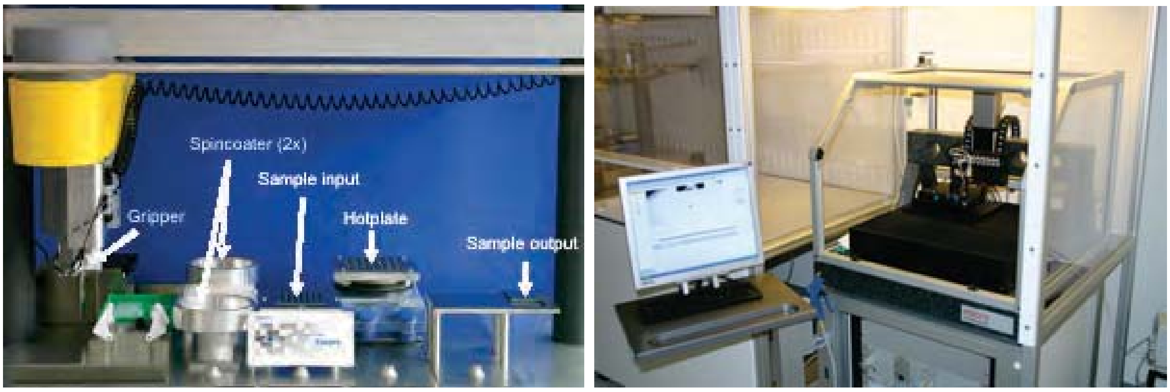

Figure 2: CSEM's ink-jet printer (left) and the high throughput fabrication robot (HTF-7) for polymer devices based on a modified pipetting robot (right).

Cell characterization methods and tools (UJI, TUE, CSEM, ZHAW): Electrical characterisation of solar cells by impedance spectroscopy has been pioneered at UJI for dye sensitised solar cells. Equivalent circuit models are physically motivated and able to reveal loss mechanisms. While impedance spectroscopy has also been employed in the past to study OLEDs, little is known in the context of organic solar cells and the numerical modelling thereof.

Cell modelling (ZHAW, UJI): A comprehensive device model for the study of operation mechanisms and the interpretation of measured data will be developed. It will cover the whole process chain from light absorption, exciton dissociation, charge carrier transport and collection by electrodes. The ZHAW has expertise in numerical modelling of opto-electronic processes in transient and steady state in OLEDs. The maximum achievable short circuit-current will be addressed with optical simulations that provide the spatial exciton generation rate density. It is intended to distinguish the detrimental effects of charge trap, recombination and collection losses by the use of drift-diffusion simulations.

Cell prototyping (CSEM): CSEM has established organic layer deposition by spinning, ink-jetting (cf. figure 3), screen printing as well as hot-embossing of 3D structures as part of an EU-project ("ROLLED") on roll-to-roll OLED fabrication. The printing challenges arise with viscosity constraints, interface roughness, thickness non-uniformity etc. and lead to a reduction of the record efficiencies compared to spin-coated devices.

PERFOR ED WOR AND ACHIE E ENTS

WP1 (Materials: BASF, TUE)
In 2010 the BASF branch in Basel was reorganized. The acquisition of Ciba by BASF has not affected the collaboration within this project. Batches of most promising novel materials have been sampled and their key material parameters have been determined by BASF. The materials were distributed to CSEM and TUE for device fabrication. BASF emphasises on printing technologies and investigations on suitable solvents.

WP2 (Cell optimisation and new concepts: TUE, CSEM, ZHAW)
The Technical University of Eindhoven and the Centre Suisse d'Electronique et de Microtechnique fabricated spin-coated solar cells based on materials provided by BASF. The influence of the fabrication parameters such as the choice of solvents and the blend concentration on the blend layer morphology was analysed by AFM. Maximum power conversion efficiencies close to 6% were achieved. Moreover new concepts for tandem cells were investigated and an algorithm for cell optimisation was developed at TUE. This algorithm allows to estimate key figures such as the short circuit current, the fill factor and the maximum power point (see Figure 3) based on characterized single cell units and simulations by the software SETFOS. The predictions were successfully validated experimentally. Tandem cells with an open-circuit voltage of 1.4 V and a power conversion efficiency slightly above 6% were achieved. These are very promising results. Calculated cell thickness optimization results are shown in Fig. 3. Several scientific publications in this context were published recently by TUE [2-6].

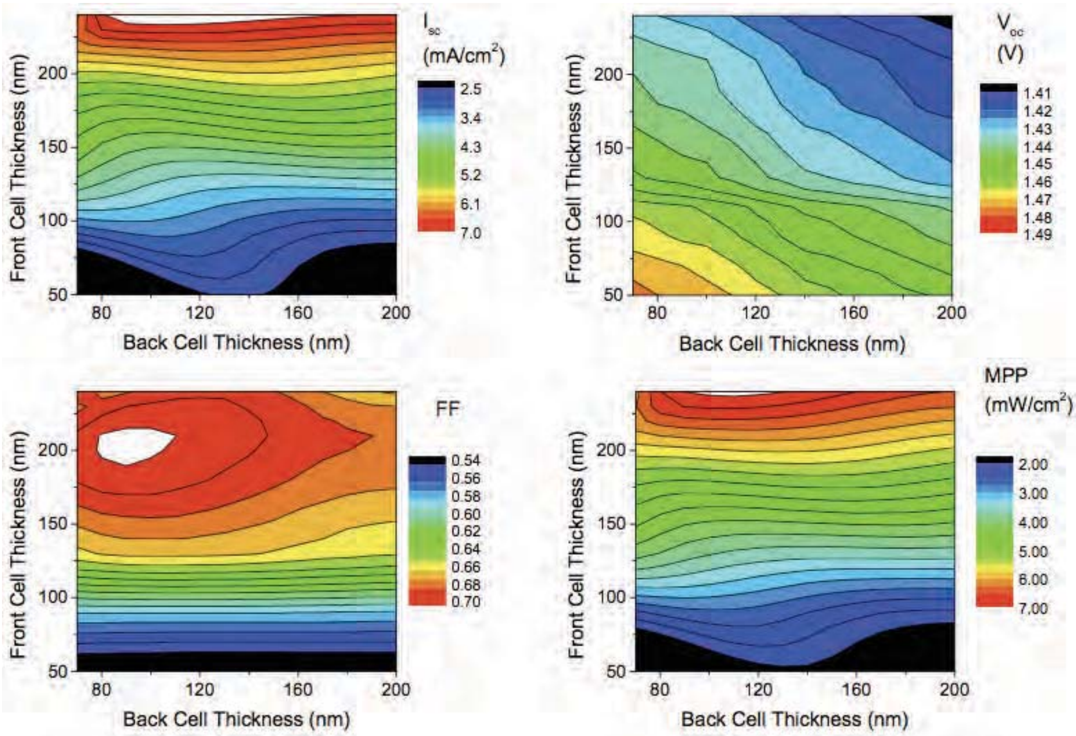

Figure 3: The algorithm allows to optimise the key figures including the short circuit current, the fill factor, the open-circuit voltage and the maximum power point of tandem cells.

WP3 (Cell characterisation methods and tools: UJI, TUE, CSEM, ZHAW)
The Zurich University of Applied Sciences and the University Jaume I in Castellon extracted device and material parameters by advanced experimental methods for solar cells that were fabricated at CSEM Basel. At the ZHAW an integrated measurement system for steady-state, transient and photo-CELIV characterisation for model-based parameter extraction was developed. The measurement setup includes an integrated amplifier for both illumination and photocurrent at extremely low series-resistances (1 Ω) and a significantly improved signal-to-noise ratio by on-board high-frequency connectors (see Figure 4). The measurement system allows to accurately extract material parameters such as field-dependent mobilities and investigate electrical loss mechanisms.

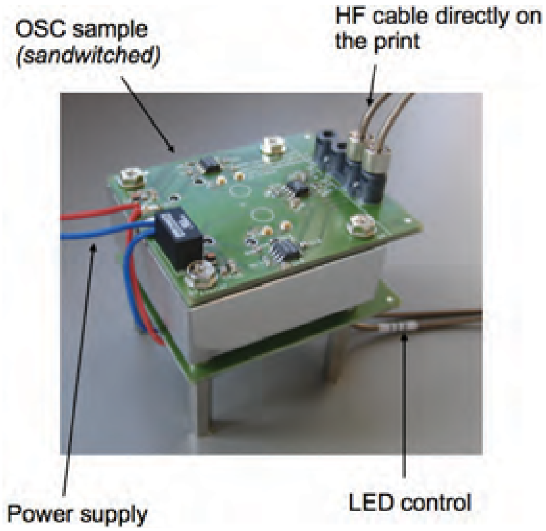

Figure 4: Integrated steady-state, transient and photo-CELIV measurement setup
for parameter extraction developed by ZHAW.

Figure 5 shows the bi-molecular decay of charge carriers generated by a pulsed optical excitation. Monitoring the transient decay of charge carriers allows to study recombination losses in organic solar cells. The recombination in spin-coated cells is much more efficient than in printed cells which must be correlated to morphological effects.It is notable that the recombination factor deduced this way is comparable to values obtained by fitting the fully-coupled opto-electronic model to photocurrent data as a response to a step-wise turn-on of illumination.

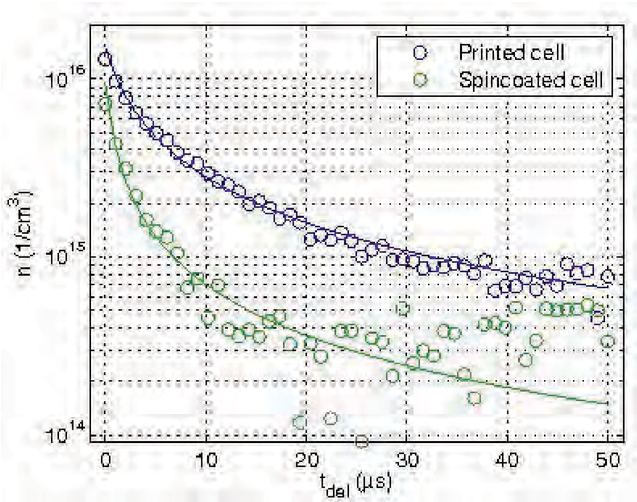

Figure 5: Transient charge carrier density as a function of the time delay after
pulsed optical excitation measured at ZHAW.

Defect states might have detrimental effects on the solar cells performance. Charged defects within the gap alter the electrical field profile and might reduce the drift driving force for carrier transport, and consequently diminish carrier collection at the contacts. In extreme cases, the electrical field can be even suppressed in a significant portion of the active layer. UJI analysed polymer gap states as a function of temperature by impedance spectroscopy and transient measurements of the open-circuit voltage (see Figure 6). The investigated polymers show a defect band slightly above the HOMO level at E_0 ~50-70 meV, with a σ of 30 meV at a density N_t of 10^{15} cm^{-3}. The observed filling kinetics is extremely slow within the range of 0.1-10 Hz. The defects levels are considered as electron acceptors responsible for the polymer p-doping. The variation of V_{oc} in Figure 6 (right) was obtained by varying the illumination intensity. At high illumination levels, the carrier lifetime determined by impedance spectroscopy (equivalent circuit model approach) agrees well with the lifetime obtained from photovoltage decay measurements. The results obtained by UJI have been published recently [11].

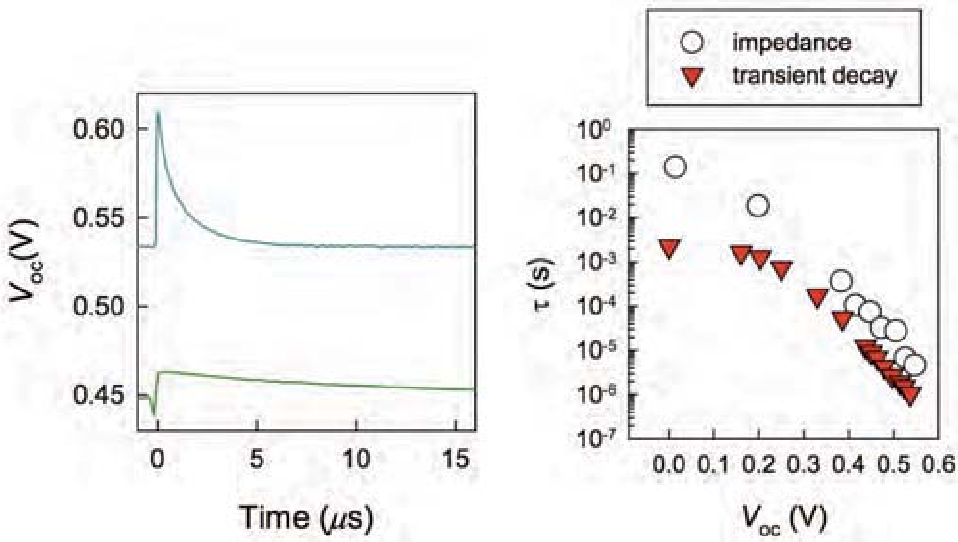

Figure 6: Transient measurement of the open-circuit voltage and carrier lifetime vs. open-circuit voltage. The latter were both determined by impedance spectroscopy and transient decay measurements.

WP4 (Cell modelling: ZHAW, UJI)
An accurate determination of the charge carrier mobilities is essential to model and improve organic solar cells. A frequently used method to determine charge carrier mobilities is the CELIV technique (charge extraction by linearly increasing voltage). In this technique a voltage ramp is applied to the device in order to extract free charge carriers inside the bulk. The free charge carriers can be created by injection or by a short light flash (photo-CELIV). With a simple analytical formula the mobility is commonly estimated on the basis of the temporal position of the current peak. We simulate the photo-CELIV experiment with a fully-coupled electro-optical model and measure CELIV currents for several voltage slopes and transient photo-currents of an organic bulk heterojunction solar cell. By fitting our numerical model to the multiple curves we show that important material parameters like the electron mobility, hole mobility, charge generation and recombination efficiency can be determined using numerical parameter extraction. The series resistance of the experimental setup has a strong influence on the measured result and can therefore not be neglected in the simulation. The electric circuit with consideration of R is used in the simulation approach shown in Figure 7. Notably, the effective applied voltage V_{app} at the OSC (organic solar cell) device is the voltage of the function generator V_{Source} minus the voltage V_R across the series- resistor R_s.

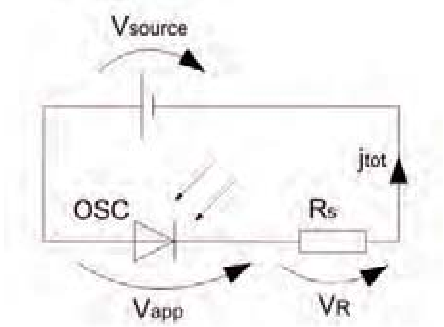

Figure 7: Sketch of the electrical circuit used in the numerical model.

Measured and modelled IV-curves of both a printed and a spin-coated cell are plotted in Figure 8 as a function of illumination intensities. The measured current-voltage curves can be reproduced successfully by the simulations with slight deviations from the s-shape observed in the experiment. With the introduction of a light source with calibrated illumination intensity we obtain an additional scaling variable to investigate.

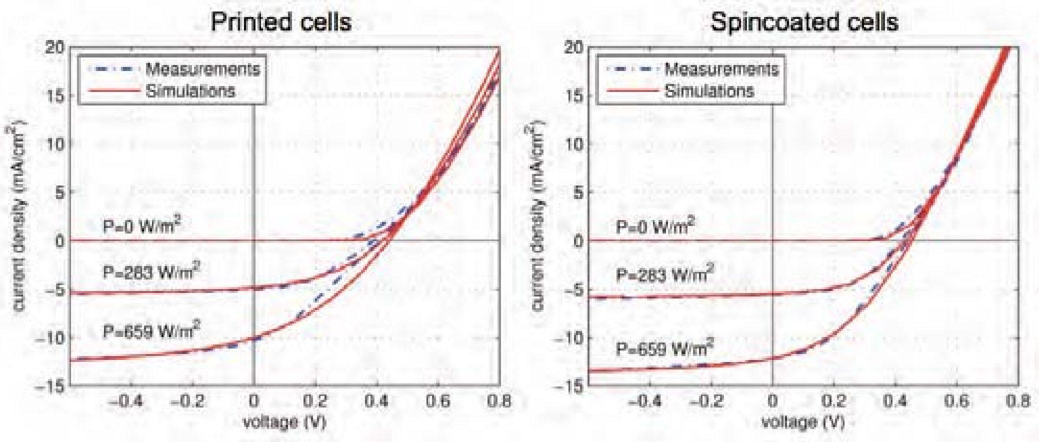

Figure 8: Measured and simulated current-voltage curves for ink-jet printed cells and spin-coated cells measured at different illumination intensities.

Figure 9 (a) shows measured CELIV currents with different voltage slopes and the corresponding simulations. For all voltage slopes the same set of simulation parameters is used. The transient currents can in general be reproduced with a numerical drift-diffusion model that simply assumes constant charge mobilities. In Figure 9 (b) the photo-current response to a light pulse is shown. For the simulation the same set of parameters is used as for the CELIV simulation. The raise and the fall of the simulated photo-current transients show a slight deviation from experiment. This may originate from trapping and releasing charge carriers which is not considered in this simulation. An influence of a field dependence of the mobility is also possible since with the given series-resistance on the sample a voltage drop of 0.3 V occurs. Our CELIV analysis results were published recently [7,8].

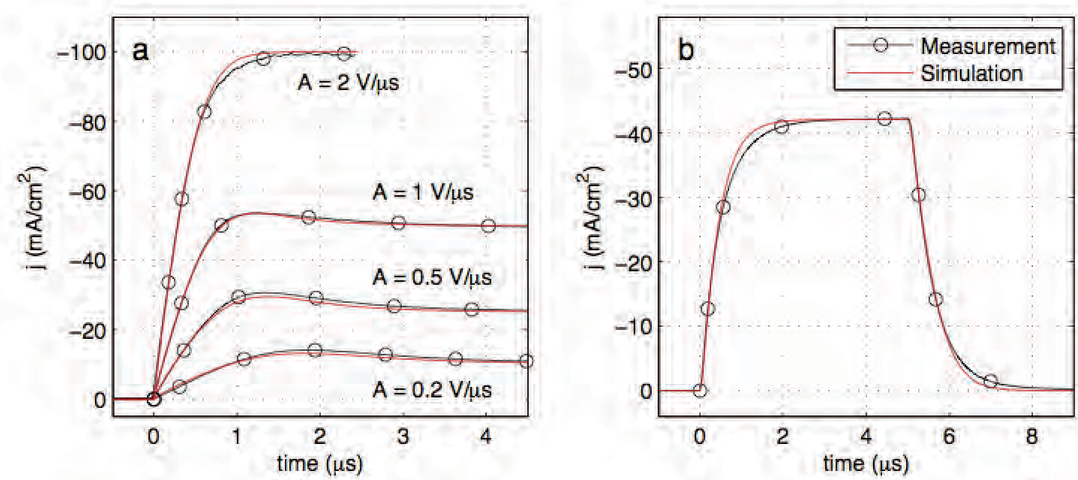

Figure 9: (a) Measurement and simulation of transient CELIV currents for different voltage slopes. (b) Measurement and simulation of the transient photo-current as response to a 5 µs light pulse at 0 V applied voltage.

WP5 (Cell prototyping: CSEM)

Structural ordering of the polymer chains and the resulting improvement of the carrier mobility is favourable in achieving efficient solar cells. Direct evidence of crystallinity in our polymer films is given by x-ray diffraction (XRD) data. Our measurements show the structural ordering corresponding to the inter-chain spacing and the π-π stacking between the molecules.

The morphology on a larger length scale resulting from de-mixing of the polymer and the fullerene in the blended film is critical for efficient device performance. AFM can give some indication about the morphology of the film. The morphology of the active layer is influenced by the choice of solvent, annealing conditions, drying rate, and the deposition method. In Figure 10 AFM measurements on layer deposited from different solvent compositions are presented.

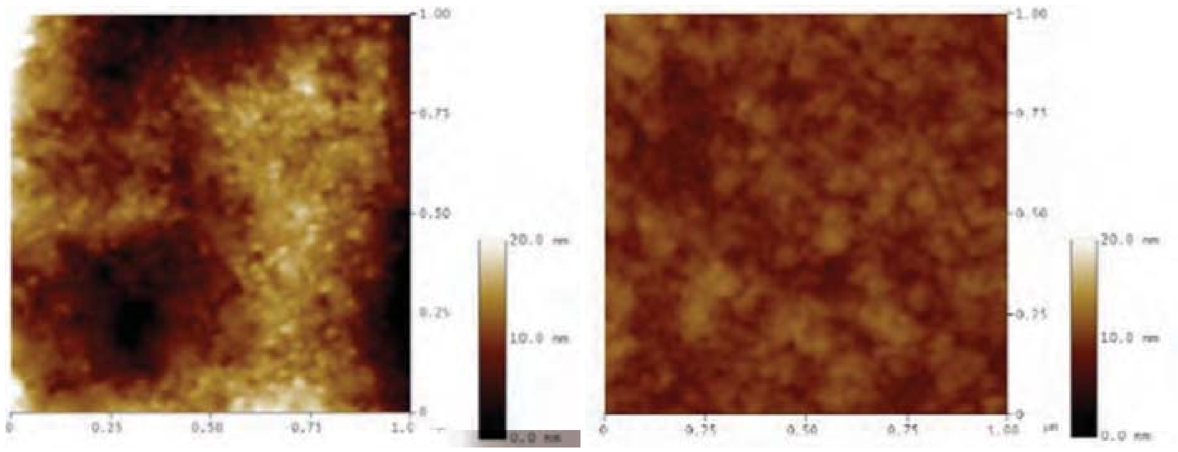

Figure 10: Surface topography images of layers inkjet printed from oDCB:chloroform 4:1 (left) and spin-coated from oDCB:chloroform 1:4 solution. (right). The image size is 1x1 µm^2.

We achieve ink-jet printing of polymer blends with a good layer uniformity by tuning solvent mixture composition, concentration, print head velocity and dot spacing. Polymer solar cells have been fabricated based on the ink-jet printed active layer. By optimising the printing parameters, power conversion efficiencies of ~4.5% for 0.04 cm^2 inkjet printed cells and ~3.4% for 1 cm^2 inkjet printed cells have been achieved. Figure 11 shows images of the ink-jet printed layers. The obtained results on printed solar cells were published recently [9,10].

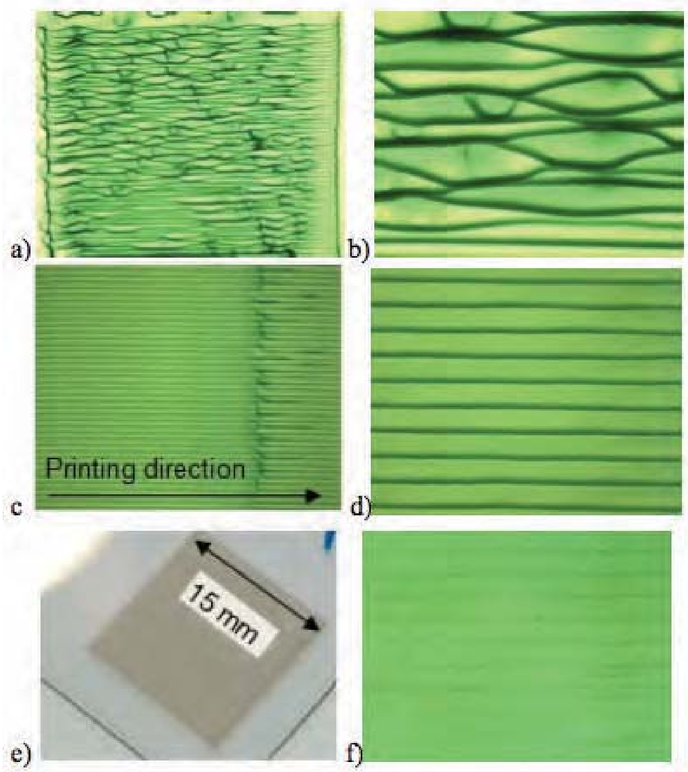

Figure 11: Microscope image of the ink-jet printed layers. a) Dot spacing 0.05 mm. b) Magnification of a). c) Dot spacing 0.07 mm. d) Magnification of c). e) Photograph of a ink jet printed layer in a 15x15 mm2 area. f) Microscope image of e).

ASSESS ENT OF ACHIE E ENTS IN 2010 AND OUTLOO

In the first project year, the consortium was quickly getting up to speed with respect to fabricating devices based on new polymers from BASF. In the second year the characterization of basic material properties has indicated that the new materials enable potentially very good solar cell performance. The project partners that do not have device fabrication facilities available received cells fabricated by CSEM and investigated them further by dynamic electrical characterization techniques and modeling. The spin-coated cells were optimized to achieve nearly 6 % power conversion efficiency while the ink-

jet-printed cells reach up to 4.5%. An efficiency of 3.4% was achieved for solar cells printed by CSEM with relevant cell sizes of 1 cm^2. Moreover, optimized tandem-cells with power conversion efficiencies above 6% were achieved. Defect states in organic solar cells have been analyzed by impedance spectroscopy. Novel experimental and numerical characterization tools based on the photo-CELIV method were developed at the ZHAW which allow extraction of material parameters in organic solar cells.
The project team has held meetings every 6 months and regular telephone conferences. The swiss partners have held additional meetings to further improve the collaboration inside the consortium.

Some outlook on work to be done next:

Tandem cells will be further optimized and the deposition and material of the charge recombination layer will be investigated.
A series of bulk heterojunction blends dissolved in different solvents will be used for solar cell fabrication. The cell performance will be evaluated by model-based data analysis. The correlation of the cell performance with the blend morphology is studied.
Further experiments with time-dependent characterisation techniques (e.g. CELIV, impedance spectroscopy) will be carried out.
Key performance indicators (device efficiency, maxPPS, EQE) obtained by ink-jet printing show that there is still margin of improvement when compared to other polymer deposition such as spin-coating. Further process development guided by models and other experimental data will be undertaken in the next period.
The very promising results are obtained with good solvents for polymers (physical chemical definition), which are not ideally suited for mass solar cell fabrication. Further investigations of alternative formulations will be carried out as deemed relevant by the consortium.

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HIOS-CELL

NANOSCALE STRUCTURING OF HETEROJUNCTION IONIC ORGANIC CELLS BY LIQUID-LIQUID DEWETTING

Annual Report 2010

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Project- / Contract Number	SI/500297 / SI/500297-01 (102914 / 153738)
Duration of the Project (from – to)	1.1.2009 - 31.12.2010
Date	3.12.2010

ABSTRACT

We use the phenomenon of liquid-liquid dewetting to fabricate films of cyanine dye / PCBM blends with a well defined phase morphology. Liquid-liquid dewetting has proven to enable the fabrication of phase structures with length scales ranging from 30nm to 3μm, liquid-liquid dewetting also allows to induce controlled H-aggregation of cyanine dye molecules. The electro-optical properties of H-aggregates are such that they can be of use for light harvesting, if utilized properly. We here point to the features that make H-aggregates useful for organic photovoltaics and further describe a novel method to induce organization of dye molecules in an organic thin film. Ultimately, we want to quantify the effect of aggregation on the power conversion efficiency of cyanine – fullerene solar cells and improve the cell efficiency.

Introduction / Objectives

Improved efficiency of organic photovoltaics requires novel materials which are chemically tuned to the maximum of the solar photon flux. From the class of cyanine dyes, numerous molecules are available commercially. Blending cyanine dyes with the electron acceptor PCBM leads to interdigitated phases between the dye and PCBM by a process called liquid-liquid dewetting. In earlier work we demonstrated that a large diversity of structures can be generated by liquid-liquid dewetting [1]. Characteristic for liquid-liquid dewetting is the development of the final morphology through a transient bilayer of the phases, offering more opportunities to the experimentalist to control self-assembly than it is possible for a system that phase separates by spinodal decomposition. Differently from classical dewetting, liquid-liquid dewetting allows for the formation of submicron features even for thicker films. Still, the process has not yet been exploited to manufacture photovoltaic devices.

In project phase 1 (2009), we investigated main parameters that influence structure formation to give the experimentalist a powerful tool to generate a large variety of different morphologies and explored the opportunities that arise from that novel type of structure formation mechanism for photovoltaics. One of the most striking features that accompanied liquid-liquid dewetting of a PCBM / cyanine dye blend is the controlled H-aggregation of the cyanine molecules.

Aggregates carry outstanding optical properties which are advantageous for light harvesting, namely efficient exciton coupling and fast energy migration. In project phase 2 (2010), we focused on the controlled aggregation of dye molecules during liquid-liquid dewetting.

The overall objective of the project is to realize a cyanine dye based organic solar cell with improved efficiency, taking advantage of the features generated by liquid-liquid dewetting. We identified controlled H-aggregation as one of the most promising features of liquid-liquid dewetting.

Short project description

The possibility to employ H-aggregates as light harvesting complexes has been reported in the literature [2-4]. Aggregation of cyanine dyes is a phenomenon that is well know from aqueous solutions, similiarly, dye aggregates have been successfully employed as spectral sensitizers in the photographic process. Much less is known about aggregates in their function as light harvesting antennas in amorphous films, we believe that this phenomenon has not been fully exploited because of lack of reliable manufacturing methods. We here for the first time report controlled aggregation in an organic film in combination with an organic electron acceptor.

The advantage of dye aggregation is two-fold: ordering of dye molecules into precisely ordered structures leads to an extra-ordinarily high cross section for light absorbtion (H-aggregation peak in the absorbance spectrum), in case of H-aggregates this peak is blue-shifted compared to monomer absorbance, thus expanding the absorbtion range of the dye. Secondly, aggregates are characterized by a large exciton delocalization length, that means the excitation energy is available at any place where it could be used for photo-induced electron transfer.

The effect of aggregation is summarized in Fig. 1, for simplicity only aggregation of 2 monomers to a dimer are considered. H-aggregates are characterized by almost parallel molecular dipoles. When summing the transition moments of the dimer, we obtain the S+ state with the associated transition from the ground state (indicated by an arrow). When the momentums zero each other out, we obtain the S- -state, whereby the transition from the ground state to this state is forbidden. The consequences of this geometry is most attractive: the excited state will relax by internal conversion into the lower excited level. The return from the lower excited state to the fundamental state is less likely, and the excitation can diffuse over relatively long distances. Exciton diffusion length of ~ 100 nm are expected, which is large compared to the exciton diffusion length of 10-20 nm which is normally assumed for organic systems. The exciton can then dissociate at a donor-acceptor interface, or the excitation can be eventually transferred to the monomer. Both pathways would benefit the photovoltaic effect.

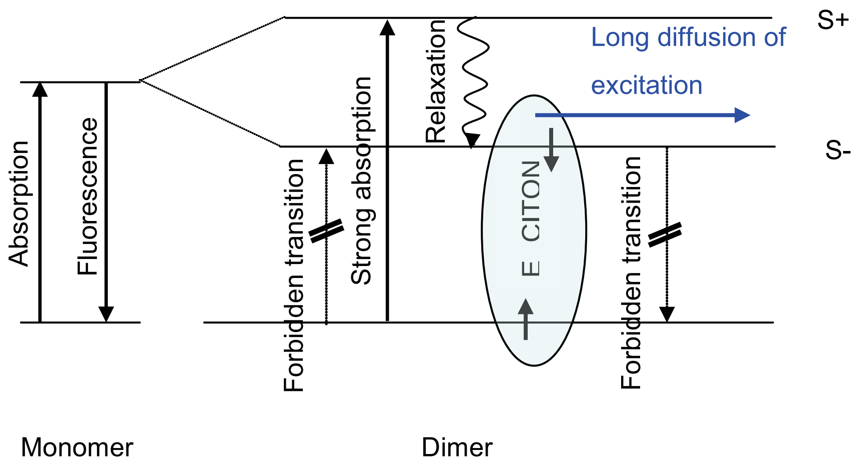

Fig. 1: Schematic diagram of the energy levels in an H-aggregated dye

Work performed and results obtained

H-aggregation is observed in thick PCBM / dye layers that destabilize via a liquid-liquid dewetting route. In Fig. 2 we show attenuance spectra of PCBM / blend films of different thickness. For a total film thickness of 400 nm, the signature of H-aggregation is most dominant and visible as a sharp peak in attenuance. The height of the peak is a direct measure of the interaction of the aggregated molecules with light, it is obvious that H-aggregate absorbance contributes largely to the overall dye absorption. H-aggregation is linked to a thickness regime where dye remains within cavities of PCBM. In Fig. 3 we visualize the aggregation process and show a schematic diagram of the film morphology. A necessity of H-aggregation is the formation of nano-cavities within the PCBM. That can be made visible by slightly ablating the PCBM domains (Fig. 3).

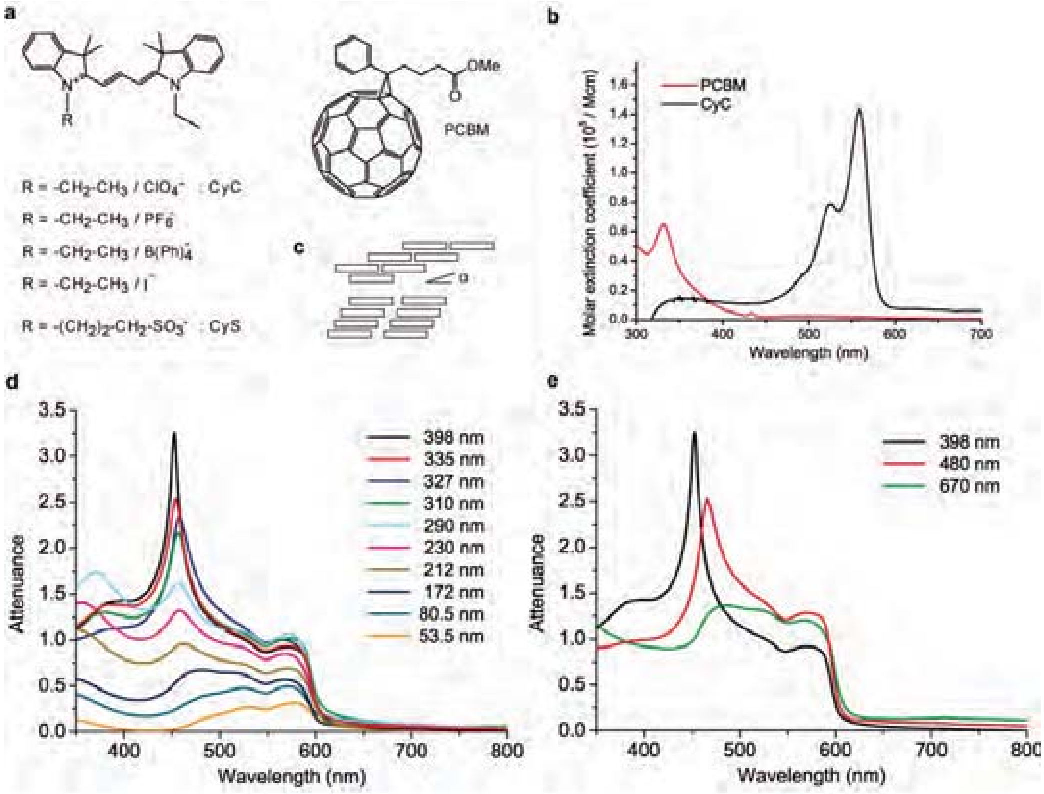

Fig. 2: Molecular structure of the molecules investigated, cyanine dye aggregation and optical characterization. (a) The fullerene derivate PCMB ([6,6]-phenyl C61-butyric acid methyl ester) and the cyanine dye with the free counter ions ClO_4^- (CyC), PF_6^-, $B(Ph)_4^-$, I^- and CyS with the covalently linked SO_3^- anion. (b) Attenuance spectra of PCBM and CyC in chlorobenzene solution. (c) Schematic view of dye aggregation examples in the brickstone arrangement. J-aggregates result for small packing angles α (above, α=19°), H-aggregates for large angles (below, α=64°) (d,e) Attenuance spectra of blend films of PCBM and CyC for different thicknesses. With increasing film thickness enhanced attenuation is observed towards lower wavelength, which turns into a sharp H-aggregate peak in a narrow film thickness range. Figure reproduced with permission from Ref 5. Copyright ACS 2010.

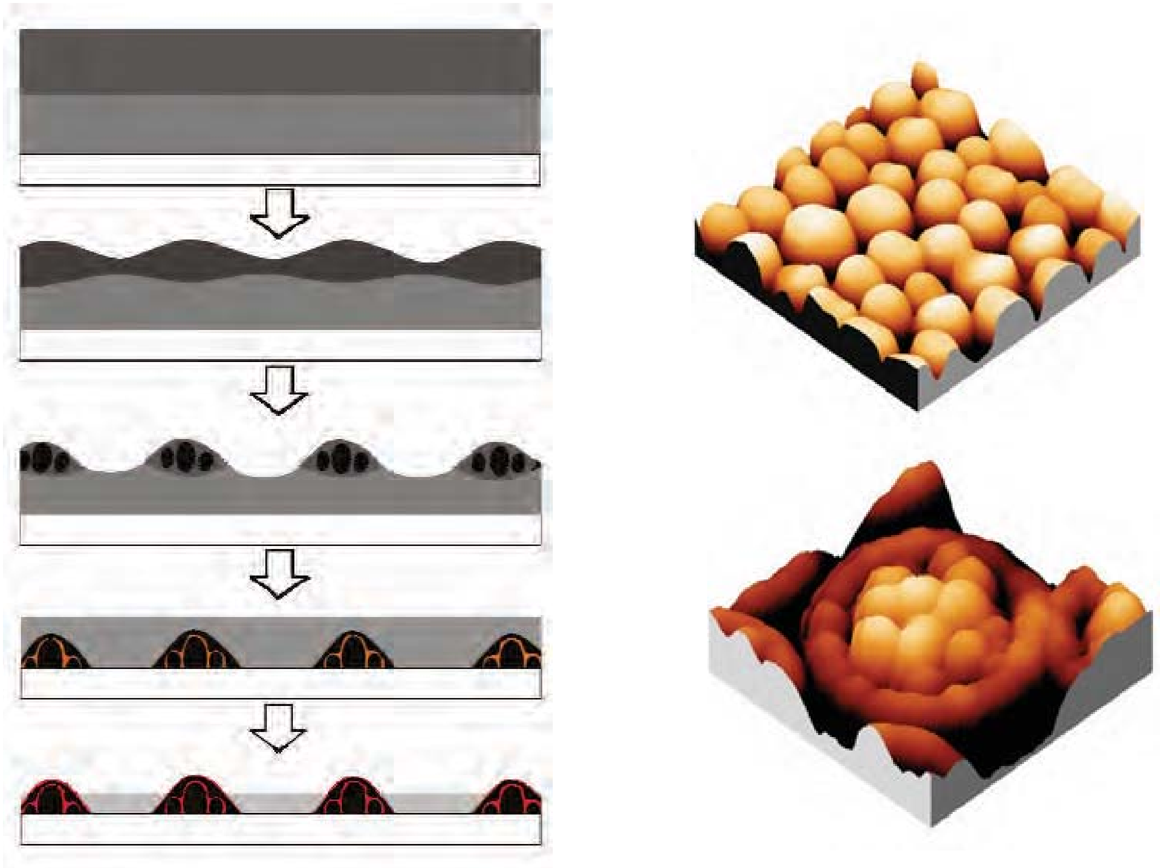

Fig. 3 (left) Sketch of structure and aggregate formation in mixed PCBM/CyC films. In the initial stages of spin coating, the blend phase separates into a PCBM-rich solution (dark) and CyC-rich solution (grey), whereby PCBM forms a layer against the vacuum interface. Consequently, the solvent evaporates primarily from the PCBM, eventually leading to formation of solid PCBM sub-clusters within the PCBM rich phase. The dye minority component of that phase then forms H-aggregates (red). Only after rupture of the PCBM film, the CyC-phase starts to solidify. The figure is not drawn to scale. (right) Scanning force microscopy (SFM) images of PCBM domains that evolve during phase separation with the cyanine dye CyC. The bottom image shows PCBM domains that have been immersed in hexane to partly dissolve PCBM and reveal the inner morphology. The size of the image in the top row is 5 μm $\times$ 5 μm, the size of the image in the bottom row is 1.2 μm $\times$ 1.2 μm.

H-aggregation is induced by nano-structured PCBM. This can be most easily demonstrated by selectively dissolving the dye from the film, and then immersing the substrate in a cyanine solution. With that process we can reproduce the initial dye aggregation. The process also demonstrates the versatility of the aggregation process (Fig. 4).

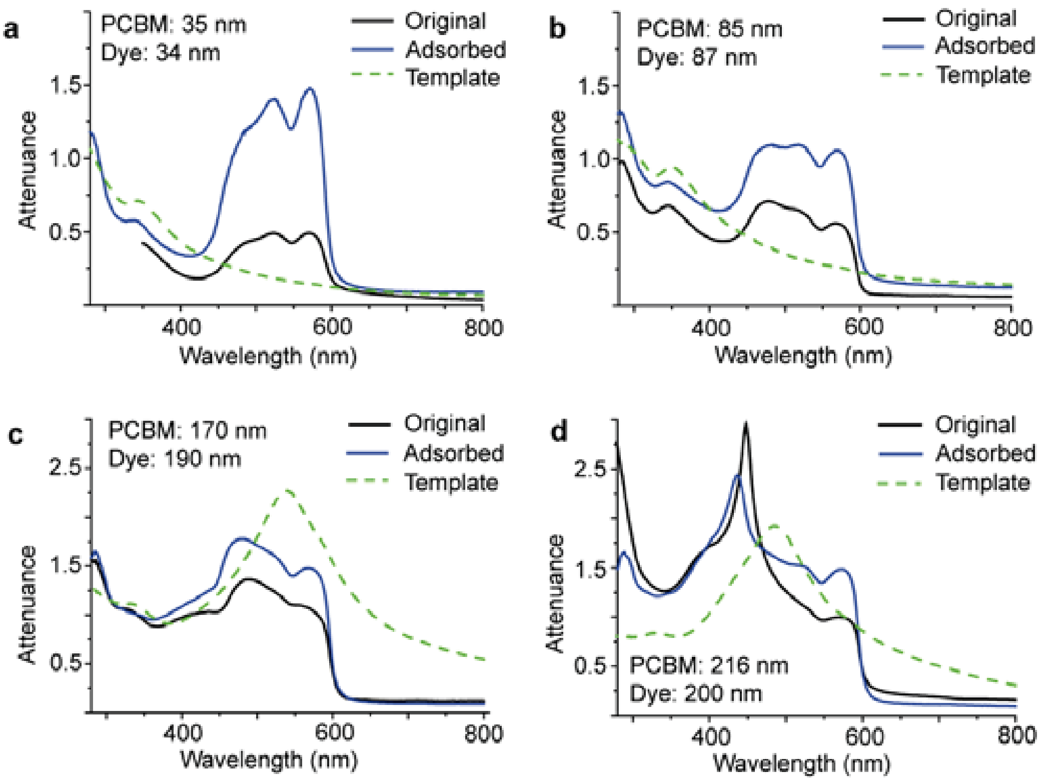

Fig 4: Attenuance spectra of the original films, the remaining PCBM templates after CyC dye dissolution and films where the dye was re-adsorbed onto the templates. The spectra of the re-adsorbed dye resemble the original spectra. The quality of PCBM as nucleation site for aggregates increases from the upper left corner to the lower right corner (a-d). While for the upper panels the template attenuance corresponds to the PCBM absorption spectra (a, b), in the lower panels (c, d) the PCBM attenuation stems mainly from scattering on the PCBM sub-clusters. Figure reproduced with permission from Ref 5. Copyright ACS 2010.

National / international collaborations

HIOS-CELL is a transnational project within the PV-ERA NET call POLYMOL between EMPA in Switzerland and the University of Utrecht (the Netherlands). POLYMOL is funded by the Bundesamt für Energie (Switzerland) and SenterNovem (the Netherlands). The project greatly benefits from collaborations with Cambridge University (UK) and the ETH Zürich.

Evaluation 2010 and perspectives 2011

With liquid-liquid dewetting we started to explore a new structuring mechanism for applications in organic photovoltaics. The complexity of the system made it impossible to fully understand and exploit new effects, namely ion diffusion and H-aggregation, which are associated with liquid-liquid dewetting. We chose to focus our investigations on the phenomenon of aggregation, as this is one of the most startling discoveries of the project. Next to the complexity of the materials system, also time and man power within POLYMOL did not allow us to realize improved photovoltaic cells. In the granted SNF-project “Structured templates of PCBM for applications in photovoltaics and photonics”, 200021-132502 we will continue working on that topic and directly exploit the POLYMOL findings.

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FABRI-P Transparent fabric electrodes for organic photovoltaics

Annual Report 2010

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Project- / Contract Number	KTI 9995.1
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Date	10.12.2010

ABSTRACT

Developing low-cost materials that are flexible and conductive is an important step towards mass produced organic electronics. The current state of the art material, which is ITO on a plastic substrate such as a PET sheet, is subject to rising costs for the indium and a lack of mechanical stability. We use a precision fabric developed by Sefar AG that combines high conductivity and transparency with very good mechanical stability as the front electrode in organic photovoltaic devices. After careful characterisation of the material we are implementing both bilayer and bulk heterojunction device structures on the electrodes. Earlier we produced bilayer devices with MEH-PPV / C_{60} on the fabric electrodes and achieved similar performance to cells on ITO substrates. With the higher performing P3HT / PCBM blend composition we have also managed performances that are close to those of ITO reference devices. With the P3HT / PCBM blend composition we have so far reached conversion efficiencies of 2.2 % for the fabric devices.

Introduction and objectives

Photovoltaic (PV) devices based on organic materials, as small molecules or polymers, are promising candidates for cheap and flexible energy sources [1]. An important part of the PV cell is the substrate electrode. This needs to be both transparent and conductive. Usually it consists of glass with an indium tin oxide (ITO) layer together with a hole injection buffer material such as PEDOT:PSS. Although ITO can have a low surface resistivity of about 6 Ω/□ and a high transparency (>90%), the increasing cost of indium and the relatively slow process and associated high cost per area of the sputtering process to produce it makes it a component that needs to be replaced in order to reduce production costs. Furthermore, applied to a flexible substrate such as PET the surface resistivity increases (~20 - 60 Ω/□) and the mechanical stability is not very good due to the brittle nature of metal oxides.

This project involves using a precision fabric with metalised fibers to replace the ITO. The fabrics can be made conductive by metalising the finished mesh or integrating metal wires with the polymer fibers before weaving. Additionally the metal wires can be weaved in only one or both directions and at different spacing, allowing for cost optimization (Figure 1). A difficulty of using such fabrics as electrodes is the fact that the mesh dimensions are on the micrometer scale while the thickness of the optoelectronic film to be deposited on top of the electrode is approximately two orders of magnitude smaller. It is the goal of this project to define the right treatments of the fabric and methods to produce flexible organic PV devices with state of the art conversion efficiencies [2, 3, 4]. With relatively cheap raw materials and compatibility with high throughput roll-to-roll manufacturing we believe this novel electrode substrate might contribute to the success of low-cost organic electronics [5].

Work performed and results obtained

Characterisation of the fabric materials included measuring optical and electrical properties. The optical transmission experiments showed that there is a large portion of the light being scattered. Using an integrating sphere to collect all the scattered light transmittance values were typically between 70 and 90 % depending on the fabric sample. On the one hand the roughness (height difference between peaks and valleys) of the fabric changes the scattering, higher roughness equals more scattering. On the other hand the metal wires contribute to the scattering by reflecting light at different angles. Transmittance curves for a fabric sample about 8 cm from the detector and in an integrating sphere were compared. The lower light intensities at distance was caused by scattering. This scattering of light should be beneficial in PV devices since the scattered light penetrates the active layer at a different angle from 90º, thereby increasing the optical path length for absorption. A rather thick layer of PEDOT:PSS on the fabric is required for full covering of the fabric compared to ITO and accounts for the lower transmittance when the fabric is used. More important than the scattering of light by the fabric it was found that the fabric needs to be as “smooth” as possible, or in other words should have an as low height difference between fiber peaks and the valleys in between fibers as possible. With the information from the device performances the fabrics were improved and height differences as low as ~10 µm were developed at Sefar AG.

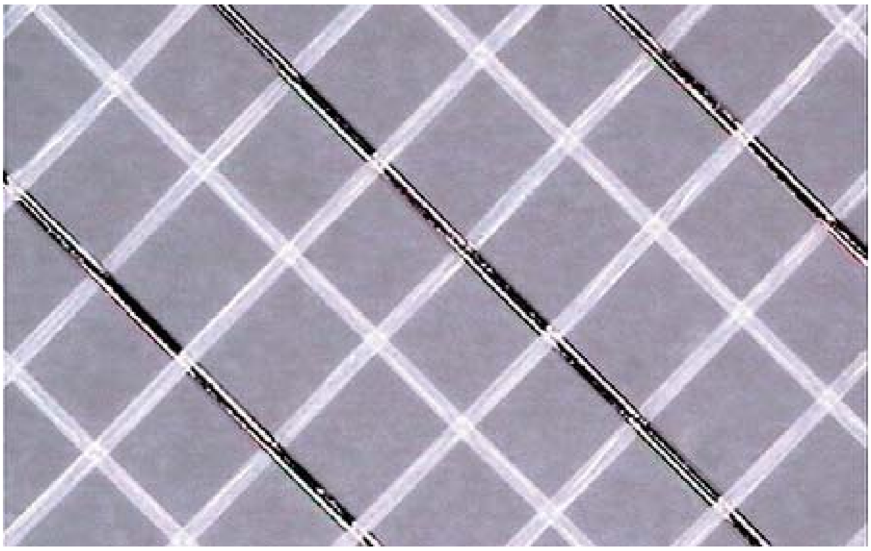

Figure 1. Optical microscope image of a woven mesh with metal wires in one direction and with a polymer fiber between each metal wire.

Sheet resistance measurements on the fabrics show relatively low surface resistivities of between ~1 and 9 Ω/□ depending on the spacing distance between metal wires (0.3-1.1 mm). Calculations of photo current losses in the PEDOT:PSS layer depending on separation distance between the metal wires suggest that the distances between the metal wires (0.3-1.1 mm) in the fabric are close enough to minimize resistive losses to less than 5 % as long as the PEDOT:PSS has a good enough bulk conductivity. Therefore, commercial PEDOT:PSS pastes with bulk conductivities between 20 and 100 S/cm are sufficient according to the calculated current losses.

We found that the bladed PEDOT:PSS layer needs to be around 800 nm thick in average to cover all the fibers completely. It is of great importance that the entire surface is covered when preparing organic electronic devices. After finding the right method to deposit a covering layer several techniques such as AFM and SEM were used to confirm that there was indeed complete coverage.

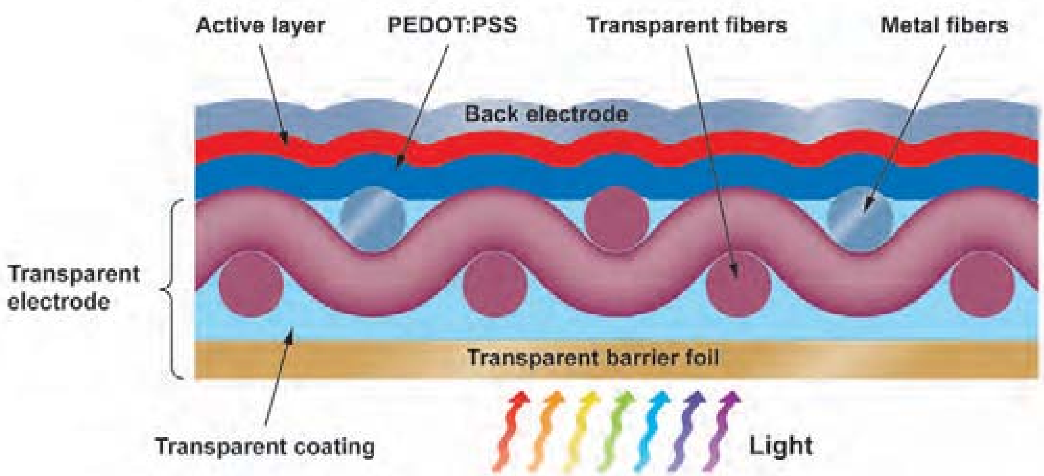

Figure 2. Side view image of transparent fabric electrode covered by PEDOT:PSS, active layer and aluminium back contact. The metal fibers act as the anode and the back electrode as cathode.

Photovoltaic devices were prepared with the conjugated polymer P3HT as the donor material and PCBM as acceptor material. The two compounds are spin-coated onto the PEDOT:PSS covered fabric as a blend. A side view of the complete device is shown in Figure 2. The device performance measured under AM1.5 light was comparable to that of devices using ITO on glass with the same active layer. In Figure 3, three different average thicknesses of PEDOT:PSS on the fabric were prepared for devices and measured. At thicknesses of and below 500 nm short circuits dominate probably due to contact between metal wires or PEDOT:PSS and the aluminium back contact. Increasing thicknesses to ca. 1000 nm show good device performance but shunt currents remain and result in poor fill factor. Going to thicker layers of PEDOT:PSS decreases the short circuit currents but the shunt currents are reduced and an improved fill factor is reached. In comparison with devices made on ITO substrates with thinner, spin-coated PEDOT:PSS, the fabric works rather well and conversion efficiencies of 2.2 % were reached with the fabric devices.

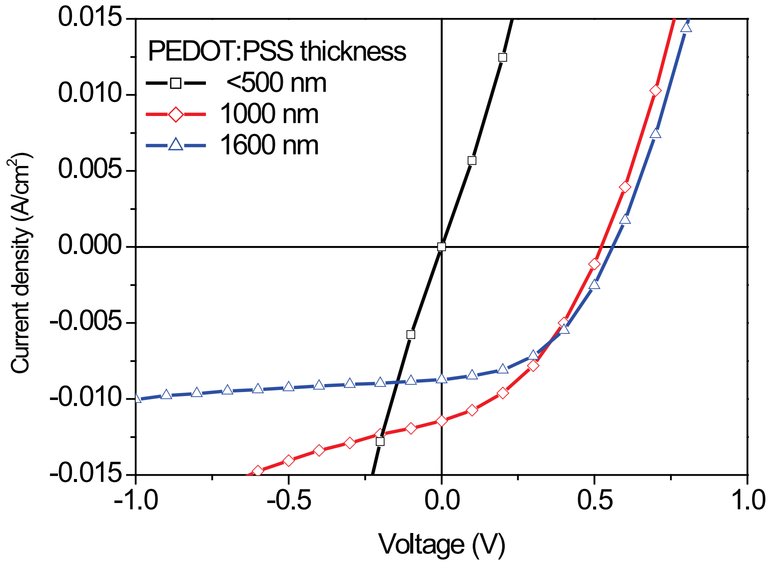

Figure 3. J-V measurements of PV devices using the fabric as transparent electrode with different thicknesses of the PEDOT:PSS layer.

The devices of Figure 3 were small scale (0.03 cm^2) and it is desirable to go to larger devices where the low sheet resistance of the fabric should be of advantage. Large scale devices were prepared but for sizes >0.5 cm^2 the performance is so far still limited by shunt-currents. This means that larger devices without short-circuits are still difficult to produce and need further development. To test the potential of the fabric in a large scale device an experiment where the photo-current was measured at different distances from the PV device was designed. The fabric electrode with PEDOT:PSS was compared to a glass slide with a layer of the same PEDOT:PSS. Figure 4 shows the design of the samples. As can be seen by the amount of photo-current that is collected at different distances in the two cases (Figure 4), it is clear that the fabric in combination with the PEDOT:PSS minimizes losses with distance. With the comparatively high sheet resistance of PET-ITO (~20-60 Ω/□) the fabric/PEDOT:PSS combination should also have lower power losses on larger scale devices.

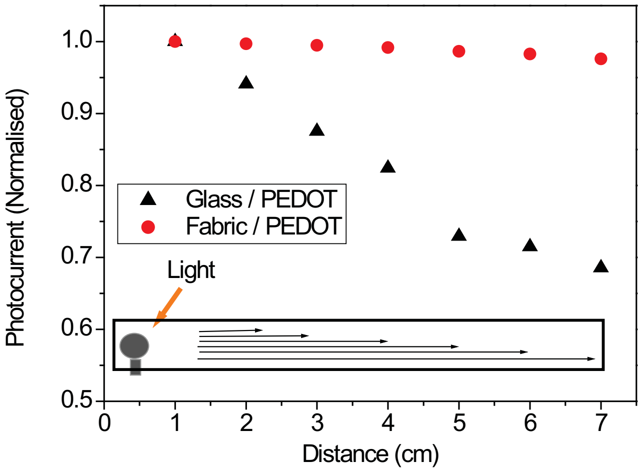

Figure 4. Photo-current collection as a function of distance using an electrode consisting of PEDOT:PSS on glass (black trainagles) or fabric with PEDOT:PSS (red circles).

Evaluation of 2010 and perspectives for 2011

We have successfully applied precision fabrics as transparent electrodes for organic photovoltaic devices. The application of different layers apart from the aluminium back contact has been developed to be compatible with low-cost roll-to-roll production i.e. blading in ambient air. Optical, topographical and electronic characterisations of the fabrics have been carried out. These characteristics have a direct influence on device performance. On larger scales the device performance is still limited but we are confident to have identified the main parameters for further improvement. In ongoing work we try to achieve higher efficiency PV devices with low-cost production methods. In parallel, there are many parameters to optimise experimentally such as maximum distance between metalised fibers without current losses. Also more characterisation methods of the fabric will be developed such as estimating light scattering angles and mechanical tests. The use of the fabric electrodes for the construction of tandem solar cells will also be investigated.

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C ANINE D E ULTI LA ER ORGANIC SOLAR CELLS

Annual Report 2010

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Project- / Contract Number	Co-financed by Empa, BFE, COST
Duration of the Project (from – to)	Since 2007
Date	01.12.2010

ABSTRACT

Solution-processed, small-molecular organic multilayer photovoltaic devices are promising for inexpensive solar energy conversion. We report that cyanine dye / fullerene heterojunction solar cells with an efficiency of 3% can now be produced. Oxidative doping of the cyanine layer and energy level matching at the anode / cyanine interface were the most important steps for device improvement so far. The prospects for further advancements are based on special characteristics unique to cyanine dyes: these include the possibility to tune the dye light absorption by straightforward chemistry, the pronounced aggregation tendency of cyanines that allows to transport charge and/or excitation energy over large distances, such as the presence of mobile counter anions, whose controlled arrangement at heterojunctions can be used to implement device functionalities that are difficult to realize with conventional silicon technology.

Introduction and objectives

Polymers are still leading the field of solution-processed, pure organic photovoltaics (OPV), and power conversion efficiencies of over 7% have been reported. However, it has recently been realized that small molecules possess some merits over polymers, such as ease of synthesis or monodispersity. The best-performing small-molecular organic solar cells have reached efficienices of ~ 4% in 2010, rapidly increasing from 1.3% in 2007 and 1.7% in 2008.

This project specifically relates to the fabrication of all-solution processed, stable and high-performing bilayer cyanine / fullerene OPV. Cyanines are small molecular dyes that are attracting our interest in OPV for several years [1]. Cyanines are commercially available and relatively cheap, they have good film-forming properties from several organic solvents, and their wavelength of absorption can be tuned over the visible to the near-infrared region by simple chemistry (see Fig. 1). Importantly, they have very high light extinction coefficients, and this allows fabricating cyanine OPV cells in simple bilayer architecture. This avoids the tedious control of the blend film morphology of organic bulk-heterojunction solar cells and simplifies the investigation of related dyes.

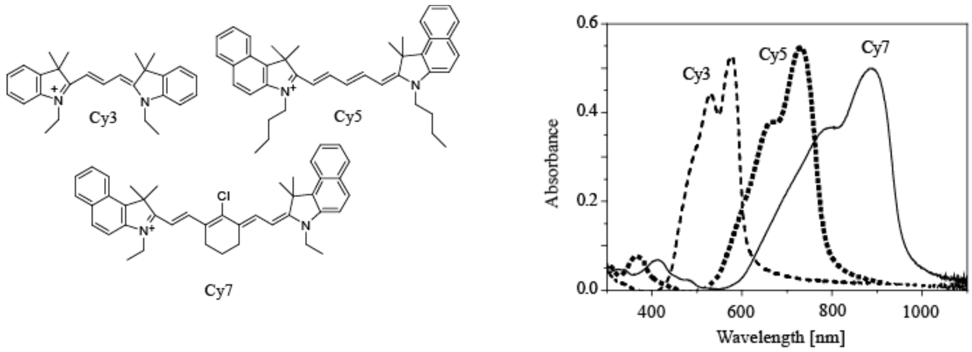

Fig Chemical structures of typical cyanine dyes left ith increasing number of three Cy , five Cy and seven Cy methine groups, and corresponding thin-film absorption spectra right The associated counter anions are omitted

Work performed and results obtained

We found that oxidative doping of the cyanine layer had a positive effect on solar cell performance. When using the chemicals iodine, XeF_2 and O_2/light/water to dope cyanine films directly, a pronounced increase of the short-circuit current (I_{sc}) and the open-circuit voltage (V_{oc}) was observed; however, the doping level was difficult to control and devices were not stable, probably due to chemical side reactions. The best doping chemical so far has been $NOBF_4$. Concentrated stock solutions were first produced in acetonitrile where the NO^+ cation is stable for several hours. Aliquots of the stock solution were then added to a cyanine solution in chlorobenzene and used for coating smooth doped films. Performance characteristics of ITO/PEDOT/doped cyanine/C_{60}/Alq_3/Al solar cells were I_{sc} = 8.3 mA/cm^2, Voc = 0.72 V, FF = 0.34, η = 2% (100 mW/cm^2), where FF is the cell fill factor and η the power conversion efficiency [2].

Oxidative doping increases the conductivity of the cyanine films. This lowers the series resistance limitations encountered in the clean film, improves the hole transport and results in an increased I_{sc} and FF. At the same time, doping improves the charge injection contact between PEDOT and the dye. As a consequence, the charge collection is facilitated, and the effective anode work function and V_{oc} are increased. Indeed, the energy gap between the HOMO energy levels of PEDOT and the cyanine dyes is large (> 0.5 eV), potentially resulting in unfavourable hole transfer kinetics. We therefore argued that lowering the energy barrier at the anode results in more balanced charge collection and improved device performance.

In one example, we modified the anode work function with a dipole layer (see Fig. 2) [3]. For this purpose, a thin salt layer was sandwiched between PEDOT and the cyanine. The arrangement of molecules and charges created an internal electrical field and resulted in an increase of the respective work function. Thereby, the energy offset for hole extraction was reduced and the cell efficiency increased.

In another example, we used doped polyaniniles (PANI) layers as interface materials between ITO and the cyanine layer [4]. The work function of PANI (~ -5.4 eV) is substantially higher than the work function of PEDOT (~ -5 eV), and the energy offset at the anode/cyanine interface is importantly reduced. Best results so far were achieved when using PANI doped with dodecylbenzenesulfonic acid, and for an ITO/PANI/cyanine/C_{60}/Alq_3/Al solar cell, I_{sc} = - 6.92 $mAcm^{-2}$, V_{oc} = 0.72 V, FF = 0.61, η = 3.0% was measured.

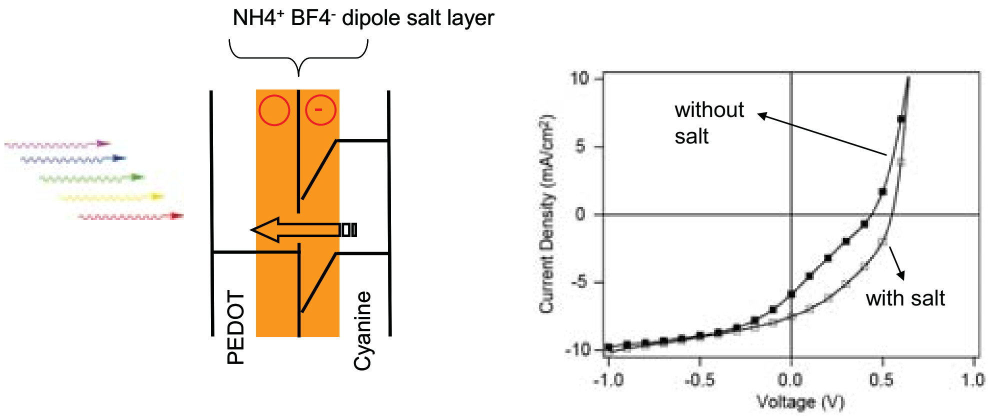

Fig : salt layer increases the anode or function and reduces the energy offset for hole extraction left I-V characteristics right of cyanine / C solar cells ith open squares and ithout filled squares an intermediate layer of NH F

Our research results indicate that cyanine aggregates might play a very significant role in the charge generation process in cyanine / fullerene solar cells. It is known that cyanines can self-assemble into highly ordered structures (aggregates) consisting of thousands of molecules (see Fig. 3, left). The photoexcited state is extended over the entire aggregate, and results in exciting optical phenomena such as instantaneous energy migration, narrow and intense light absorption or resonance fluorescence. We speculated that cyanine aggregates serve as light-harvesting antennas over larger distance through the cyanine layer to the heterojunction [5]. Usually, cyanine aggregates form in low-concentrated water solutions, which is unsuitable for organic opto-electronic device applications. Recently, we found a way to fabricate aggregates from organic solvents in a controlled way, and will correlate solar cell performance with their occurrence [6,7].

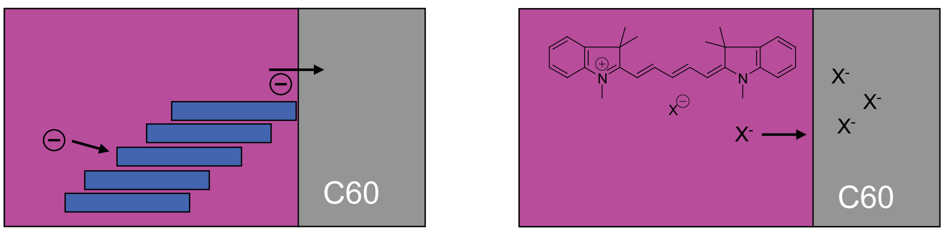

Fig : e argue that cyanine aggregates may be responsible for efficient transport of excitation energy and/or charge over larger distances to the cyanine / C heterointerface left The positive charge of the cyanine chromophore is balanced by counter anions right These anions are mobile and are displaced into adjacent layers

Another characteristic of cyanines is the counter anions that balance the positive charge of the dye chromophore (see Fig. 3, right). Iodide usually results from the chemical synthesis, but I^- can be exchanged with other anions such as ClO_4^- or PF_6^-. We demonstrated that these anions are mobile and can drift (reversibly) and diffuse into the C_{60} layer. The build-up of ionic space charge creates internal electrical fields and induces potential energy shifts at heterojunctions similar to conventional p-n junctions. Thereby, microscopic processes such as photoinduced electron transfer and charge transport can be tuned. The ionic radius and special chemical affinities determine the extent and distance the anions are displayed into the C_{60}. So far, we showed that the type of anion has a distinct influence on the solar cell performance [8]. In ongoing work, we follow strategies that will allow to permanently fix-ing such ionic junction in a desired distribution, and aim ultimately for using ionic charge to control the flow of electronic current in organic thin-film devices.

National / international collaboration

Prof. J.-E. Moser, EPFL	Photophysics of cyanines
Prof. C. Hinderling, ZHAWädenswil	Synthesis of cyanines, synthesis of salt dipole layers
CCEM project DURSOL	Stability of thin film solar cells

Evaluation 2010 and perspectives for 2011

During the years 2009 and 2010, we could improve the power conversion efficiency of layered cyanine dye / fullerene solar cells rapidly, and significantly to 3% (from 0.01% in 2005 and 0.1% in 2006), measured under 100 mW/cm^2 simulated sunlight. This breakthrough was possible by doping the cyanine layer to improve the film conductivity, and by matching the energy levels at the anode side by replacing PEDOT with polyaniniline as the common ITO overlayer.

In ongoing work, we are synthesizing cyanine dyes that can be chemically stabilized after film formation, search for more stable (than PEDOT or polyaniline) high-workfunction anode materials and use cyanine dyes with broad spectral absorbance to collect a larger part of the sunlight. Of central interest are the occurrence of small mobile counter anions that are associated with the dye chromophores and the strong tendency of cyanines to form low-dimensional nanostructures. Understanding and controlling these property characteristics will not only allow to further increase the performance of cyanine bilayer solar cells, but offer means for the fabrication of nanostructured semiconducting films and advanced opto-electronic devices that are difficult to realize with inorganic materials [9].

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ORION

ORDERED INORGANIC-ORGANIC HYBRIDS USING IONIC LIQUIDS FOR EMERGING APPLICATIONS

Annual Report 2010

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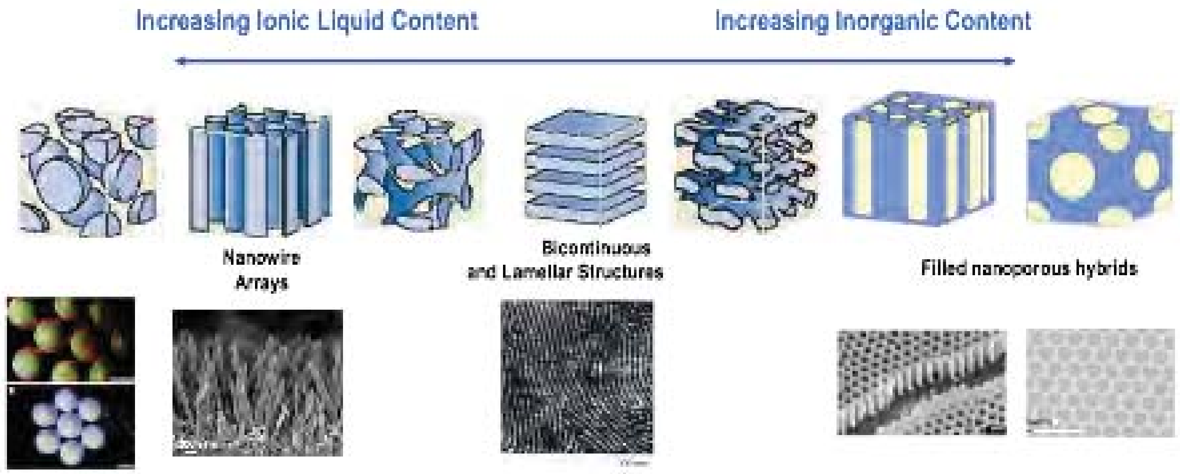
Project- / Contract Number	FP7-NMP-2008-LARGE-2-229036
Duration of the Project (from – to)	1.10.09 – 30.09.13
Date	22 February 2011

ABSTRACT

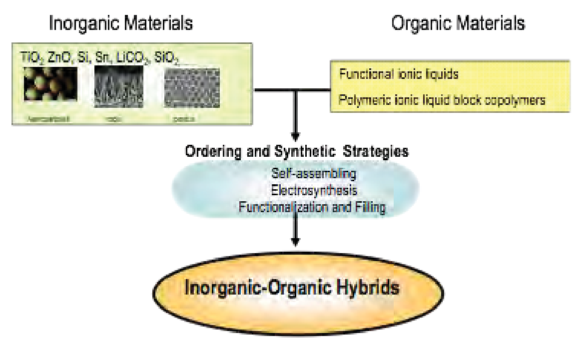
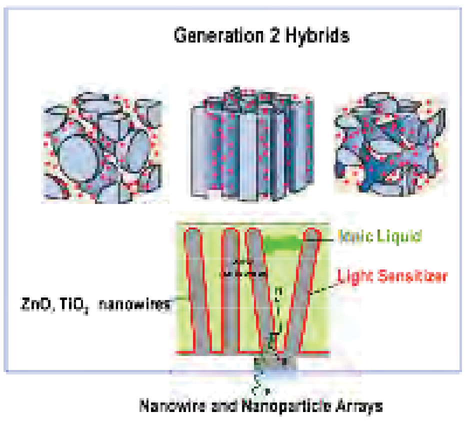
ORION puts together a multidisciplinary consortium of leading European universities, research institutes and industries with the overall goal of developing new knowledge on the fabrication of inorganic-organic hybrid materials using ionic liquids. Maximum research efforts within ORION will be addressed to achieve inorganic-organic hybrids with an ordered nanostructure and to understand and characterize the next generation of inorganic-organic hybrids for energy conversion and storage. The final goal is to optimize the best possible materials and processing methods for increasing the performance of batteries and innovative solar cells.

Introduction and project objectives

The main concept of the project is the development of a new family of functional inorganic- organic hybrids materials characterized by an ordered morphology. The hybrids will be composed of an inorganic material such as (TiO_2, SiO_2, ZnO, Si, Sn, $LiCoO_2$) and a new functional ionic liquid as the organic component. At high inorganic oxide contents the preferred structures will be ordered nanoporous inorganics filled with ionic liquids hybrids.
At low inorganic oxide contents, nanoparticle, nanotube and nanowire arrays embedded in ionic matrixes will be searched. At intermediate compositions bi-continuous and lamellar structures will be presumably obtained. The phase diagram of the ordered inorganic-organic hybrids is shown below. The ordered geometry of the final hybrid will allow a synergic combination of the properties of each individual component, ensuring good electrochemical and photonic performance.



Two different complementary generations of hybrids will be developed. First, Generation 1 inorganic-organic hybrids will be synthesized for applications in lithium batteries. Although the complete phase diagram will be investigated, the expected morphologies of choice will be nanoporous structures because of their higher charge capacity and enhanced charge/discharge rate possibilities. On the other hand, Generation 2 inorganic-organic hybrids will be developed for application in innovative solar cells. In this case, a third component named light sensitizer (dye, semiconducting polymer or quantum dot) will be added to the inorganic component/ionic liquid system. Generation 2 will prefer nanoparticle and nanowire arrays morphologies. This will facilitate electronic and ionic transport and will allow the introduction into the hybrid of a third component (light sensitizer) which will be added to bring optical activity to the hybrid.

<table>
<tr><th>Generation 1</th><th>Generation 2</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Illustration of the synthetic approaches to Generation 1 Ordered Inorganic-Organic Hybrids.</td><td>Graphical presentation of generation 2 hybrid architectures (inorganic nanoparticle or nanowires surface functionalized with a light sensitizer and embedded into ionic liquid media).</td></tr>
</table>

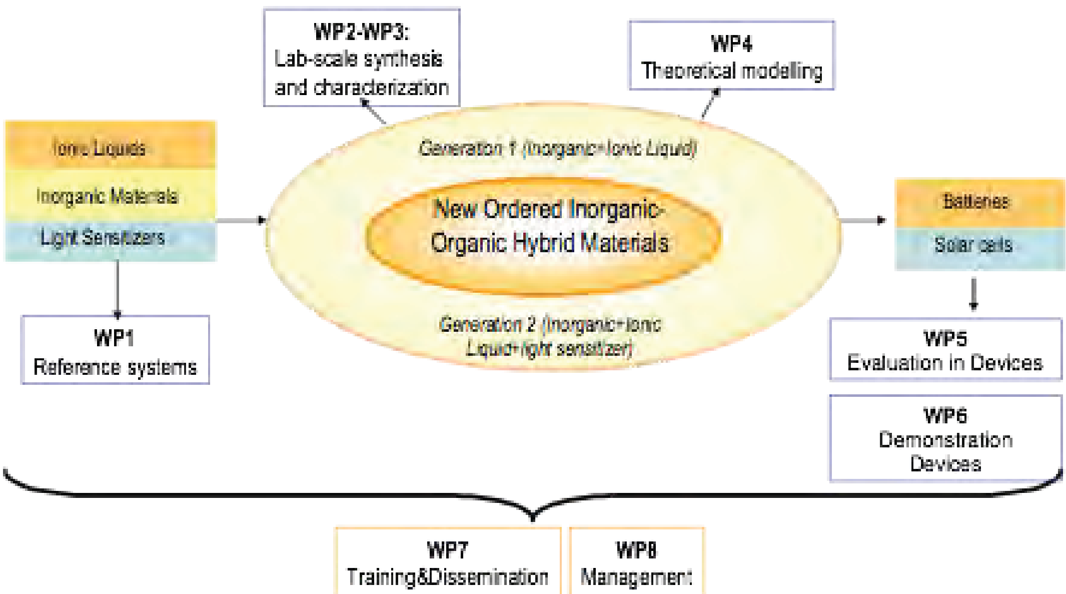
SCIENTIFIC AND TECHNICAL OBJECTIVES:

ORION captures the main goal into the next particular scientific and technical objectives to be achieved in the project:

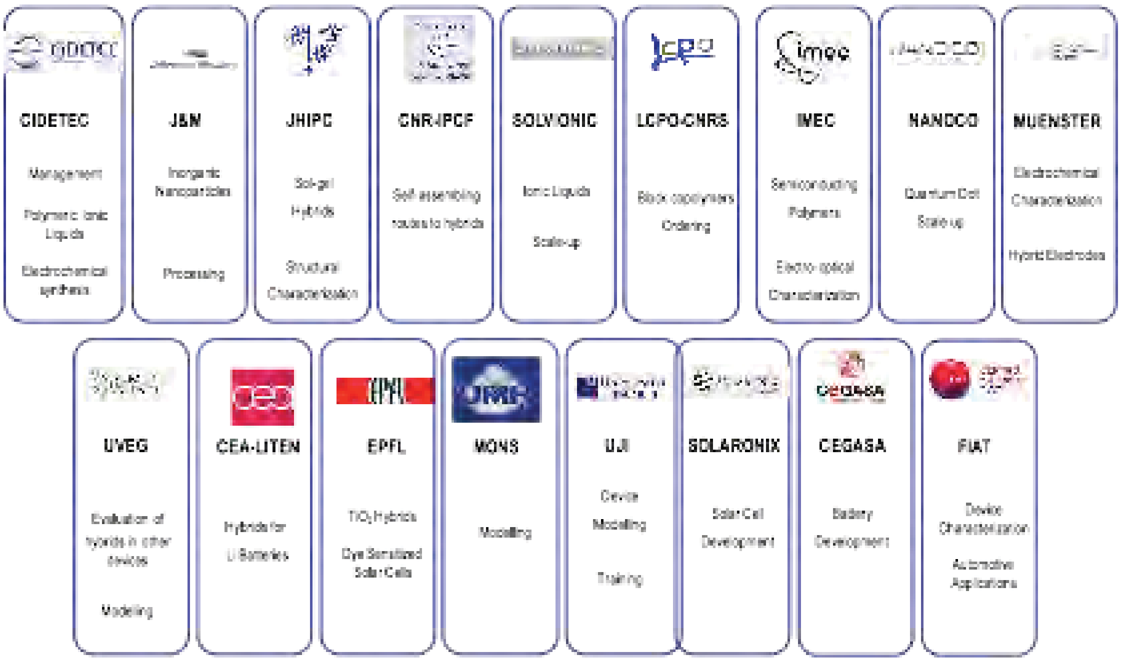
- Design and processing of ordered inorganic-organic hybrid materials for energy applications.
- Understanding of self-assembling methods for the synthesis of ordered inorganic-organic hybrids using ionic liquids.
- Development of new methods for ordering inorganic-organic hybrids using functional and polymeric ionic liquid block copolymers as structure directing agents.
- New functional Ionic Liquids and polymeric ionic liquid block copolymers including chemical functional groups such as triethoxysilane, carboxylic, phosphoric and thiol functionalities enabling the ionic liquids to act as functional templates in the synthesis of ordered inorganic-organic hybrids.
- Development of ordered hybrid materials composed of an inorganic component and ionic liquid for battery applications. (Generation 1)
- Synthesis of light sensitizers (organic dyes, quantum dots and semiconducting polymers) with adequate functionality to be added to the inorganic-organic hybrids.
- Development of complex ordered hybrid materials composed of an inorganic component, ionic liquid component and a third component named light sensitizer (organic dye, semiconducting polymer or quantum dot) for innovative solar cells.(Generation 2)
- Complete characterization of innovative hybrid materials: morphological characterization, electrochemical and transport studies including ionic, electrical and hole conductivities, and functional performance (half-cell devices).
- Theoretical modeling of new inorganic-organic materials and prediction of their properties and performance in devices.
- Processing of inorganic-organic hybrids by different methods including ink-jet printing and screen printing.
- Development and optimization of innovative inorganic-organic electrode materials for lithium batteries. To propose a high storage capacity battery with a long lifetime (respectively>200 Wh/kg, 30% improvement).
- Development and optimization of innovative inorganic-organic hybrids for solid solar cells with high efficiencies (>10%) and high cyclability (10'000 h) (30% improvement).
- Evaluation of organic/inorganic hybrids in other applications (supercapacitors, sensors and light-emitting devices).

Project partners & role of Solaronix

ORION is a Large Scale Collaborative Project involving 17 partners with duration of 48 months. The work program is divided into 7 logical Work packages (WPs), covering RTD, Management, Demonstration and Training activities



The 17 project partners are:



Solaronix has a total commitment of 28 person-months within ORION, mainly in the following tasks:

Task 1.1 Requirements of final applications (FIAT, CEGASA, SOLARONIX, CEA-LITEN) (M1- M6) Within the task the requirements of final applications will be explored paying particular attention how existing automotive systems could be improved, depending of proper functionality, through introduction of new targeted materials. Particularly power accumulation systems will be investigated in order to improve performances (emission, power consumption, power accumulation, charge etc...), functionality and usability. The energy requirements for targeted automobile components such as internal lighting systems (LEDs matrices, OLEDs), rear and view mirrors or other car equipments (navigator, smart card, etc..) will be specified. The selected specifications will be used to select the technology during the development and synthesis of referenced materials paying attention to functionality for energy accumulation.

Sub-Task 1.4.3: Dyes (EPFL, UVEG, SOLARONIX))
In work package 1, we will pursue four different directions for sensitizer design: 1.) A novel generation of ruthenium complexes, both thiocyanate-heteroleptic and thiocyanate-free cyclometallated ruthenium complexes, which are likely to exhibit remarkable stability and performance as a sensitizer, with extended absorption into the IR; 2.) meso-substituted push-pull Zn(II)-porphyrins, which are proven to be effective optical absorbers in the visible and near-IR region, due to the presence of low-lying charge transfer bands; 3.) “charge-transfer” dyes, where extreme directionality in electron injection and hole-separation enable rapid charge generation and long lived charge separated species; 4.) Dual component sensitization via the use of both inorganic quantum dots and modified sensitizers.

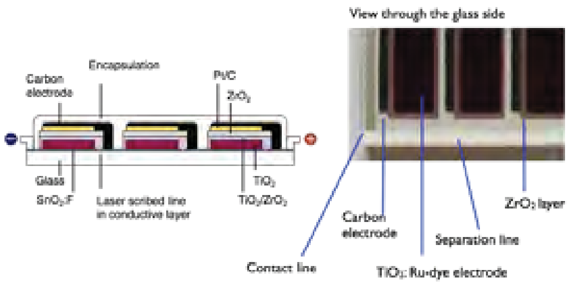
Task 3.4 Processing methods of inorganic-organic hybrids (JM, CIDETEC, CEGASA, SOLARONIX, SOLVIONIC) (M24-M42) Investigation on the best processing methods of the inorganic-organic hybrids. Formulation of inks based on inorganic-organic hybrids to be used for the application of large-scale coating solutions. To be evaluated: Screen printing, spray/jet coating, knife coating, ink-jet printing and electrodeposition.

Task 5.2 Inorganic-organic hybrid materials in innovative solar cells (EPFL, IMEC, UJI, CIDETEC) (M18-M48) The most promising sets of generation 2 inorganic-organic hybrid materials will be evaluated in innovative solar cell concepts. Within this task, the design and fabrication of laboratory cells, whose stability matches the requirements for outdoor applications and whose standard global AM 1.5 solar to electric power conversion efficiency reaches at least 10 percent for an active cells area of 1 cm2. Demonstrate 14 percent power conversion efficiency on single junction cells and 15 percent conversion efficiency of tandem cells. Development of sandwiched devices using modified flat and heterostructured metal oxide substrates and materials and materials architectures developed in WP1 and 2. The devices, will use a transparent bottom contact and an air-stable metal top contact (Al, Pt, Ag or Au). To verify solar cell efficiency using the ordered inorganic-organic hybrids the charge transfer, back-transfer, transport and recombination time resolved spectroscopic techniques will be used in combination with electrical analysis of single and double carrier devices. Characterization will be done using the extensive testing facilities available at EPFL, SOLARONIX, IMEC and UJI, involving high resolution current-voltage, spectral response measurements and time resolved spectroscopy. Additionally, initial stability test will be performed. Demonstration prototypes will be prepared by SOLARONIX (solar cell modules).

Task 6.2 Solar cells demonstrators (SOLARONIX) (M18-M48)
Demonstration prototypes of solar cells with the highest possible efficiency (13% target) will be prepared by SOLARONIX (solar cell modules). Activities will be coordinated with WP5 results in task 5.2.

Work performed and results obtained

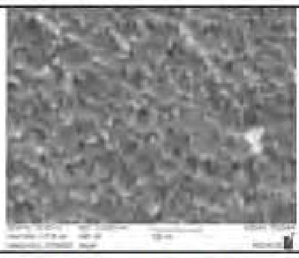
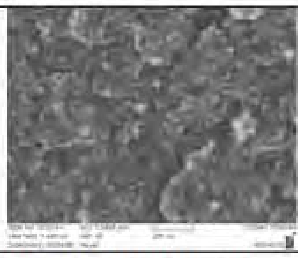
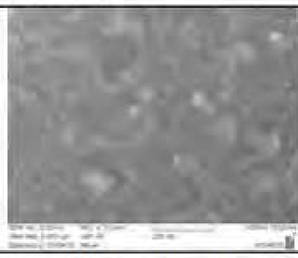
The dye solar cell technology to be improved thanks to the ORION hybrid inorganic-ionic liquid materials is the monolithically integrated module (MIM) setup, allowing for simple and low cost manufacturing of large area modules.



For the Task 1.1, contributions to the deliverable D 1.1 "Report on industrial requirements: batteries, solar cells and automotive sector" have been brought in with the materials specifications required to build dye solar cells fulfilling the industrial requirements. In particular, the desired properties of the sensitizer support material (currently nano-TiO_2) in terms of porosity and electron diffusion coefficient, the sensitizer itself, characterized by the of HOMO and LUMO energy levels, the optical properties and stability requirements. Finally the hole conducting media (electrolyte or redox couple in a solvent/ionic liquid) criteria are redox couple level, viscosity, boiling points (for solvents), mobility and conductivity for solid-state hole conductors.

The planned dye solar cell technology to be improved thanks to the hybrid inorganic-ionic liquid materials is the so called monolithically integrated module (MIM).

The deliverable D1.2 "First set of inorganic components" calls for listing and characterizing the available inorganic materials, now being TiO_2 in the pure anatase phase (XRD) made by an in-house hydrothermal process, yielding TiO_2 nanoparticles from ~ 9 to 30 nm in diameter, typically formulated for various printing techniques (spin-coat, doctor blading or screen printing).

	Ti-Nanoxide HT	Ti-Nanoxide T	Ti-Nanoxide T37
Material	TiO_2 anatase	TiO_2 anatase	TiO_2 anatase
SEM picture			
SEM Particle size	11.4 nm averaged on 112 particles	18.6 nm averaged on 121 particles	26.3 nm averaged on 111 particles
BET Particle size	12.4 nm estimated from pore size	18 nm estimated from pore size	N/A
Porosity	0.631	0.524	N/A
BET Pore diam.	13.3 nm	11.1 nm	~ 25 nm
Surface area	125 m^2/g BET	87 m^2/g BET	~ 40 m^2/g BET
Applications	well transparent nano-TiO_2 layers, photochemistry, DSSC electrodes	transparent nano-TiO_2 layers, photochemistry, DSSC electrodes	Experimental DSSC electrodes

Some of the above TiO_2 materials have been made with a scaled-up 5 liter autoclave to understand the possibility to rationalize the in-house nanoparticles production.

As alternative TiO_2 material to the "classic" hydrothermally grown anatase nanocrystals, we have investigated TiO_2 nanofibers produced by electrospinning at Elmarco in Czech Republic (Nanospider TiO_2). The typical nanofibers are ca. 150 to 200 nm in diameter and several tens of microns long, by sonication, the fibers were shortened to obtain a processable paste.

Spot ID	Ti layers	J mA/Cm^2	Voc (V)	FF	eff.
SX ref 1	SX Titania	17.86	0.65	0.69	7.95 %
SX ref 2	SX Titania	17.69	0.64	0.70	7.99 %
SX ref 3	SX Titania	18.45	0.66	0.70	8.51 %
SX ref 4	SX Titania	18.80	0.65	0.71	8.71 %
Elmarco nanofibers					
Sp15120110FO	75% NF2/ 25% SX	11.81	0.68	0.64	5.19 %
Sp16120110FO	75% NF2/ 25% SX	10.33	0.68	0.65	4.58 %
Sp17120110FO	75% NF2/ 25% SX	10.60	0.68	0.66	4.75 %
Sp18120110FO	75% NF2/ 25% SX	10.44	0.66	0.59	4.11 %

The Elmarco nanofiber material based pastes actually performed less good than the spherical shaped anatase particles, moreover adhesion problems were also encountered with too high nanofiber content.

In view of upscaling the TiO_2 paste production, an alternate vehicle composition was investigated where instead of using 2 types of ethylcelluloses (named EC45 and EC7), only one (EC7) was used to simplify the manufacturing, and improve printability of the pastes. Small 0.36 cm^2 sized cells with both types of pastes have been compared

Spot ID		Area	Isc	Voc	FF	J	eff.
Sp01-2880410FO	Titania Ec7	0.36	6.35	0.66	0.68	17.65	7.87 %
Sp02-280410FO	Titania Ec7	0.36	6.74	0.67	0.67	18.72	8.32 %
Sp03-280410FO	Titania Ec7	0.36	6.67	0.66	0.67	18.53	8.24 %
Sp04-280410FO	Titania Ec7	0.36	6.73	0.66	0.66	18.69	8.15 %
Sp05-280410FO	Titania Ec7	0.36	6.79	0.65	0.67	18.87	8.26 %
Sp06-280410FO	Titania Ec7/Ec45	0.36	6.23	0.66	0.68	17.30	7.79 %
Sp07-280410FO	Titania Ec7/Ec45	0.36	6.39	0.66	0.68	17.75	8.04 %
Sp08-280410FO	Titania Ec7/Ec45	0.36	6.09	0.67	0.68	16.93	7.68 %
Sp09-280410FO	Titania Ec7/Ec45	0.36	6.49	0.67	0.67	18.03	8.10 %

From this first experiments, the easier to manufacture TiO_2 paste with only one ethylcellulose type performed similarly to the classic recipe having both types.

To benchmark the ionic liquid materials synthesized in-house and to complete the deliverable D 1.3 "First set of ionic liquids", we have characterized by 1H-NMR, 13C-NMR and by viscosity, a first set of purified ionic liquids (some are actually solid at room temperature):

Compound	Short name	State
N,N-Dimethyl-imidazolium iodide	DMII	Solid
1-ethyl, 3-methyl-imidazolium iodide	EMII	Solid
1-allyl, 3-methyl-imidazolium iodide	AMII	Solid
1-propyl, 3-methyl-imidazolium iodide	PMII	Liquid
1-propyl, 2,3-dimethyl-imidazolium iodide	DMPII	Solid

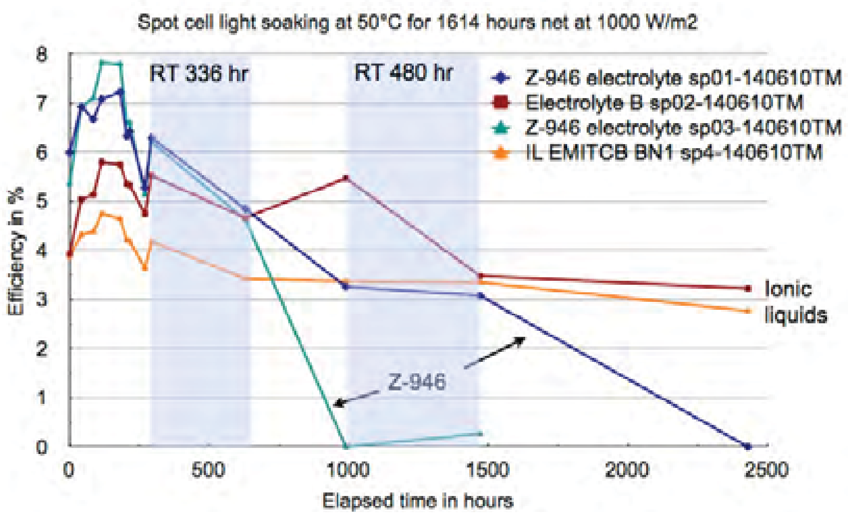
Compound	Short name	State
1-hexyl, 3-methyl-imidazolium iodide	HMII	Liquid
1-hexyl, 2,3-dimethyl-imidazolium iodide	DMHII	Solid
1-ethyl, 2,3-dimethyl-imidazolium dicyanoamide	EMIDCA	Liquid

The Workpackage 2 was launched with Task 2.1 "Generation 1 Organic Hybrid Materials" and we have formulated 2 ionic liquid based dye solar cell electrolytes with the iodide/tri-iodide redox couple ("Electrolyte B" known from Nature Materials 2008, 7, 626-630, and "Electrolyte EMITCB" - a own formulation), to be compared with the state-of-the art high boiling point 3-methoxypropionitrile solvent based "Z-946" electrolyte, being the best candidate for temperature stable solar cells.

A first set of small solar cells (surface 0.72 cm^2 with black mask) have been made to have a preliminary information about stability of ionic liquid formulations.

Cell	Electrolyte	Voc mV	Isc mA	FF	Efficiency %
sp01-140610TM1	Z-946	631	11.2	0.611	5.99
sp01-140610TM2	Electrolyte B	584	7.78	0.622	3.93
sp01-140610TM3	Z-946	623	9.21	0.672	5.35
sp01-140610TM4	EMITCB	607	6.45	0.600	3.88

The laboratory cells were followed over 2'500 hours time (> 14 weeks), with most of the time (1'600 h net) they have been irradiated with artificial sunlight at 1000 W/m^2 in our Sunirad C-65 light soaking bench while keeping the samples at ~ 50°C.



From the plot following the efficiency (measured in the Class B SolarSim-150 solar simulator calibrated to 1000W/m^2), it is clearly visible that the cells filled with the "Z-946" electrolyte formulation, containing the 3-methoxypropionitrile and 150 mM tri-iodode, showed a failure after ~ 2'000 hours (cell sp01-140110TM and sp03-140610TM), while the 2 ionic liquid filled cells are still working, although with a reduced efficiency of ~ 3 %, corresponding to 75 % of the initial value. The cell sp02-140610TM contained the "Electrolyte B" based on a mixture of 3 ionic liquids (AMII, EMII and EMITCB) and sp04-140610TM contained the "EMITCB" mixture based just on EMII and EMITCB, both ionic liquid cells are still in the light soaking rig for continued stress exposure.

During the first 12 months of the ORION project, a total of 7.73 person-months have been spent:

Workpackage	Planned	Spent	Comment
WP1	2	4.65	Additional TiO_2 electrospun nano fiber based TiO2 paste characterizations as alternate reference material to the "classic" hydrothermally grown anatase nanocrystals. Improve TiO_2 paste vehicle with new formulations as reference materials for later-on scale-up simplification
WP2	2	1.42	Preparation of benchmark solar cell and preliminary aging to qualify a first set of ionic liquids
WP3	6	1.65	Set-up of light soaking test equipments, SEM characterization of TiO_2 nanoparticles
		7.72	

Apart from further characterization of materials and solar cells (WP3), the upcoming works will concentrate on testing ionic liquid polymers, "Generation I" ordered inorganic-organic hybrid materials and alternate sensitizer dyes received from project Partners (WP5).

National and international collaboration

Launch & running of the 3 years "KTI-Project" N° 10584.1 PFIW-IW with the EMPA Dübendorf (Switzerland) on the topic of "Squaraine"-based organic sensitizers.

The partnership with a large Swiss chemicals company is successfully ongoing for the investigation of new materials and the feasibility of large scale manufacturing of monolithic modules using all printed active layers.
The Eureka program E!4413 LCSC with 3GSolar (Israel) is still active in investigating the manufacturing of large area monolithic dye solar cell modules.

FP7-Project "INNOVASOL" – coordinated by Dr. Leo Marchese of the SiSTeMI center at the University of Piedmont, Italy.
INNOVASOL aims to increase the efficiency of exitonic solar cells to 15 % by using innovative approaches in cell designs and novel materials (see www.innovasol.eu)

FP7-Project "SOLAMON" – coordinated by Dr. Nathalie Baclet at the CEA-Grenoble, France.
SOLAMON focuses on improving "3rd generation" thin film solar cells (a-Si and dye sensitized) by employing plasmon generating materials to improve light collection in the active layers (see http://www.solamon.eu/).

FP7-Project "SOLHYDROMICS" - coordinated by Prof. Guido Saracco at the Politecnico Torino, Italy.
This project aims to build a photoelectrochemical water splitting device based on organic (or biological) catalysts for light collection (PSII system) and hydrogen evolution materials without noble metals (see http://solhydromics.org/).

Evaluation of 2010 and perspectives for 2011

During 2010, the forks focused on defining the requirements of new hybrid organic-inorganic materials needed for improving the dye solar cells, a benchmarking of existing ionic liquids in small laboratory cells and the formulation / characterization of our different TiO_2 materials, that we could also provide to the project Partners. In 2011, the first samples from the Partners will be tested in dye solar cells (small size ~ 0.36 cm2) and on out monolithic modules (10 x 10 cm and 30 x 30 cm). Processing aspects of the active layers will also be examined, such as the possibility to print the electrolyte prior sealing of the solar module.

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http://www.cidetec.es/ORION/index.html

Schweizerische Eidgenossenschaft
Confédération suisse
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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

ODELING, SI ULATION AND LOSS ANAL SIS OF D E-SENSITI ED SOLAR CELLS

Annual Report 2010

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ABSTRACT

Dye-sensitized solar cells (DSCs) are an innovative technology for the production of electricity from solar energy, which was invented in Switzerland. In DSCs the sun light is harvested by a dye, adsorbed on a highly porous structure of titanium-dioxide nano-particles. A thorough understanding of the optical and electrical processes taking place in dye-sensitized solar cells (DSCs) is crucial for the development of highly efficient and stable devices. The goal of this project is to develop validated models for DSCs. Modeling of the coupled optical, electrical and electrochemical processes in the DSC allows us to analyze quantitatively the different loss mechanisms of the energy conversion in the solar cell.

In the present project we developed an experimentally validated coupled optical and electrical model for the dye-sensitized solar cell. The DSC model has been implemented into a simulation software equipped with a graphical user interface (GUI). The software allows to simulate the steady-state performance of DSCs and various time-dependent measurement techniques (e.g. impedance spectroscopy, photovoltage and photocurrent decays). The different loss channels in the energy conversion process within the DSC can be quantified.

By comparing quantum efficiency and time-dependent measurements to simulations from the software, the transport and recombination properties of the charge carriers inside the DSC was studied. The essential model parameters (diffusion length, recombination rate and trapping parameters) were extracted.

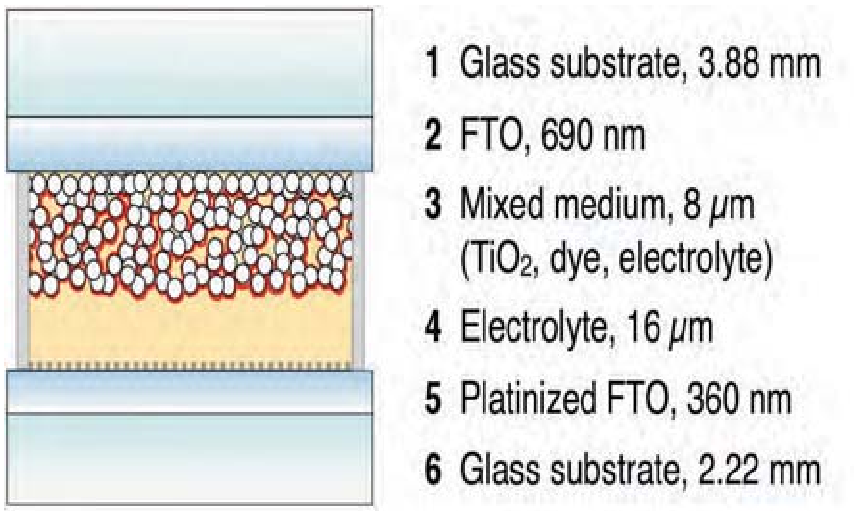
Introduction / Project Goals

Dye-sensitized solar cells (DSCs) can convert solar radiation into electricity efficiently and cost-effectively by means of a light-harvesting sensitizer anchored to a high surface area mesoporous semiconductor film [1]. Record efficiencies of over 11% have been achieved with ruthenium-complex sensitizers on laboratory-scale devices [2], but progress in efficiency enhancement has been slow in the past years. Materials screening and device optimization is often addressed with an empirical approach, which could be greatly accelerated with an accurate simulation of the optical and electric processes in the device [3,4].

The goal of the present project is to develop validated models for the DSC. These models aim at providing a mathematical description of the coupled optical, electric, and electrochemical processes taking place within the DSC. This allows to analyze quantitatively the different loss channels of the energy conversion process within the DSC. Research and development of this type of solar cells can be accelerated to a large extent, if these new models are implemented into accurate and efficient numerical algorithms. It is a goal of this project to make the numerical algorithms accessible through a user-friendly software (graphical user interface) for research at academic laboratories and for DSC manufacturing companies. The software should be applicable for the interpretation of measurement data and for the optimization of different DSC parameters.

Short description of the project

Accurate modeling of DSCs should lead to a better understanding of the physical and electrochemical processes responsible for the energy conversion in DSCs and to new approaches for their optimization. With a user-friendly simulation software available, these new approaches could be investigated in a cost-effective way and on a shorter timescale. Academic laboratories as well as possible DSC manufacturers could largely benefit from such a software.



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The device structure of a DSC is schematically shown in Figure 1. The DSC uses a photoactive sensitizer (dye) attached to a thin nanoporous TiO_2 film (< 12 μm) to harvest the sunlight. The photoexcited dye injects an electron into the TiO_2 conduction band and is rapidly regenerated by a mediator redox couple in the electrolyte, which permeates the pores. The injected electron diffuses through the TiO_2 network to a transparent conducting electrode (fluorine-doped tin oxide, FTO) and migrates through an external electric circuit to the counter electrode, where it regenerates the oxidized mediator.

In the present project we develop a comprehensive and experimentally validated model of the DSC, which simulates the light in-coupling into the complete device, the charge generation profile in the photoactive layer, and subsequent transport of charges in the semiconductor film and recombination at its interface. The optical model accounts for multiple reflections at interfaces and absorbance in the layers of the device using coherent and incoherent optics. In this way, the light intensity, the absorbance, and the charge generation profile in the photoactive layer are computed accurately. The charge generation function then serves as a source term in the continuity equation for free charge carriers, thus coupling the optical with the electrical model. Using the coupled optical and electrical model, the steady-state behavior of the DSC (current-voltage curve, spectral response) can be simulated. The model is validated by comparison of simulation results to experimental data.

Results and Discussion 2010

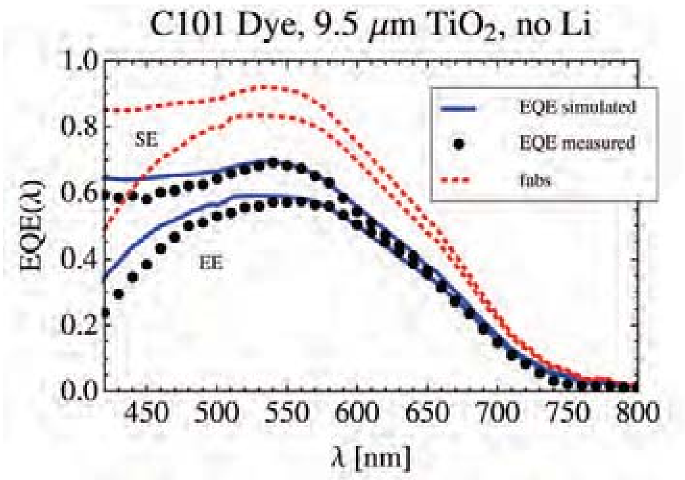
Simulation soft are PECSI

We implemented the developed DSC model into a simulation software called PECSIM (PEC-SIM=photoelectrochemical cell simulator). PECSIM is written in Mathematica and is equipped with a graphical user interface (GUI). The GUI makes the software easy to use, such that the user can immediately benefit from it. Currently, four simulation modes are implemented:

1. Steady-state analysis
2. Electrochemical impedance spectroscopy (EIS)
3. Transient photovoltage and photocurrent decay
4. Quantitative loss analysis

Stead -state behavior

Two important electrical parameters characterizing the steady-state performance of the DSC are the electron injection efficiency, which describes how effectively the excited dye molecules insert electrons into the nanoporous TiO_2 layer, and the electron diffusion length, which characterizes the charge transport properties inside the semiconductor. By measuring the short-circuit current density and external quantum efficiencyy for illumination from either the substrate electrode (SE) side or the electrolyte electrode (EE) side and comparing these measurements to simulations, the influence of these two parameters can be disentangled and they can be determined [5,6]. Performing this analysis for different types of DSCs (i.e. with different dyes, electrolytes with varying additives) supports the optimization of DSCs. An example of such an analysis is shown in Figure 2.



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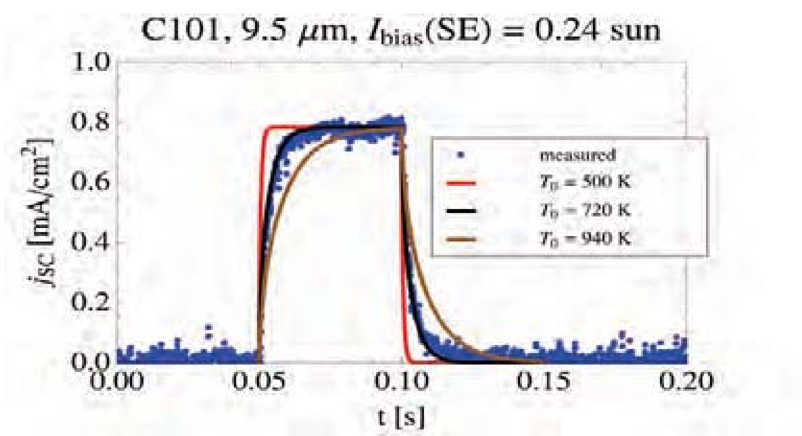
E traction of model parameters

Analyzing the steady-state of the DSC is not sufficient in order to understand the different physical and electrochemical processes within the cell. Therefore, various time-dependent experimental techniques, such as electrochemical impedance spectroscopy and small perturbation photovoltage and photocurrent decay experiments are crucial diagnostic tools. With these measurement techniques, the linear response of the DSC on a small time-dependent perturbation is examined. For instance, in small perturbation photovoltage/photocurrent decay experiments, the DSC is put in



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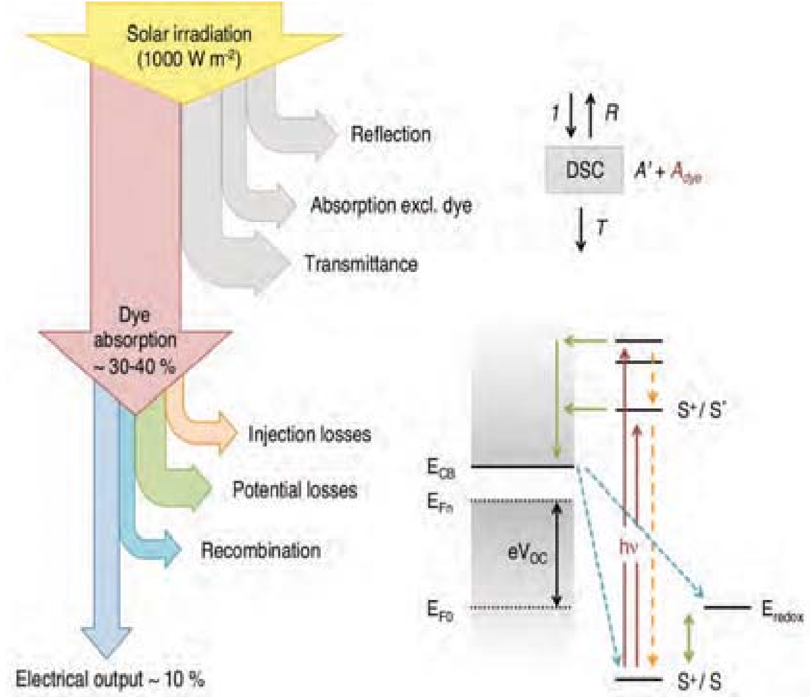
its steady-state by illuminating the cell with white bias light. Subsequently, the DSC is perturbed by a short (50 ms) red light pulse of small intensity. The response of the solar cell in voltage and current output is measured.

The developed simulation software PECSIM allows to simulate this measurement technique. Then, by comparing experimental data to simulated data, the influence of the different model parameters on the response can be disentangled. Model parameters like the electron lifetime, the total density of states for trapped electrons etc. are determined in this way [7,8]. Figure 3 shows exemplary a measured and simulated small perturbation photocurrent decay.

uantitative Loss Anal sis

In order to optimize dye-sensitized solar cells it is important to minimize the different loss channels of the solar to electric power conversion. We developed a simulation mode to accurately quantify the different optical and electric losses and implemented it into the software. Optical losses are reflection, absorption in layers other than the active layer and the transmittance through through the whole cell. Electric losses are e.g. caused by recombination of electrons with electrolyte species. The different loss channels are schematically depicted in Figure 4.



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National Collaboration

This project is a collaboration of the *nstitut utati na P sics P* at the ZHAW and the *a at i P t ni u t nt ac s P* at EPFL. Since the first demonstration of a laboratory DSC by B. O'Regan and M. Grätzel at EPFL in 1991 [1], the LPI has acquired a long standing experience in experimental research on DSCs [2]. On the other hand, the ICP has a broad know-how in modeling complex multi-physics devices, such as fuel cells, organic light-emitting diodes and organic solar cells. The project is funded by the *R R* .

Evaluation 2010 and Outlook 2011

In the reporting year, the present project was completed. The aimed work packages and milestones of the project were completed. The results of the project were presented at EU PVSEC conference 2009 [5] and at HOPV conference 2010 [7] and will be published in peer-reviewed journals [6,8].

The project allowed the ICP to extend its experience of simulating solar cells to dye-sensitized solar cells and to broaden the know-how in the simulation of optical and electrochemical processes within these devices. The ICP currently evaluates the acquisition of several follow-up projects. The objectives of these projects will be to improve the DSC simulation software . The DSC model should be extended and refined, in order to incorporate e.g. lateral losses, which is important for the loss analysis for DSC modules. Furthermore, it is planned to enhance the contained material library (dyes, electrolytes etc.), such that more types of DSCs with varying material combinations can be simulated.

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ETA SOLAR CELL

E TRE EL THIN ABSORBER SOLAR CELL BASED ON ELECTRODEPOSITED NO NANOSTRUCTURES

Annual Report 2010

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Date	01.12.2010

ABSTRACT

In the last few years, the idea for making solar cells based on nanostructured materials has been attracted a lot of attention, especially Dye-Sensitized Solar Cells (DSSC) which is the most well-know nanostructured solar cell discovered in 1991 [1]. DSSC is a sort of photoelectrochemical device, in which the solar light is absorbed by a monolayer of dye molecules that are adsorbed on the surface of a wide bandgap semiconductor. Subsequently electrons are transferred from the excited state of dye into the conduction band of the pourous semiconductor and the dye molecules are regenerated by a redox couple. Solar energy conversion efficiency of 11 % has been obtained at the laboratory level. Even though, the DSSC has good prospective development, but for the commercial application, the long-term stability of the dye and the electrolyte evaporation still has to be solved. As the result, an alternative fully solid-state solar cell, based on the same concept has been proposed: Extremely Thin Absorber (ETA) solar cells [2]. This solar cell is generally based on inorganic semiconductors in which an extremely thin film absorber is sandwiched between two transparent and nanostructured inorganic semiconductors. Comparing to DSSC, the dye is replaced by an ultrathin layer of a narrow band gap semiconductor playing the role of a light absorber. ETA-solar cells have been developed for several years, the conversion efficiency in the order of 2-3 % has been achieved but still lower than DSSC, thus, more fundamental studies are necessary to gain a further insight into the present limitations and open some routes to enhance the performance. The aim of the "ETA solar cells" project is to study separately the different materials used for the fabrication of this kind of photovoltaic device in order to improve the solar efficiency. Previously we have shown a new fabrication technique to synthesise electrochemically a highly surface area of ZnO nanostructure used as a n-type semiconductor in ETA devices [3]. This has led to a dramatic improvement of the light scattering. In this report the focus is on the light absorber materials. The electrodeposition of CdSe on ZnO nanowire arrays will performed and its thickness will be optimised. The electrodeposition and the physical properties of CdTe as a new absorber in ETA solar cells will be also presented in this report.

Introduction and project objectives

Among the most widely used inorganic semiconductor sensitizers, CdTe has a high optical absorption coefficient (> 10^4 cm^{-1}) and narrow band gap of ~ 1.5 eV matching the preferred range of the solar radiation spectrum [4]. In addition, it forms a typical type II band alignment with ZnO, allowing effective injection of photogenerated electrons from CdTe into ZnO [5]. Consequently, a ZnO/CdTe core/shell array on a transparent conductive substrate would hold great potential in a number of photoelectrical applications especially in ETA solar cell devices. CdSe has been used previously as a light absorber in ETA solar cells based on ZnO nanostructures. The physical properties of CdSe and CdTe are close to each other. However the band alignment of CdTe matches much better than CdSe with ZnO in a ETA solar cell device (See Figure 1).

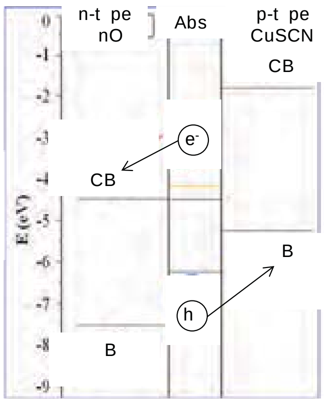

Figure : and diagram of n n / CdSe or CdTe /CuSCN heterostructure C and V are the conduction and valence bands, respectively

Therefore, the ZnO/CdTe/CuSCN heterostructure will enforce much better than ZnO/CdSe/CuSCN the separation of charge carriers. On the other hand the theoretical study of Taretto et al [6] predicts that the use of CdTe in ETA solar cells devices can lead to efficiency up to 15 %.

CdTe can be synthesized by different techniques such as CVD [5], sputtering [7], spray pyrolysis [8], electrodeposition [9], etc. Electrodeposition of CdTe on ZnO nanostructures seems to be the method of choice because it presents many advantages on the others, such as: low temperature and vaccum process, many parameters to control the deposition, no shadow effect, etc. Unfortunately, most of the electrolytes currently used in electrodeposition of CdTe are either acidic solutions (pH 1-3) or basic solutions (pH 10) containing NH_4 both of which can severely etch the ZnO.

Our objectives in this part of project were:

a) Optimization CdSe thickness.

b) Find new electrolyte with close-to-neutral pH to electrodeposit CdTe on ZnO nanostructures and compare with CdSe..

Work and results

Optimi ation of CdSe Thickness

The efficiency of an ETA solar cell will be determined by its absorption of the solar light (photogeneration of charge carriers) as well as its electronic performance (injection and transport of photogenerated charge carriers). In this framework, the influence of CdSe thickness on the optical and electronic performance of ZnO/CdSe is analyzed.

For this study we have used a series of ZnO nanowire (NW) arrays with constant dimensions (diameter ~ 100 nm, length ~ 1.5 µm and density ~ $5x10^9$ NWs/cm^{-2}). For that, ZnO NW arrays were deposited under the same conditions. The electrodeposition of CdSe was performed by using different charge density in the 0.1-0.4 C/cm^2 range to modify the thickness of the CdSe coating. Figure 2 shows the obtained NW arrays of ZnO/CdSe for the lowest and highest charge density values.

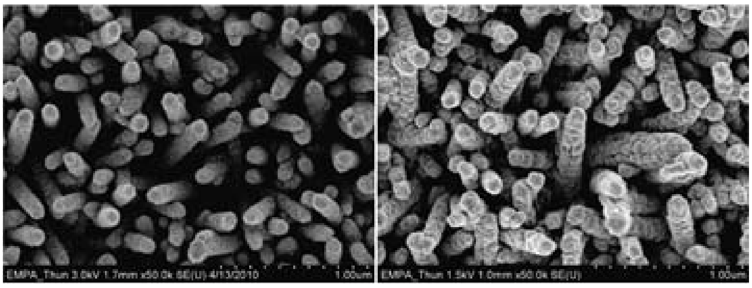

Figure : SE micrographs of the nano ire arrays after CdSe electrodeposition for the a lo est C/cm and b the highest C/cm charge density

The thickness of the CdSe coating, estimated from a statistical evaluation of the NWs diameters before and after CdSe deposition, for the different samples is summarized in Table 1.

Table : Values of charge density, CdSe thic ness and E for n /CdSe arrays

Charge density C/cm	*Thic ness nm*	*E - nm*
0.15	20	76.2
0.2	30	82.7
0.25	40	86
0.3	65	87.4
0.4	110	91.4

As a first step, the influence of the thickness of CdSe coating on the optical absorption of ZnO/CdSe NW arrays is analyzed. Figure 3 displays the absorption spectra in 400-1000 nm wavelength range for the samples from Table 1.

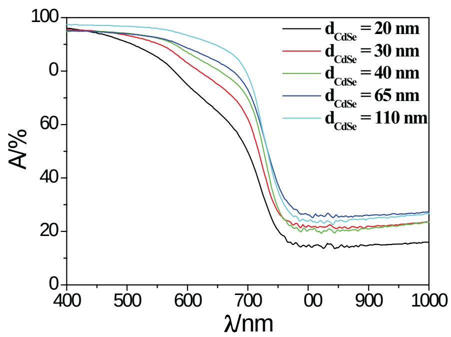

Figure : The absorption spectra of samples ith different CdSe thic ness

Figure 3 shows that there are no significant differences for the absorption in 400-500 nm range. However, for wavelengths between 600 and 725 nm (CdSe exhibits relatively low absorption coefficient), the absorption increases with the thickness of CdSe. This induces important differences in the effective absorption (A_E) in the 400-725 nm (AM1.5) solar spectrum range as shown in Table 1. Absorption of 91.4 % was obtained for the ZnO/CdSe nanowires covered by the thickest CdSe coating (110 nm).

Noting that A_E is determined by this formula: $$A_E = \int_{\lambda 1}^{\lambda 2} A(\lambda) J_0(\lambda) d\lambda \Big/ \int_{\lambda 1}^{\lambda 2} J_0(\lambda) d\lambda \quad \text{(VI.1)}$$

with J_0 the solar photon flux (AM1.5).

To study the influence of CdSe thickness on the electronic performance of ZnO/CdSe/CuSCN ETA-solar cells, a series of solar cells was performed by using ZnO/CdSe nanowire arrays of Table 1 as building blocks. CuSCN was deposited on them to fill their porosity and to obtain a relatively flat CuSCN overlayer that facilitates the deposition of the back electrical contact (Au).

The current-voltage (I-V) characteristics of the ZnO/CdSe/CuSCN solar cells were measured under illumination of half sun (500 W/m^2). The I-V curves, under illumination, of all solar cells of the series are displayed in Figure 4. The parameters of these solar cells are summarized in Table 2.

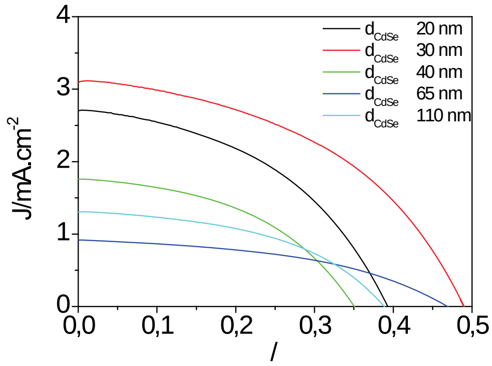

Figure : I-V curves of solar cells ith different CdSe thic ness under illumination /cm

Although the highest absorption is observed in sample of d_{CdSe} = 110 nm (Figure 3), the highest J_{sc} is obtained for solar cell of 30 nm (Figure 4). Figure 5 shows the evolution of J_{sc} and $A_{E400-725}$ as a function of the CdSe thickness. Though the solar cells of 40, 65 and 100 nm absorb more photons from solar light than the solar cell of 30 nm, the amount of charge carriers collected in the latest is the highest. Thus, the best electronic performance occurs for CdSe thickness of 30 nm. This gives an idea about the diffusion length of the photogenerated charge carriers in CdSe. If CdSe thickness is much higher that the diffusion length a considerable portion of electrons and holes are lost by recombination before their injection into ZnO and CuSCN, respectively.

Thic ness nm	*V_{oc} V*	*$_{sc}$ m /cm*	*FF*		*$_E$ - nm*
20	0.4	2.93	0.44	1.02	76.2
30	0.5	3.48	0.43	1.48	82.7
40	0.38	2.1	0.48	0.76	86
65	0.5	1.5	0.42	0.63	87.4
110	0.39	1.3	0.46	0.47	91.4

Table : The open circuit voltage Voc , short circuit current sc , fill factor FF and solar energy conversion of n /CdSe/CuSCN ET solar cells ith different d_{CdSe} The values of effective absorption in the - range of solar flux are also sho n

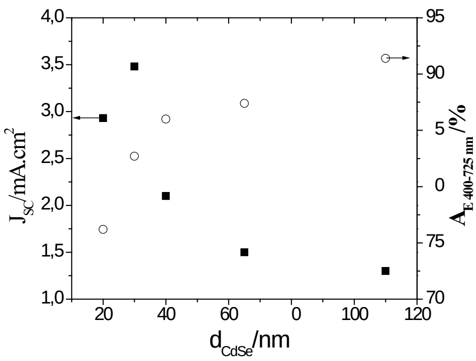

Figure : The short current density $_{sc}$ and effective absorption in - nm range of sun flux as a function of CdSe thic ness d_{CdSe}

With respect to V_{oc}, the best value was also observed for solar cell of d_{CdSe} = 30 nm. Nevertheless, a clear trend with the CdSe thickness is not observed. Further series of solar cells as a function of CdSe thickness were performed to check the reproducibility of the experiments, observing some dispersion in J_{sc}, V_{oc} and η values (most probably due to the poor control of the CuSCN deposition process). However, the evolution as a function of the CdSe thickness was confirmed and the best J_{sc} corresponded to d_{CdSe} values in the 20-30 nm range, suggesting than the diffusion length in CdSe is around 20-30 nm. The best V_{oc} corresponded to d_{CdSe} = 30 nm, suggesting that a minimum CdSe thickness is necessary to avoid the tunnelling recombination (electrons from the conduction band of ZnO to the valence band of CuSCN). This value is slightly higher than that predicted by theoretical studies to avoid the tunnelling in this kind of nanostructured systems (~ 20 nm) [6]. However, it is important to note that the d_{CdSe} values here reported correspond to the mean estimated values and lower CdSe thickness can be locally found in the ZnO/CdSe/CuSCN ETA-solar cells. Thus, we can conclude that the optimal thickness of CdSe coating for the electronic performance of ZnO/CdSe/CuSCN ETA solar cells is around 20-30 nm. This value is slightly lower than that used in the first ZnO/CdSe/CuSCN ETA solar cell (~ 40 nm) [2] and is not enough to harvest solar light efficiently by using ZnO NWs with the actual dimensions (see above). However, the knowledge gained during this part of the project on the optical configuration of the ZnO NW arrays and the influence of the scattering of visible light on their sensitization to solar light will allow us to fabricate ZnO/CdSe/CuSCN solar cells with the optimal d_{CdSe} thickness from the electronic point of view without losing in the solar light harvesting. Thus, this study not only gives some insights into the performance of ZnO/CdSe/CuSCN ETA solar cells, but also opens some practical routes to enhance the present efficiency.

Optimi ation of CdTe electrodeposition on nO NW arra s

CdTe was deposited in a three-electrode electrochemical cell with TCO or TCO/ZnO_{buffer}/ZnO_{NWs} substrates as working electrodes. The electrolyte is an aqueous solution of 0.005 M potassium tellurite (K_2TeO_3), 0.05 M nitrilotriacetic acid trisodium salt (NTA, $C_6H_6NO_6Na_3$) and 0.02 M cadmium acetate ($CdC_4H_6O_4$) and the pH was adjusted to ~8.3 by acetic acid. The solution was kept at room temperature.

To investigate the electrochemical potential of CdTe in the close-to-neutral electrolyte, a cyclic voltammetry test was performed on a bare TCO substrate.

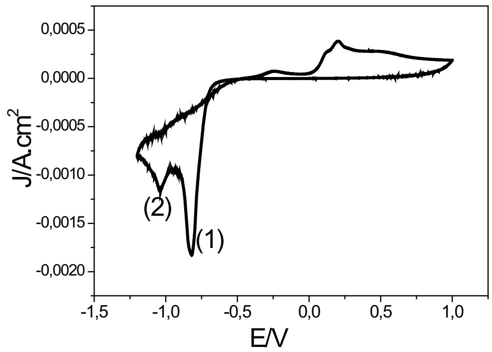

Figure : Cyclic voltammogram of the electrodeposition solution on TC substrate

In the cyclic voltammogram of Figure 6 two cathodic current peaks appeared at -0.8 V (1) and -1.0 V (2), which respectively correspond to the reductions of TeO_3^{2-} to elemental Te and Te to Te^{2-} precipitating with Cd^{2+} generated CdTe, according to the following equations according to [10]:

$TeO_3^{2-} + 3H_2O + 4\ e^- \rightarrow Te^0 + 6OH^-$ Eq.(1)

$Te^0 + Cd^{2+} + 2e^- \rightarrow CdTe$ Eq.(2)

Therefore, for depositing CdTe, the fixed potential of -1.0 V has been provided to promote the one-step reaction of TeO_3^{2-} and Cd^{2+} shown in Equation (3):

$TeO_3^{2-} + Cd^{2+} + 3H_2O + 6e^- \rightarrow CdTe + 6\ OH^-$ Eq.(3)

To check this trend, film has been deposited on TCO substrate at -1 V for a charge density of 0.5 C/cm^2. The atomic stoechiometry as well as the structural properties of this film have been analyzed by Energy-dispersive X-ray spectroscopy (EDX) and X-ray diffraction (XRD), respectively. Base on EDX spectrum (Figure 7a), ~50 % of Cd and ~50 % of Te atoms have been detected, the Cd/Te atomic ratio close to 1 suggests that the electrochemical reactions of TeO_3^{2-} and Cd^{2+} take place in one step as in Equation 3, without the formation of intermediate elemental of Te.

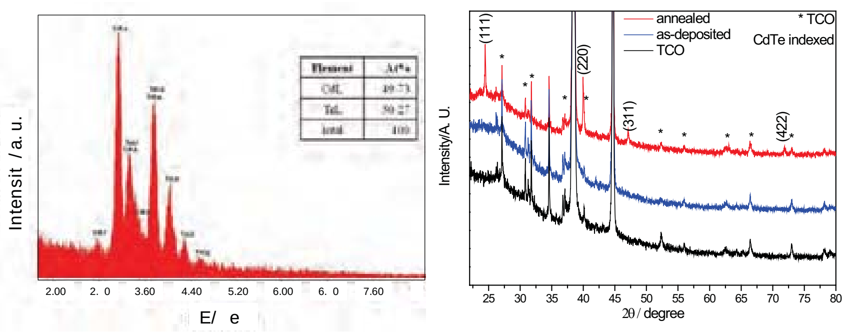

Figure : a ED spectra of CdTe, b D patterns of bare TC , as-deposited CdTe and annealed CdTe in rgon atmosphere at C for h

XRD analyses have been done to study the structural properties of the obtained CdTe deposit. Bare TCO and as-deposited CdTe have been measured and their XRD data are compared and shown in Figure 7b. By comparing the two spectrums (black and blue) no orientation peaks corresponding to the crystallized form of CdTe have been observed. This means that the obtained deposit is amorphous CdTe. Tena-Zaera et al. [11] have demonstrated that the crystallinity of CdSe plays an important role on ETA solar cells performance. In other term they found that annealing the absorber layer can improve dramatically the solar cell efficiency. For these reasons and after optimization we have annealed the as-deposited sample of CdTe in Argon at 350° C for 1 h and the XRD diffractogram is shown in Figure 7b (red curve) and compared to the one without annealing. After analysis four peaks could be found which are indexed to the (111), (220), (311) and (422) planes of the zinc-blende (ZB) CdTe.

SEM plan view images comparing the as-deposited and annealed samples are depicted in Figure 8. From the SEM images we can clearly see an important change of CdTe crystallinity after annealing at 350 °C (Figure 8b). The nanocrystalline layer morphology is altered into a collection of bigger angular grains. This change in the morphology and crystallinity can offer in the ETA solar cell device a direct and faster charge separation because the grain size is increased. Therefore a decrease in the electron-hole recombination can be expected. Additionally, the SEM images in both case show that there are some holes in the CdTe layer which may be due to the hydrogen evolution reaction during the deposition at relatively high negative potential (- 1 V).

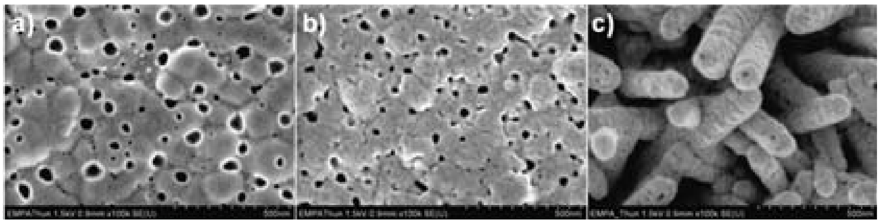

Figure : SE images of as-deposited a and annealed CdTe in r atmosphere at C for h on TC substrate b and on n N arrays c

In order to compare the absorption ability of CdTe, the same thickness (~20 nm) of CdTe (Figure 8c) and CdSe layers have been deposited on ZnO NW arrays and then annealed. Interestingly CdTe have been deposited uniformaly on ZnO NWs without any etching of ZnO (Figure 8c). The optical properties of these two core/shell NW arrays are measured and the results are shown in Figure 9.

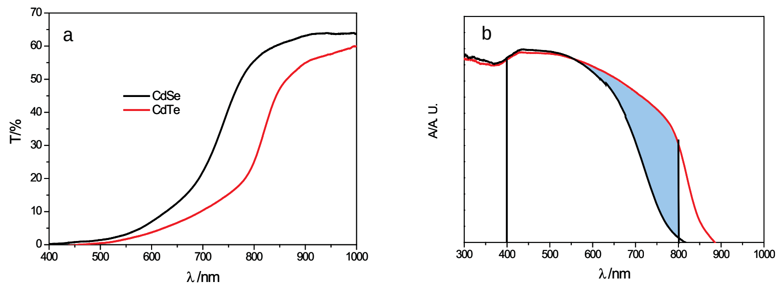

Figure : a Transmission and b bsorption spectra of TC / n buffer/ n N s/CdSe and TC / n buffer/ n N s/CdTe arrays

From the transmission curves (Figure 9a), we can see clearly the different energy band gaps that are indicated by the absorption edges which correspond to 1.72 eV (720 nm) and 1.49 eV (830 nm) for CdSe and CdTe, respectively. Due to the different position of energy band gap, CdTe shows ~20% (indicated by the filled blue area in Figure 9b) higher light absorption than CdSe in the visible range (400~800 nm) which gives an expectation for a better performance in solar cells.

Evaluation of 2010 and perspectives for 2011

Between the beginning of the project in the end of 2009 and the first period of 2010 our works were focused on the control of dimensions, morphologies and organisation of ZnO nanostructures used as n-type semiconductor (electrons collector) and building-block for ETA solar cells with the aim to tailor the light diffusion and increase the roughness factor. During 2010 the focus in our project was on the light absorber part of the cells. We have optimized the thickness of CdSe in order to have the highest efficiency in ETA solar cells devices. Although this kind of solar cells present good stability with time comparing to other devices based on a similar concept (e.g. DSSC), the efficiency obtained with CdSe still relatively low to make ETA solar cells competitive in the market. Among the many possibilities we have to improve the conversion efficiency (e.g. increase of ZnO surface area, control the light diffusion, improve the doping of CuSCN, etc.) the use of CdTe as a new light absorber seems to be a good option because it presents many advantages on CdSe (see comparison above). The challenge was to find a solution with close to neutral pH in order to deposit CdSe on ZnO NWs without any etch of ZnO materials. During the year we have reached this goal and succeeded to deposit uniformly CdTe thin layers on ZnO nanostructures. Moreover CdTe with good crystallinity has been obtained after annealing. More interestingly the comparison between the light absorption of ZnO/CdTe and ZnO/CdSe nanostructures had shown an improvement of 20 % in the case of CdTe.

According to the Work package defined in the project in 2009 the main perspectives in 2011 will be:

1. Complete the fabrication of ETA solar cells based on CdTe and compare to the ones based on CdSe.
2. Study the effect of morphology and dimension of ZnO nanostructures on ETA solar cells performance.
3. Improving the hole mobility in CuSCN p-type semiconductor by playing on the chemistry of the synthesis solution

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DE ELOP ENT OF EFFICIENT LU INESCENT CONCENTRATORS BASED ON INORGANIC/ORGANIC NANO ATERIALS FOR APPLICATIONS IN SOLAR ENERG CON ERSION

Annual Report 2010

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Project- / Contract Number	KTI 9231.2
Duration of the Project (from – to)	01.05.2008 – 31.08.2010 (extended until 31.12.2010)
Date	06.12.2010

ABSTRACT

The supramolecular organization of dye molecules in the linear channels of zeolite L (ZL) is used as a basis to develop materials for luminescent solar concentrators (LSCs). Efficient Förster resonance energy transfer (FRET) between light absorbing and emitting dyes allows us to spectrally separate absorption and emission processes, thereby reducing self-absorption to a minimum (ZeoFret® materials). Our work in 2010 focused on achieving a high ratio between light absorbing (donor) and emitting (acceptor) dyes without compromising the FRET efficiency. In parallel, we have improved our preparation methods (dye inclusion, ZeoFret®/polymer thin film casting) and initiated experiments for scaling up from lab-sized batches to industrial scale.

Optical Additives GmbH is currently acquiring industrial customers for prototyping applications with ZeoFret®. The field of applications is large and covers battery operated mobile and wireless devices, such as mobile phones, watches, computer mice and keyboards. Construction, buildings, and transportation are other fields where ZeoFret® based LSCs offer an attractive alternative to current solutions by providing selectable colors and shapes for light energy conversion systems.

Introduction / Project Goals

The basic idea behind luminescent solar concentrators (LSCs) is to concentrate light with an inexpensive polymer-based device onto efficient photovoltaic cells and thus reduce the price of solar electricity [1]. Light incident onto the face of the LSC plate is absorbed by luminescent species dispersed within the plate. A large part of the subsequently emitted photons is trapped in the plate by total internal reflection and guided toward the edges. Self-absorption is the key problem that has to be solved in order to develop commercially viable LSC products. Dyes with high luminescence quantum yields typically feature a spectral overlap between absorption and emission. A fraction of the photons is therefore emitted in a spectral range where the LSC plate has a low transmittance, leading to considerable losses [2]. Our primary goal is the development of a LSC with spectrally separated absorption and emission, thus solving the self-absorption problem.

General Concept

Our concept of an advanced LSC with reduced self-absorption is based on dye-zeolite inclusion compounds [3,4]. We have termed these materials ZeoFret® (containing "Zeo" from *it* and "Fret" from *st s nanc n t ans*). Due to its structural properties, zeolite L (ZL) is an ideal host to produce such materials [4]. ZL is a crystalline aluminosilicate and therefore highly biocompatible and inexpensive. The cylindrical crystals of ZL contain a large number of linear channels (approx. 67'000 for a crystal with a diameter of 500 nm). These channels are filled with a large number of donor molecules, which absorb the incident light and subsequently transport the electronic excitation energy to a comparatively small number of acceptor dyes by means of FRET (Fig. 1). As the donor molecules are not able to absorb the acceptor luminescence, photons emitted by the acceptor molecules can travel through the LSC with low self-absorption losses.

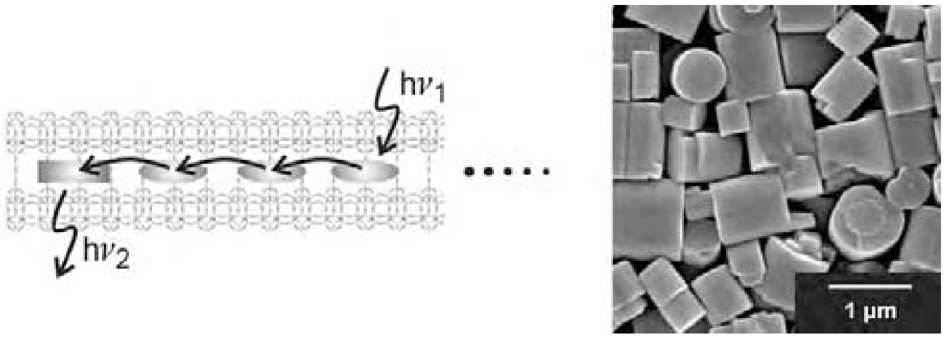

Figure eft: F ET in a small section of a dye-filled nanochannel Donor dyes ovals absorb the incident light and transfer the energy to an acceptor dye rectangle The emitted light cannot be absorbed by the donor dyes Self-absorption by the acceptor dyes is ept to a minimum by lo acceptor concentrations ight: Scanning electron microscopy image of The entrances of the linear channels are located at the base surfaces of the cylindrical crystals

We have developed methods to disperse the dye-filled ZL crystals in index-matching polymers and produce thin film LSCs with good optical quality. There is a variety of dyes that can be introduced into ZL, leading to intriguing possibilities in terms of color tuning. Dyes do not necessarily need to be compatible with the employed polymer, as the process of dispersing the dye-filled ZL crystals in the polymer is independent of the type of dye.

Results

Apart from an efficient FRET between donor and acceptor dyes, the donor-to-acceptor ratio (d/a) needs to be high to reduce self-absorption. Our sample reported in the Annual Report 2009 (Fig. 2, left) featured a d/a of 33 and a still rather intense donor emission. Luminescence of the donor is undesired due to strong self-absorption. We have considerably improved this system in the first half of 2010 by increasing the d/a to 52, as well as by optimizing the light-harvesting and FRET efficiency (Fig. 2, right). We can estimate that one channel of ZL now contains 150 donor dyes and on average 1.5 acceptor dyes at each channel end [5]. This is an important proof for the feasibility of the high donor-to-acceptor ratios required for the reduction of self-absorption.

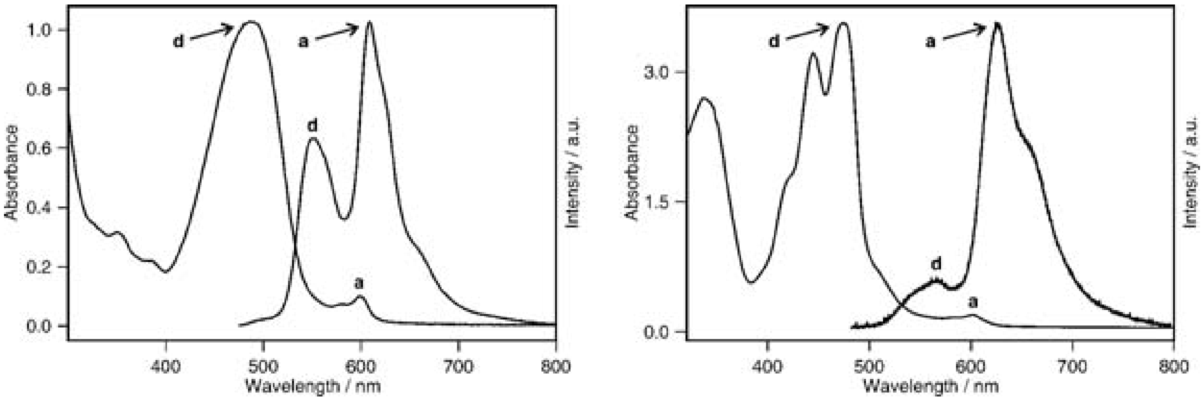

Figure eft: bsorption and emission spectrum of a eoFret SC ith a d/a of The emission as measured upon selective excitation of the donor at nm ight: bsorption and emission spectrum of a eoFret SC ith a d/a of Note the increased absorbance of the donor d relative to the acceptor a Excitation as performed at nm

The high d/a system shown in Fig. 2 can be further optimized by improving the light-harvesting efficiency. This can be achieved by adding a second type of donor dye. While this has been already accomplished for the short-wavelength range (below 400 nm), we are currently working on extending the absorption further into the red. This requires an acceptor dye with red-shifted absorption and emission compared to the system shown in Fig. 2. We expect that increased FRET efficiency will be obtained by collinear alignment of the electronic transition dipole moments of the donor and acceptor dyes. As the size of a dye determines its orientation in the ZL channels [6], we already have the know-how for producing such an alignment.

In addition to the optimization of the optical efficiency of the ZeoFret® LSCs, we have been improving our methods of device preparation. The desired absorbance of the LSCs can already be achieved with ZeoFret®/polymer composite films that are no more than 20 µm thick. The ZeoFret® content of the films is less than 10 g/m². The material can be coated in a single casting step onto various substrates, including glass and PMMA (Fig. 3). We have also developed a triple-layer technique that increases the optical quality and the adhesion of the films. The attachment of solar cells to the ZeoFret® LSCs has been studied based on our experience with conventional thin film LSCs [2].

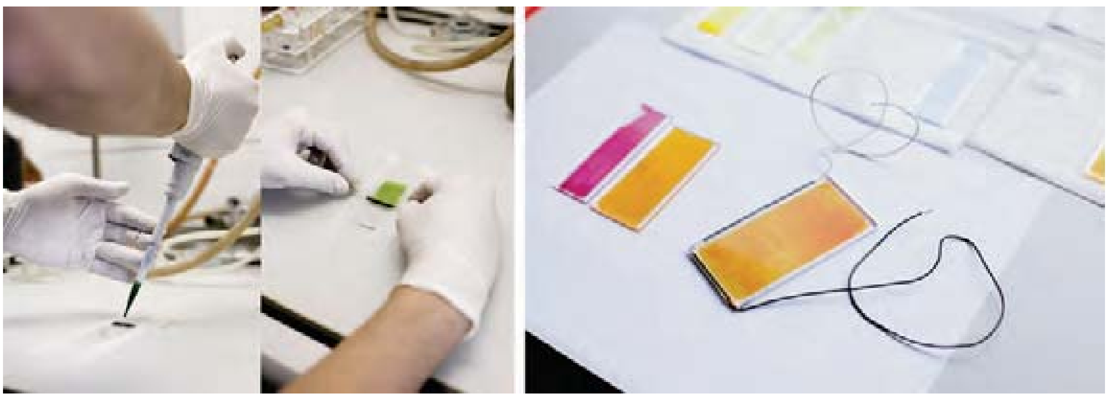

Figure eft: pplying a eoFret coating is straightfor ard: mixture of eoFret , polymer P , and solvent is cast onto a glass plate ight: Test device eoFret /P film on a P substrate ith solar cells attached on t o edges The remaining edges are mirrored

The availability of high quality ZL crystals (purity, morphology, size distribution) was identified as a key requirement. We have excellent synthesis procedures to produce lab-scale quantities [8]. Based on these procedures, we have started scale-up to multi-kg batches. Experiments to introduce ZL into polymeric materials on an industrial scale have been initiated and are ongoing.

Collaborations

This project is a collaboration between the research group of Dr. Dominik Brühwiler (University of Zurich), Prof. Dr. Gion Calzaferri (University of Berne), and Dr. Andreas Kunzmann (Optical Additives GmbH, http://www.optical-additives.com). The project staff at the University of Zurich includes two postdoctoral researchers (Dr. Thomas Dienel and Dr. Igor Dolamic).

Evaluation 2010 and Outlook

Having a d/a value larger than 50 and efficient FRET is a key achievement of 2010 and allows us to reduce self-absorption while maintaining a good light-harvesting efficiency. Further work needs to focus on shifting the luminescence wavelength of the acceptor to the red, ideally to the near-infrared, without compromising the quantum yield. This will require a particular effort in terms of dye screening and possibly also dye synthesis. Concerning the preparation of specifically adapted dyes, collaborations with national and international [9] research groups (academic, specializing in organic synthesis) have been started.

We are now capable of preparing integrated systems with good optical quality and with stable attachment of solar cells. This forms the basis for a systematic investigation of the overall efficiency of the ZeoFret® LSCs. Work toward industrial applications of ZeoFret® materials has been started. End consumer applications are intended to be prototyped. Semi-finished ZeoFret® containing products such as foils, glues, and plates, will be developed together with industrial partners.

Optical Additives GmbH has been awarded several prizes at venture and equity fairs. A well-received article on Optical Additives GmbH and on the concept of ZeoFret® LSCs was published in "NZZ am Sonntag" on November 21, 2010.

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INNO ASOL

INNOVATIVE MATERIALS FOR FUTURE GENERATION EXCITONIC SOLAR CELLS

Annual Report 2010

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Project- / Contract Number	FP7-ENERGY-NMP-2008-1-227057
Duration of the Project (from – to)	1.04.09 – 31.03.12
Date	21 February 2011

ABSTRACT

The main objective is to leapfrog current limitations of third-generation PV devices through a drastic improvement of the materials used for assembling XSCs.
The first step is the substitution of the liquid electrolytes, currently used in dye sensitized solar cells, with solid-state hole conductors. In parallel, semiconductor quantum dots (QDs) with tuned band gap, designed to enhance the photon capture efficiency, will replace the organic dyes as light absorbers.

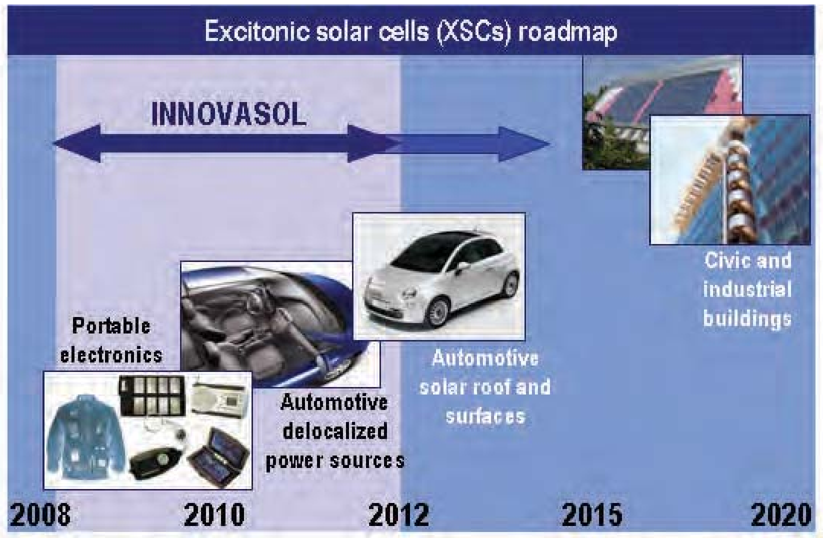
A striking improvement is expected from multi exciton generation (MEG) effects, overcoming the Shockley-Queisser efficiency limit of 31% for the PV conversion. In a second step, highly innovative QDs with supramolecular hierarchical nanostructure will be designed and synthesized: the QDs will be covered by self-assembled monolayers of amphiphilic dye molecules, mimicking the photosynthetic antenna system. The dye molecules will act as molecular relays (MRs), which connect the QDs to the transparent conductive oxide (TCO). Novel TCO architectures will be developed for efficient interface energy transfer and electron diffusion.

Six academic institutions guarantee an interdisciplinary research, based on top level theoretical and experimental approaches.
The high degree of knowledge of solid-state physics and chemistry, nanoscience and nanotechnology of the researchers assures that the new concepts and the objectives proposed will be successfully developed/pursued.

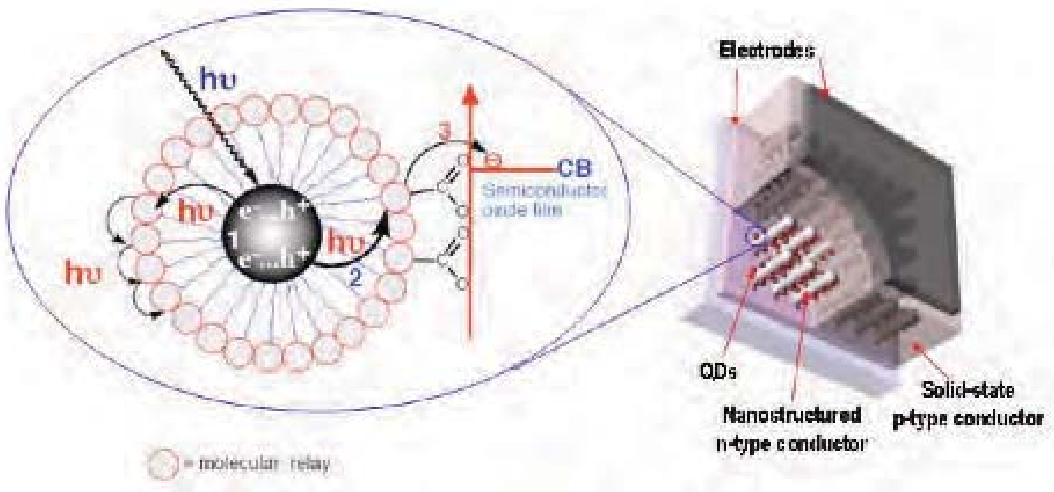
Fiat research center and Solaronix, a SME leader in the XSCs production, will provide proof-of-concept prototypes to validate the innovative materials developed by the academic partners. Materials and technological solutions of INNOVASOL are original and will pave the way for future generation XSCs alternative to devices so far developed both inside and outside Europe.

Introduction and project objectives

INNOVASOL aims to develop radically new nanostructured materials for photovoltaic (PV) excitonic solar cells (XSCs) really competitive with traditional energy sources.



INNOVASOL fulfills entirely the S&T objectives related to the topics addressed by the call “Novel materials for energy applications” in that it focuses on basic innovative material research approaches, which will involve the following tasks and milestones: i) use of semiconductor quantum dots (QDs) as the light harvesting units, with a fine tuning of the optical cross section and of the band gap (by modifying both the chemical composition, e.g. PbS, PbSe, etc…, and the size of the nanoparticles);
ii) synthesis of suitable amphiphilic dye molecules (e.g. cyanines, squaraine dyes, zinc phthalocyanine and dipolar Stilbene–like dyes), designed to act as molecular relays (MRs) that connect the QDs to electron conductor materials (Figure 2);
iii) development of novel solid-state electrolytes (and quasi-solid electrolytes) as p-type hole conductors, such as layered (Figure 3) or porous materials suitable to host anionic redox couples (e.g. I-/I3-); iv) development of specifically designed n-type semiconductor, e.g. the mesoscopic oxide film or the transparent conductive oxides (TCO), such as ZnO nanorods or TiO_2 nanofibers and nanotubes (Figure 6), with architecture, morphology and surface structure suitable to maximize the efficiency of the charge transfer processes at the QD/MR/SC interface and electron transport in the nanocrystalline TCO films.



Innovative materials and device architectures will be characterized by low production cost, high stability to UV and high light harvesting efficiency.
A possible architecture of INNOVASOL device; The inset displays a schematic model showing the supramolecular entity (QD covered by molecular relays, MRs) that are adsorbed via anchoring groups on a mesoscopic TCO film serving as electron collector.

1. Photon capture and generation of multiple excitons by light excitation of quantum dots (quantum yield >100%);
2. Energy transfer to a surface adsorbed MR;
3. Electron injection from excited MR into conduction band of the TCO film.

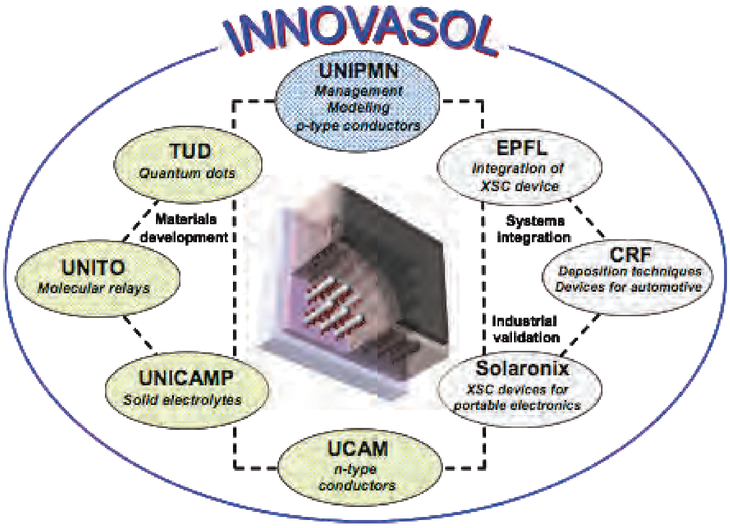
QDs have already demonstrated to be very efficient in the photon capture, with optical cross sections which can be far greater than the molecular dyes currently used in dye-sensitized solar cells (DSCs). A revolutionary improvement can be achieved by multiple exciton generation (MEG) processes, where more than one exciton is generated by a single high energy photon, leading to quantum efficiency larger than 100%. Such processes have been observed in colloidal silicon QDs, and in small band-gap IV-VI semiconductors like PbS and PbSe. INNOVASOL will explore this radically new approach to increase the XSC performance, by designing, producing and testing suitable QDs and QD/MR composites.

Project partners   role of Solaroni

INNOVASOL consortium is formed of five partners of three EU Member States (Italy, Germany and United Kingdom), two partners of an Associated Country (Switzerland) and one partner of a Third Country of Emerging Economy (Brazil).
Six internationally recognized academic institutions, a large company and an SME, namely

- Nano-SISTEMI Interdisciplinary Centre, Università del Piemonte Orientale, Italy (UNIPMN)
- Centre of Excellence Nanostructured Interfaces and Surfaces Università di Torino, Italy (UNITO)
- Centro di Ricerche Fiat, Torino, Italy (CRF)
- Physical Chemistry/ Electrochemistry, Technische Universität Dresden, Germany (TUD),
- Nanoscience Centre, University of Cambridge,U.K. (UCAM),
- Solaronix SA, Aubonne, Switzerland (SOLARONIX),
- Laboratory for Photonics and Interfaces, Ecole Polytechnique Federale de Lausanne (EPFL),
- Instituto de Química, Universidade Estadual de Campinas, Brasil (UNIPMN),

which are leading groups in different areas of solid-state physics and chemistry, nanoscience and nanotechnology, are joined together for the development of radically new materials, nanomaterials and architectures for future generation multi-exciton solar cells applications. The experience of the academic researchers in the design, modeling and synthesis of inorganic, organic and hybrids nanostructured materials, and in their characterization both with experimental and computational tools, is expected to guarantee a substantial breakthrough of knowledge based on nanotechnologies to be disseminated upon com-

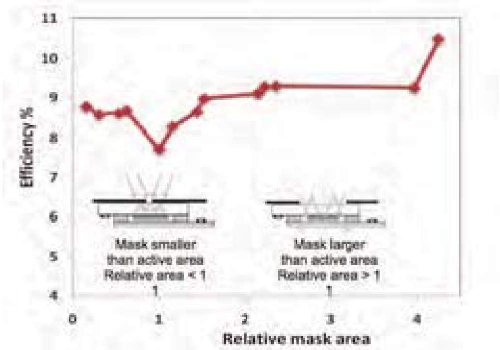


pletion of the project. The research is oriented to go beyond conventional approaches and the materials and concepts developed will pave the way for long term innovation.

Work performed and results obtained

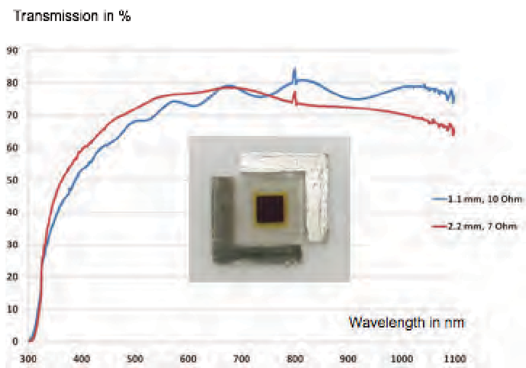
During 2010, most of the works focused on testing new materials provided by the project Partners.

To validate our spot-cells, the influence of the mask has been investigated:



The relative size of the light blocking mask is crucial for consistent efficiency measurements with small solar cells. To avoid large errors, the mask is always 1 mm wider than the TiO_2 active area, resulting in a relative mask area of a factor of 2.

The choice of the conductive glass was also critical for performance improvements, thus switching from FTO22-7 (a 7 ohm/sq 2.2 mm float glass) to Asahi U (a 1 mm thick 10 ohm/sq FTO glass) gave nearly 10 % relative increase in output



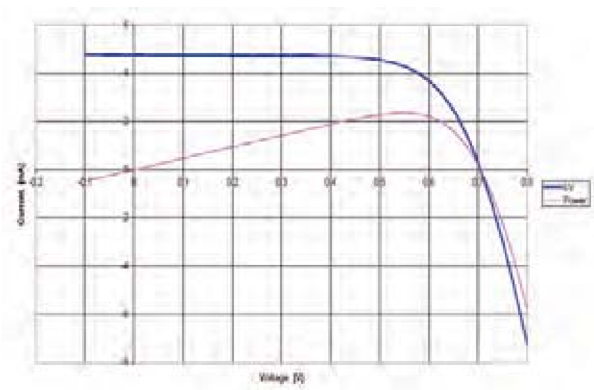
	J (mA/cm^2)	Voc (V)	FF	η
TEC 2.2 mm / 7 Ohm	16.7	0.70	0.68	8.0%
Asahi U 1.1 mm / 10 Ohm	19.7	0.70	0.65	8.9%

The best test cell gave 9.4 % using all the available improvements, while keeping the process compatible with industrial manufacturing.

Working electrode: Asahi U 1.1 mm 10 Ohm/sq
$TiCl_4$ treatment
3 Layers of SX Titania T/SP
1 Layer of SX Titania R/SP

Counter electrode: TEC 2.2 mm 7 Ohm/sq
2 Layers of SX Platisol

Dye: SX Ruthenizer 535-bisTBA (N719)



	J (mA/cm^2)	Voc (V)	FF	η
State of the art cell	19.0	0.70	0.70	9.4%

During 2 specially organized workshops / internships at Solaronix particularly, many electrolyte additives were investigated in small spot-cells.

The typical suspensions were prepared by dispersing 5% wt of each material in a 3-methoxypropionitrile based electrolyte (coded Z-946).
Solaronix SA was responsible for the cell architecture and assembly, dyes adsorption and J-V measurement. The cell architecture was kept simple and not designed for high efficiency. It consisted in a 12 microns thick transparent titania layer on a TEC 8 glass. The suspension electrolytes were injected into the cell through a hole in the platinized counter electrode. The cells were sealed using 25 or 60 microns thick hot melt gasket to prevent any mass transport limitation on the performances. Each working electrode was dipped over night in a N719 dye solution. J-V measurements were performed on 5 five cells after one night of light soaking at 50°C to allow the cells to achieve their final performances.

Different families of materials were investigated:

Talc families

	Voc (V)	FF	J (mA/cm^2)	Eff (%)	Relative Eff. (%)
Reference	0,727	0,65	13,75	6,51	100
TA0010	0,724	0,69	13,55	6,71	103
TA0012	0,735	0,65	14,04	6,74	104
TA0016	0,726	0,68	13,9	6,87	106
TA0017	0,724	0,67	14,45	6,97	107

	Voc (V)	FF	J (mA/cm^2)	Eff (%)	Relative Eff. (%)
Reference	0,727	0,65	13,75	6,51	100
RB220101	0,814	0,72	10,57	6,14	94
RB0710311	0,782	0,69	12,73	6,88	106

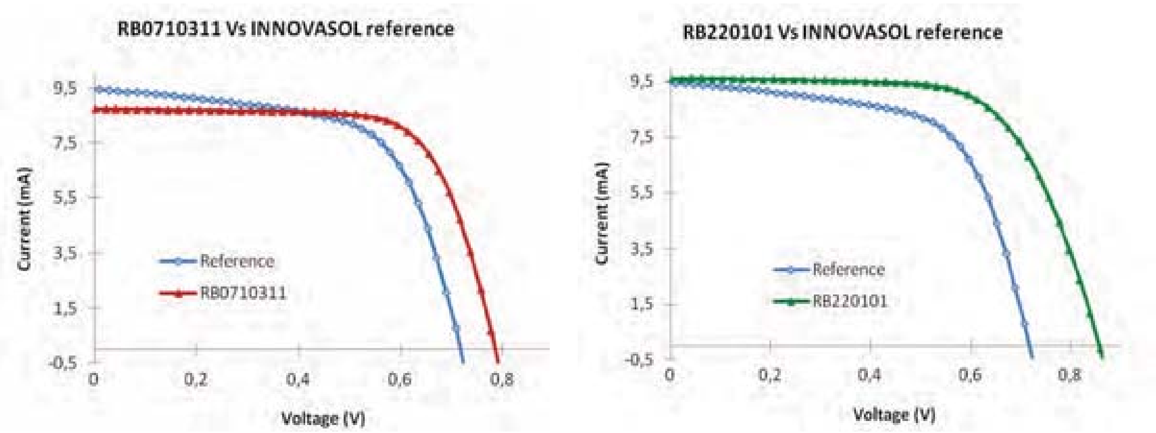


Figure 9: J-V measurements on RB0710311 and RB220101.

As seen on the curves and the table above, the organo modified talcs are interesting materials able to increase the open circuit voltage of the cell.

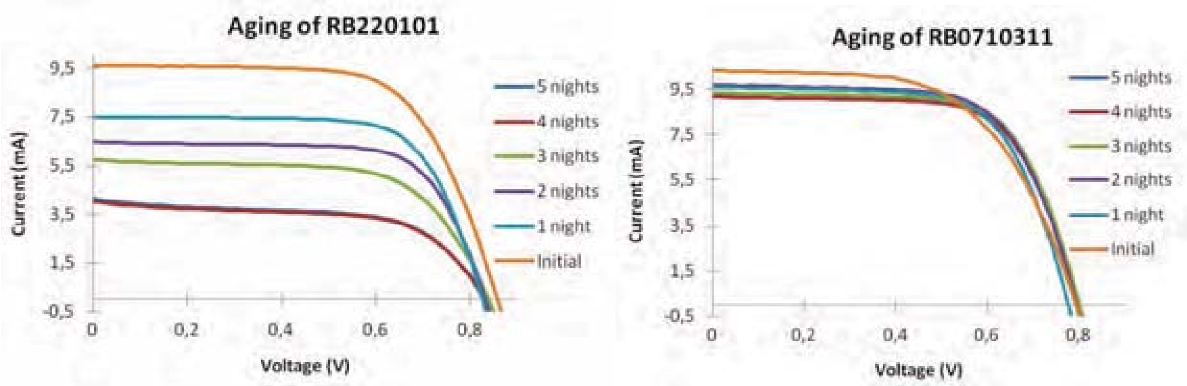


Figure 10: J-V measurements, after various nights under light soaking conditions, on RB0710311 and RB220101.

To further investigate these materials, light soaking conditions at 50°C were applied during various nights. RB0710311 showed a quick increase and stabilization of the performances whereas RB220101 was shown to be unstable.

Saponite families

Saponites having different particle sizes have been tested. As a general trend, the open circuit voltage and the fill factor of the test cells were similar to the one of the reference cell. The current densities were slightly higher. The results respected to the reference cell are presented in the table below.

	Relative Eff. (%)
Reference	100
Na Sap20	101
Na Sap50	103
PDDA Sap50	103
Na Sap110	106
PDDA Sap110	108

In the case of these materials the efficiency tends to increase when the particle sizes decrease. We were not able to distinguish a clear effect of the organic modification of these materials. The stability of NaSap110 have been successfully tested.

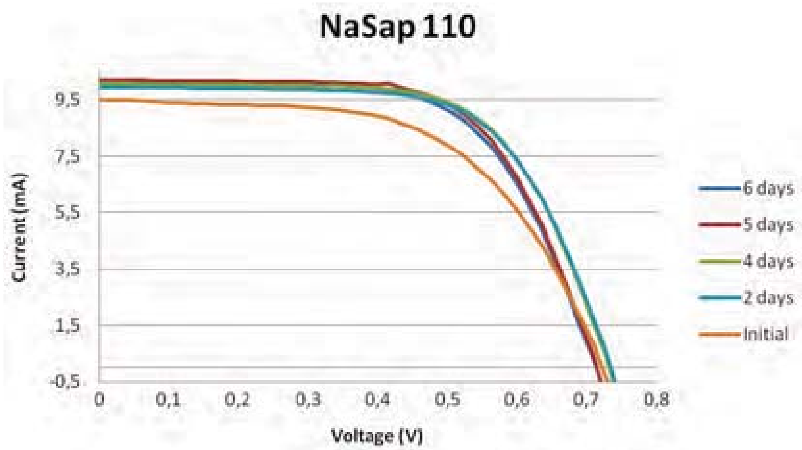


Figure 11: Stability test of NaSap110.

Alumina families

	Relative efficiency	Particle size
Al D1 C	95 %	10-20 nm
Al D1 new (Sil) + redox	100 %	10-20 nm
Al D1 new (Imi) + redox	89 %	10-20 nm
Al D1 FC	104 %	5-10 nm

Open circuit voltage and fill factors were similar to the one of the reference cell. A similar trend to the saponite families respecting to the particle size have been observed, the smallest particles gave the best results. In the case of the alumina the organic functionalization tended to help in getting higher performances.

anadium and mol bdenum o ide families

	Aging 3h	18h
V_2O_5	0,4 %	0 %
EL0016	72,8 %	4,5 %
EL0017	13,4 %	0 %
MoO_3	6,7 %	0,5 %
EL001	86,8 %	68,4 %
EL0015	56,9 %	30,3 %

Efficiencies relative to the reference cell after various time of under light soaking conditions.
These materials have been shown to be unstable and not suitable for solar cells applications.

Porous silica families

	Relative efficiency
MCM41 Nano B	100 %
MCM41 Nano NH_2	105 %
MCM41 Nano (Sil) + redox	95 %
MCM41 Nano (Imi) + redox	98 %

These materials are promising because some preliminary experiments carried out on vacuum dried samples (MCM41 Nano B) showed an increase in efficiency in comparison with the undried samples. Further experiment on vacuum dried samples should be perform to reach the final potential of these materials.

The most astonishing result were a nearly 100 mV open-circuit voltage gain when adding certain talc compounds to the electrolyte, a maximal open-circuit voltage over 800 mV was achieved on these spot-cells. Saponite compounds also seem to improve the relative efficiency by 5 tp 10% when comparing to the neat electrolyte.

National and international collaboration

Launch & running of the 3 years "KTI-Project" N° 10584.1 PFIW-IW with the EMPA Dübendorf (Switzerland) on the topic of "Squaraine"-based organic sensitizers.

The partnership with a large Swiss chemicals company is successfully ongoing for the investigation of new materials and the feasibility of large scale manufacturing of monolithic modules using all printed active layers.
The Eureka program E!4413 LCSC with 3GSolar (Israel) is still active in investigating the manufacturing of large area monolithic dye solar cell modules.

FP7-Project "ORION" – coordinated by Dr. David Mecerreyes at the CIDETEC, San Sebastian, Spain. This project investigates the development of a new family of functional inorganic-organic hybrid materials (for example metal oxide – ionic liquid) characterized by an ordered morphology (see http://www.cidetec.es/ORION/index.html).

FP7-Project "SOLAMON" – coordinated by Dr. Nathalie Baclet at the CEA-Grenoble, France.
SOLAMON focuses on improving "3rd generation" thin film solar cells (a-Si and dye sensitized) by employing plasmon generating materials to improve light collection in the active layers (see http://www.solamon.eu/).

FP7-Project "SOLHYDROMICS" - coordinated by Prof. Guido Saracco at the Politecnico Torino, Italy.
This project aims to build a photoelectrochemical water splitting device based on organic (or biological) catalysts for light collection (PSII system) and hydrogen evolution materials without noble metals (see http://solhydromics.org/).

Evaluation of 2010 and perspectives for 2011

During 2010, improved laboratory test solar cell ("spot-cells") gave a best efficiency of 9.4 % efficiency at 1000 W/m^2 on the square 6 x 6 mm sized samples. Spot-cells using the all-organic tomato-red colored «D5», gave astonishing 5.5 % efficiency on a only 4 µm thick TiO_2 electrode, performing even better than the classic ruthenium sensitizer Ruthenizer 535-bisTBA, giving ca 5.2 % in the same conditions. the D5 dye was kindly provided by Clariant in the framework of our ongoing industrial cooperation.

In 2011, the spot cell assembly methods will be further tuned to get higher performances using novel electrolyte materials provided by the partners. Module manufacturing has been streamlined to provide test samples of 10x10 cm to 30x30 cm for performance and stability investigation, using the materials elaborated within the project.

References

http://www.innovasol.eu/

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Département fédéral de l'environnement,
des transports, de l'énergie et de la communication DETEC

Office f d ral de l nergie OFEN

SOLA ON

PLASMON GENERATING NANOCOMPOSITE MATERIALS (PGNM) FOR 3RD GENERATION THIN FILM SOLAR CELLS

Annual Report 2010

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Project- / Contract Number	FP7-ENERGY-NMP-2008-1-226820
Duration of the Project (from – to)	1.02.09 – 31.01.11
Date	21 February 2010

ABSTRACT

The objective of the SOLAMON project is to develop high potential Plasmon Generating Nanocomposite Materials (PGNM) which will pave the way to the generation III solar cells (high efficiency & low cost). The objective is an augmentation in the External Quantum Efficiency resulting in an increase of 20% in the short circuit current density of the thin film solar cells.

To achieve such an ambitious goal, the project will focus on the development of fully tailored building block nanoparticles able to generate a plasmon effect for enhanced solar absorption in thin film solar cells. Such nanoparticles designed for an optimum absorption will be integrated in solar cells matrix using a recently developed room temperature deposition process designed by Mantis Deposition. This step will result in the specific design of PGNM for solar cells using a knowledge based approach coupling modeling (University of Ljubljana) at both scales: nanoscopic (plasmonic structure) and macroscopic (solar cells). SOLAMON will address three different classes of solar cells: a-Si:H thin films (TU Delft), organics (CEA) and dye sensitised (Solaronix, University of Ljubljana).

Introduction and project objectives

Objectives: The objective of SOLAMON is to develop high potential nano-composite materials (matrix + metal nano-particles) that will generate a Plasmon resonance effect which will pave the way to the generation III solar cells (high efficiency & low cost). The aim is to enhance the External Quantum Efficiency resulting in an increase of 20% in the short circuit current density of three types of thin film solar cells: a-Si:H, organic and dye-sensitized solar cells.

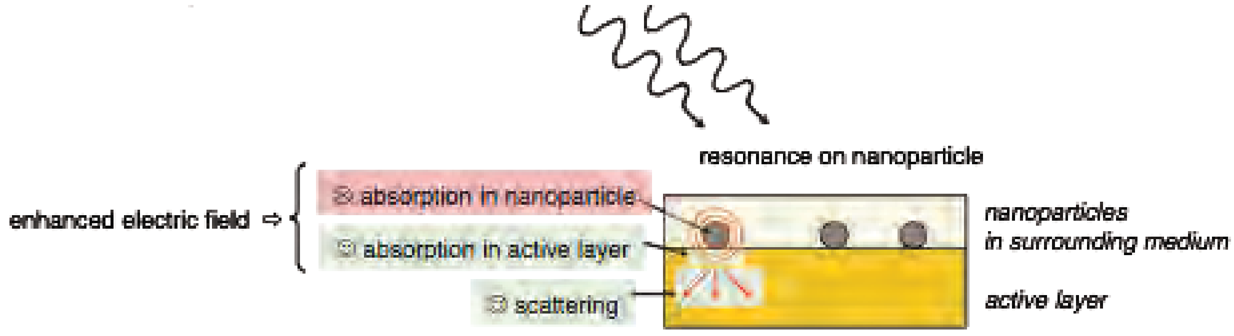
Description of the work: To achieve such an ambitious goal, SOLAMON tackles a range of difficulties remaining to be completed for the optimization of the Plasmon resonance effect in thin film solar cells. It includes the development of dedicated numerical codes able to determine the characteristics of optimized nano-particles, identify their best localization in the solar cell and predict the optical and electrical responses of solar cells. It also deals with the development of advanced nanotechnologies to fully tailor the nano-particles (nature, size, shape and surface density) embedded in a matrix chosen to generate a Plasmon resonance effect that can enhance solar absorption in a specific wavelength range.
The approach developed in SOLAMON, by strongly coupling theory (optical and electrical modelling) and experiments (finely controlled nano-particles deposition and characterization) will improve the basic understanding of localized surface Plasmon resonance effect versus the characteristics of the nano-particles that can be experimentally investigated (nature, size distribution, shape, surface density and surrounding medium). The SOLAMON approach will allow the development of reliable advanced models through a systematic confrontation between theoretical and experimental properties of the plasmonic structures investigated.
Expected results: As scientific results, SOLAMON aims at theoretically and experimentally assess various solar cells configurations utilizing Plasmon Generating Nanocomposite Materials in 3 real cases of solar cells. Beyond Photovoltaics, the results of SOLAMON should be also usable for other applications such as biological or chemical sensing, highly efficient organic and inorganic LEDs,…

Further research needs: For schedule and budgetary reasons, the present project is not investigating core-shell nano-particles, although such systems could be very useful to solve charge carriers recombination issues that can limit the interest of Plasmon resonance effect in solar cells. Future technological and theoretical investigations in that field could be very interesting to open the field of plasmonic applications to new device concepts like Plasmon resonance assisted up-conversion or Plasmon resonance enhanced radial p-n junction (nano-wire solar cells), for instance.

Brief project description

Basic principle of surface plasmon effect:

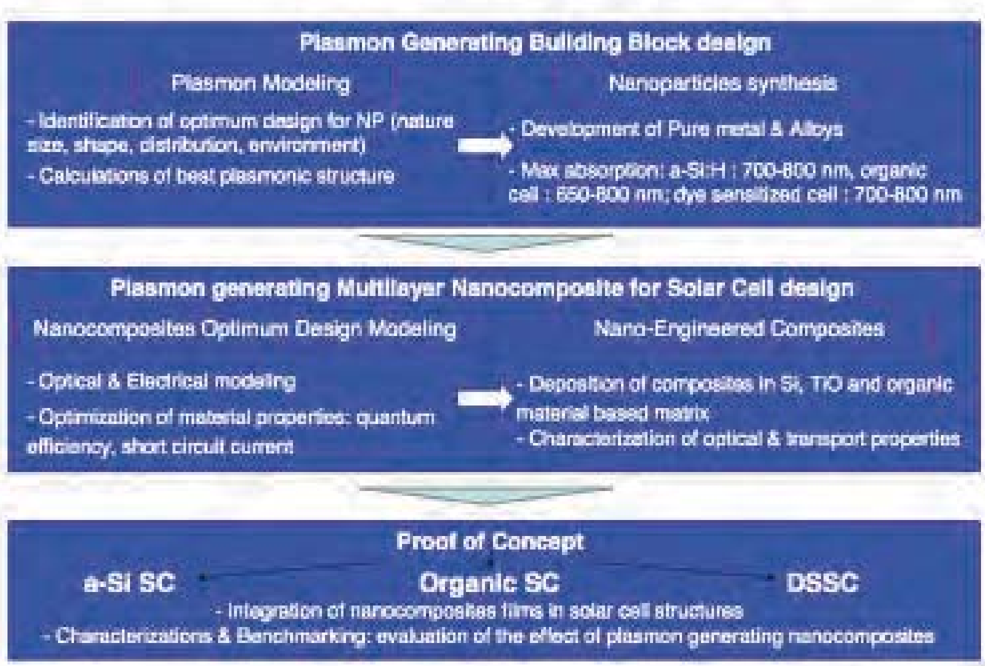
When a small spherical metallic nanoparticle is irradiated by light, the oscillating electric field causes the conduction electrons to oscillate coherently. When the electron cloud is displaced relative to the nuclei, a restoring force arises from the Coulomb attraction between electrons and nuclei that results in oscillations of the electron cloud relative to the nuclear framework. The collective oscillation of the electrons is called the dipole surface plasmon resonance. The resonance frequency on metal particles depends on the size, shape, particle material, and refractive index of the surrounding medium.
The incident light, in the region of the resonance wavelength of the particles is strongly scattered or absorbed, depending on the size of the particles. The extinction of the particles is then defined as the sum of the scattering and absorption due to the enhancement of the electric field in and very close to the metallic nanoparticle.
Scattering and absorption depend mainly on the size of the particles. Metallic particles that are much smaller than the wavelength of light tend to absorb more and hence extinction is dominated by absorption in and very close to the metal particles. As the size of the particles increases, extinction is dominated by scattering.
Both scattering and absorption can contribute to the enhancement of light absorption in the active layer of thin film solar cells.
- Scattering will induce enhanced absorption throughout the whole thickness of the photoactive active layer; in that case, one defines the scattering efficiency as the relative contribution of scattering to the total extinction;
- Absorption includes absorption in the metal nanoparticles (negative effect in the present case) but also enhanced absorption at the very close vicinity of the nanoparticles which can lead to enhanced absorption in the active layer provided that nanoparticles are close enough to the active layer.



The objective of the SOLAMON project, as illustrated below, is to develop high potential Plasmon Generating Nanocomposite Materials (PGNM) which will pave the way to the generation III solar cells (high efficiency & low cost).

The objective is an augmentation in the External Quantum Efficiency resulting in an increase of 20% in the short circuit current density of the thin film solar cells.
To achieve such an ambitious goal, the project will focus on the development of fully tailored building block nanoparticles able to generate a plasmon effect for enhanced solar absorption in thin film solar cells. Such nanoparticles designed for an optimum absorption will be integrated in solar cells matrix using a recently developed room temperature deposition process designed by Mantis Deposition. This step will result in the specific design of PGNM for solar cells using a knowledge based approach coupling modeling (University of Ljubljana2) at both scales: nanoscopic (plasmonic structure) and macroscopic (solar cells).

SOLAMON will address three different classes of solar cells: a-Si:H thin films, organics and dye sensitized. Developing the PGNM on these three classes aims at maximizing the project impact and not to compare them because scientific background acquired on these technologies could be easily transferred to other ones. As a matter of fact, a-Si:H technology targets mainly the Building Integrated PV (BIPV) market (large surfaces) whereas the two others are most suitable for the consumer good market (nomad applications).
The project workprogram, the critical path and the contingencies plans are designed to maximize both social and economic impact. For this reason, the BIPV applications (i.e. a-Si:H based technology) will be firstly considered when a strategic choice occurs, keeping in mind that, even of large economic importance, the two other technologies do not have the same key BIPV environmental and social impact.



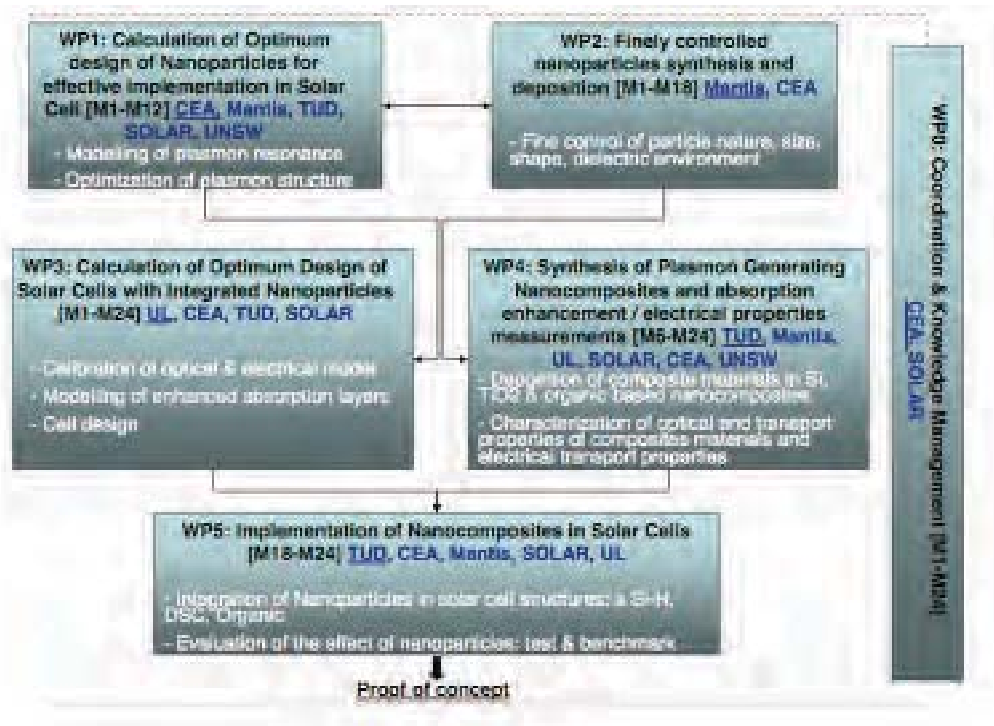
Project partners   role of Solaroni

SOLAMON gathers the key actors to address material knowledge based development, material modeling and material synthesis process. The complementary partners will therefore answer the needs of all 3 types of systems: organic (CEA1), a-Si:H thin film (TUD2) and Dye Sensitized Solar Cells (Solaronix). Clearly focused on a Concept to Feasibility approach, SOLAMON combines the most promising technique of nanoparticles deposition with an integrated modeling study. The partnership is aware of the ambitious challenge of the project and will dedicate a concentrated effort (189,5 PM over 24 months).
SOLAMON will use the exclusive expertise of the World leader in the field of plasmonic theory: the University of New South Wales (Australia).

The project partners are:

Partner	Beneficiary Name	Country	Role
CEA	Commissariat à l'Energie Atomique et aux Energies Alternatives	France	Project coordination. Optical modelling. Nanotechnology study and characterization. Organic solar cell development.
TUD	Technische Universiteit Delft	The Netherlands	a.Si:H solar cell development. Optical and electrical characterization of cells
Mantis	Mantis Deposition Ltd.	United Kingdom	Nanotechnology provider
UL	University of Ljubljana	Slovenia	Numerical modelling and simulation of cells (optical and electrical). DSSC cell development.
SOLAR	SOLARONIX SA	Switzerland	DSSC cell provider.
UNSW	University of New South Wales, Sydney	Australia	Expert on plasmonic systems.

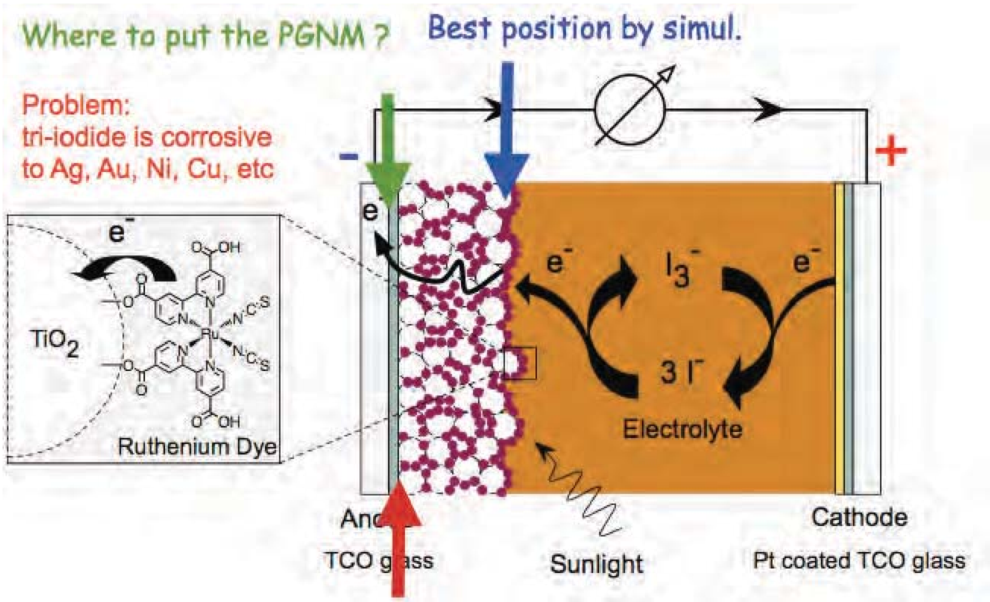
These workparkages and their dependencies are summarized in the diagram below:



Work performed and results obtained

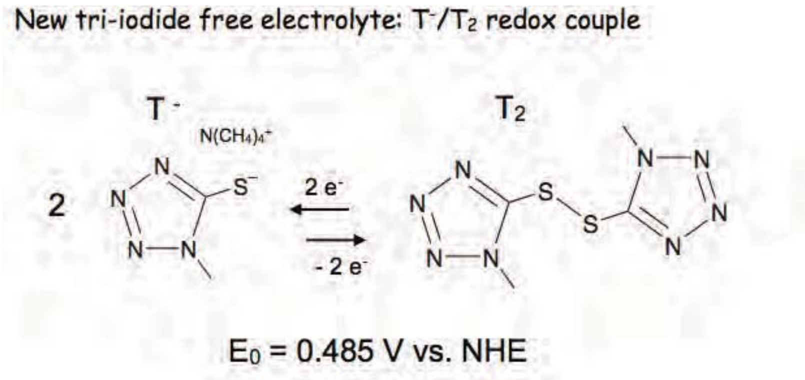
During 2010, the work focused on building the dye solar cells having the plasmon generating nano-material (PGNM) built-in. From the modeling (CEA, Uni Ljubljana), the best PNGM would by silver, in the form of nanoparticles of ca 20 to 100 nm diameter, these particles are provided by Mantis Deposition Ltd, in the UK, using their proprietary sputtering process (www.mantisdeposition.com).

A crucial issue is the placing of the PGNM layer within the solar cell device:



The difficulty is that silver gets rapidly oxidized by the tri-iodide in the electrolyte of a conventional dye solar cell. Thus other materials than silver should be employed, which is difficult as the project essentially relies on the availability of these tailored nano-Ag particles from Mantis.

An other way to solve this issue, is to use an electrolyte containing no tri-iodide in its redox couple, thus reducing or even eliminating the corrosion issue with silver.

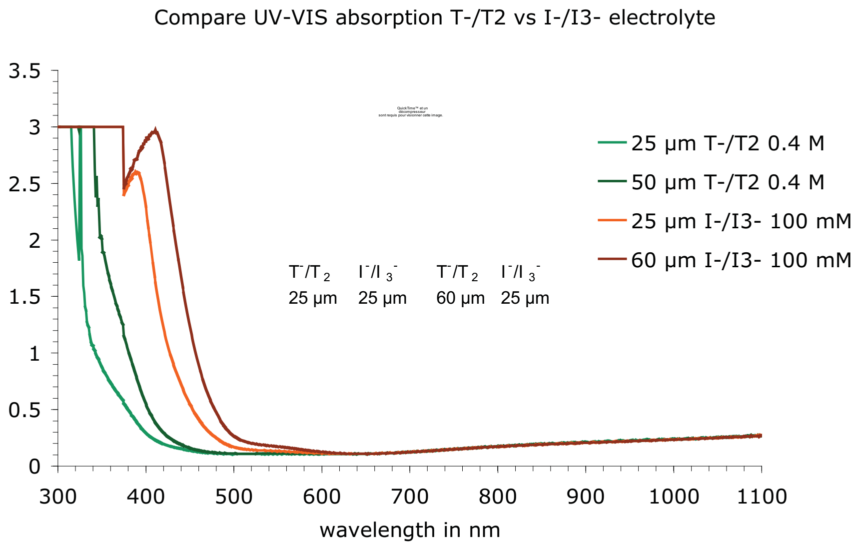


Recently, a redox couple based on 5-mercapto-1-methyltetrazolium tetramethyl ammonium and its dimer was reported by M. Wang et al. in Nature Chemistry Vol. 2 May 2010.

T = 5-mercapto-1-methyltetrazolium tetramethyl ammonium

Dye solar cells in the spot-cell format have been made to compare this new electrolyte with the classic Iodolyte AN-50 system, containing 50 mM of tri-iodide in a acetonitrile based electrolyte.

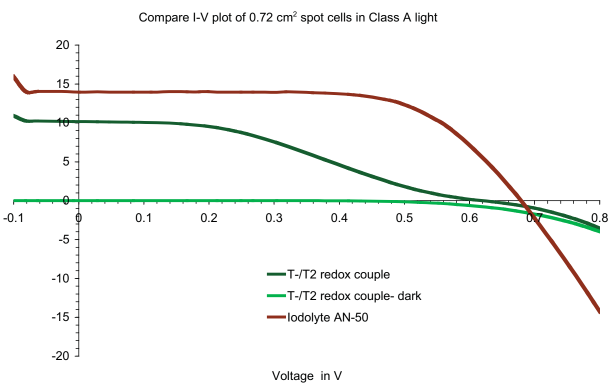
This new electrolyte system has also the advantage of being practically transparent when using 25 and



60 µm thick sealing gaskets acting as spacers in the lab cells.
The electrical results are quite encouraging when using the spot-cell design:

	Sp05-250610FO	Sp01-250610FO	Sp05-250610FO
Sample	T-/T2 BN1	AN-50	T-/T2 BN1
Surface	0.72	0.72	0.12
Efficiency	3.20 %	8.60 %	3.7 %
Isc mA/cm^2	14.129	19.443	12.9
Voc mV	619	679	561
FF	0.36	0.65	0.508

Efficiencies in the range of 3 % were achieved, still less than half that is usual with Iodolyte AN-50, giving over 8% in these conditions.

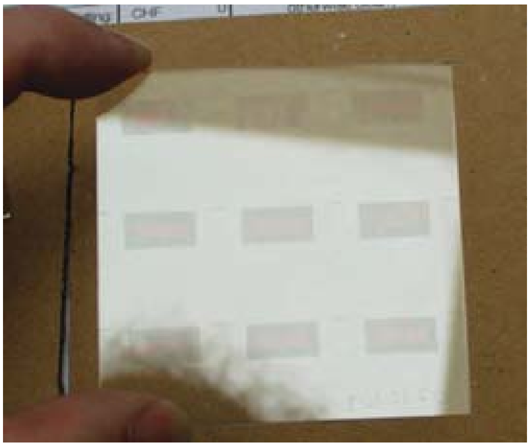


I-V plots of a Iodolyte AN-50 filled and T^-/T_2 filled spot-cells (0.72 cm^2).

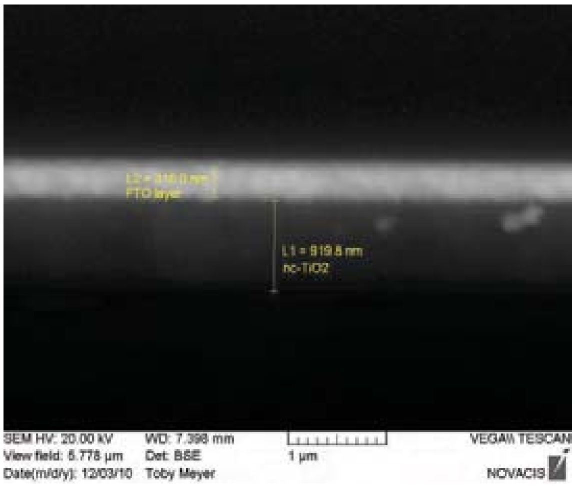
It seems that the platinized counter-electrode is not working properly, giving this «S» shaped behavior on the I-V plots shown on the left.

In order to verify the functioning of the PGNM nano-silver particles in combination with the T^-/T_2 redox couple, solar cell samples having a very thin 900 nm mesoscopic TiO_2 layer were built, with the idea to color them with the classic Ruthenizer 535-bisTBA and also with the organic dye «D5», having a higher absorption coefficient according to the literature (see Chem. Commun., 2006, 2245–2247, DOI: 10.1039/b603002e), with a value of ca. 37’000 / Mcm at 476 nm, to be compared with ca 12’000 /Mcm at 535 nm for the Ruthenizer 535-bisTBA sensitizer. A higher absorption coefficient allows the usage of thinner TiO_2 electrodes to absorb a given amount of light.

Thin reference spot cells were made with only 900 nm thin TiO_2 layers:



Picture of a 10x10 cm FTO22-15 glass having 9 screen printed reference electrodes.



SEM cross-section of a thin TiO_2 electrode, indicating the 900 nm thickness achieved with a specially formulated titania paste.

The next step is the building of working solar cells having these thin TiO_2 electrodes, colored with «D5» and Ruthenizer 535-bisTBA, and having either the classic acetonitrile based electrolyte Iodolyte AN-50 or the new corrosion safe T^-/T_2 formulation. The idea is to compare them with cells having the silver particles coated on top of the TiO_2 layer (= best position according to the modeling).

National and international collaboration

Launch & running of the 3 years "KTI-Project" N° 10584.1 PFIW-IW with the EMPA Dübendorf (Switzerland) on the topic of "Squaraine"-based organic sensitizers.

The partnership with a large Swiss chemicals company is successfully ongoing for the investigation of new materials and the feasibility of large scale manufacturing of monolithic modules using all printed active layers.
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FP7-Project "INNOVASOL" – coordinated by Dr. Leo Marchese of the SiSTeMI center at the University of Piedmont, Italy.
INNOVASOL aims to increase the efficiency of exitonic solar cells to 15 % by using innovative approaches in cell designs and novel materials (see www.innovasol.eu)

FP7-Project "SOLHYDROMICS" - coordinated by Prof. Guido Saracco at the Politecnico Torino, Italy.
This project aims to build a photoelectrochemical water splitting device based on organic (or biological) catalysts for light collection (PSII system) and hydrogen evolution materials without noble metals (see http://solhydromics.org/).

Evaluation of 2010 and perspectives for 2011

The 2010 works aimed to produce specially adapted dye solar cells to test the concepts of the SOLAMON project. Especially, a tri-iodide free electrode has been investigated to avoid the critical corrosion issue when using silver nano-particles in the classic dye solar cells. Extra-tin TiO_2 layers (900 nm only) have been printed on FTO glass with the idea to use these layers for testing the plasmon effect in real dye solar cells. In 2011, we expect to finalize all the experiments, but first we need to get the electrode samples back from Mantis to accomplish this work, as the project will end on 31 January 2011.

References

http://www.solamon.eu/

Module und Gebäudeintegration

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

S ARTTILE

INNOVATIVE PHOTOVOLTAIK-INDACHLÖSUNG

Annual Report 2010

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Project- / Contract Number	SI/500387 / SI500387-01 (102682 / 153473 and 153467)
Duration of the Project (from – to)	1.8.2008 – 30.9.2010
Date	10.12.2010

ABSTRACT

The intention of the project „SmartTile“ is to finalize the development of roof integrated photovoltaic building elements, which had started within the framework of the EU-research Project “BIPV-CIS”.

Instead of pursing the original project idea of using plastic to produce the integration frame of the PV-element in a moudling process, the actual focus of the project lies on finalizing the development of the MegaSlate®II mounting system, and complementing it with thermal collectors and skylights.

Apart of merely technical questions, also normative issues are being treated within the framework of the present project.

Einleitung / Projekt iele

Das Projekt SmartTile hat seinen Ursprung im Projekt BIPV-CIS, welches im Rahmen eines EU-Forschungsprojektes vom Bund gefördert wurde (2004 bis 2007). Ziel des Projekt SmartTile ist die Weiterführung der im BIPV-CIS angefangenen Arbeiten zur Entwicklung eines photovoltaischen Dachelementes für die Anwendung im industriellen Massstab, basierend auf Spritzguss. Dank Spritzguss sollte zusätzliche Funktionalität bereits in das Dachelement bzw. dessen Halterahmen integriert werden können.

Gegenüber dieser ursprünglichen Produktidee wurde in Absprache mit dem BFE beschlossen, die Projektziele anzupassen, und die Entwicklung eines der Kommerzialisierung näher stehenden Solardachsystems – MegaSlate®II – voranzubringen. Dieses Produkt hat in vielfacher Hinsicht von den im Projekt SmartTile geleisteten Vorarbeiten und gewonnenen Erkenntnissen profitiert.

Das Solardachsystem MegaSlate®I ist bereits seit 2002 auf dem Markt. Die Nachfolgeversion MegaSlate®II wird seit Herbst 2009 verkauft (vorerst nur PV-Elemente).

Das angepasste Ziel des vorliegenden Projektes besteht konkret darin, die Entwicklung des MegaSlate®II Solardachsystems abzuschliessen. Dazu gehören beispielsweise die Sicherstellung der Kompatibilität mit den relevanten Normen, sowie die Ergänzung mit gut integrierten thermischen Kollektoren und Dachfenstern.

Durchgeführte Arbeiten und erreichte Ergebnisse

Normpr fungen Versuche

Gemäss der europäischen Bauprodukterichtlinie 89_106_EWG müssen Bauprodukte, zu denen auch gebäudeintegrierte Photovoltaikmodule zu zählen sind, einige grundsätzliche Anforderungen erfüllen. Für PV-Module sind davon insbesondere relevant:

- Mechanische Festigkeit und Standsicherheit
- Brandschutz
- Hygiene, Gesundheit und Umweltschutz
- Nutzungssicherheit

Daraus basierend wurden Prüfungen durchgeführt in Bezug auf Produktqualität (IEC61215ed.2), Produktsicherheit (IEC61730), Mechanische Festigkeit, Brandschutz (Beflammung von aussen) und Regendichtigkeit.

Stati

MegaSlate®II wurde vom TüV gemäss TüV-Spez. TZE/2.572.10 (in Anlehnung an IEC61215ed.2) als Indachmontagesystem qualifiziert. Dazu gehörten insbesondere Statiktests, welche für Schneelast mit 5'400 Pa und für Windsog mit 2'400 Pa durchgeführt wurden. Abbildung 1 zeigt eine Aufnahme während eines Belastungstests.

ABBILDUNG 1 STATI   TEST   IT 5 400 PA

Um Statiktests einfacher durchführen, sowie um auch einzelne Komponenten prüfen zu können, wurde eine Zug- und Druckprüfeinrichtung gebaut, welche mit pneumatischen Zylindern arbeitet. Aus einer einfachen Einrichtung wurde 2010 eine Anlage gebaut, mit der ganze Module einer Statikprüfung unterzogen werden können (Abbildung 2).

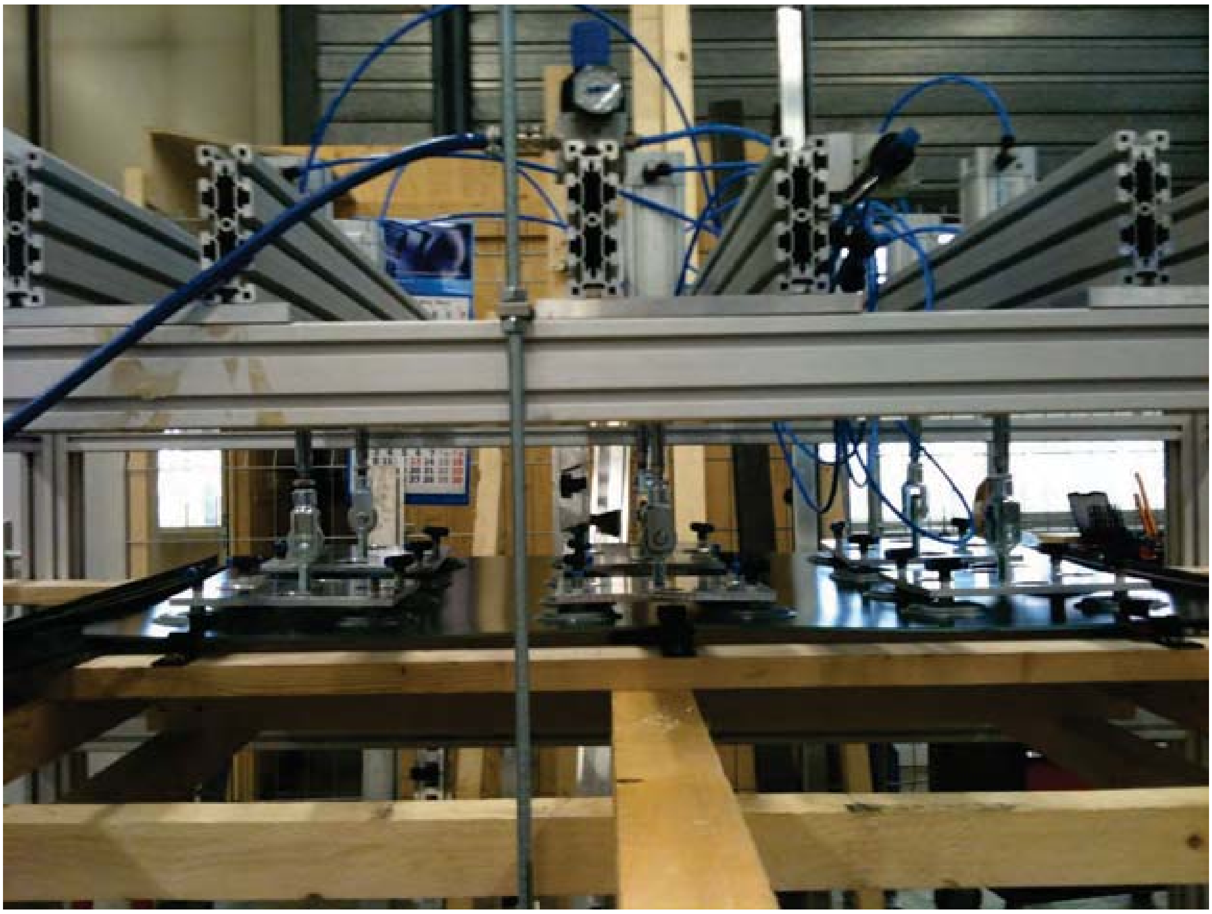

ABBILDUNG 2 ERWEITERTE ANLAGE   UR STATISCHN PR   FUNG   ON SOLAR   ODULEN

randschut

Zur Prüfung der Widerstandfähigkeit gegen Feuer von aussen wurden Prüfungen gemäss der europäischen Norm 13501-5 durchgeführt. Bei diesen Prüfungen wird ein Brandsatz auf ein Dachmodell aufgelegt und vollständig abgebrannt. Diese Prüfungen resultierten in der Erlangung eines allgemeinen bauaufsichtlichen Prüfzeugnisses. Abbildung 3 zeigt ein Bild während einer Prüfung.

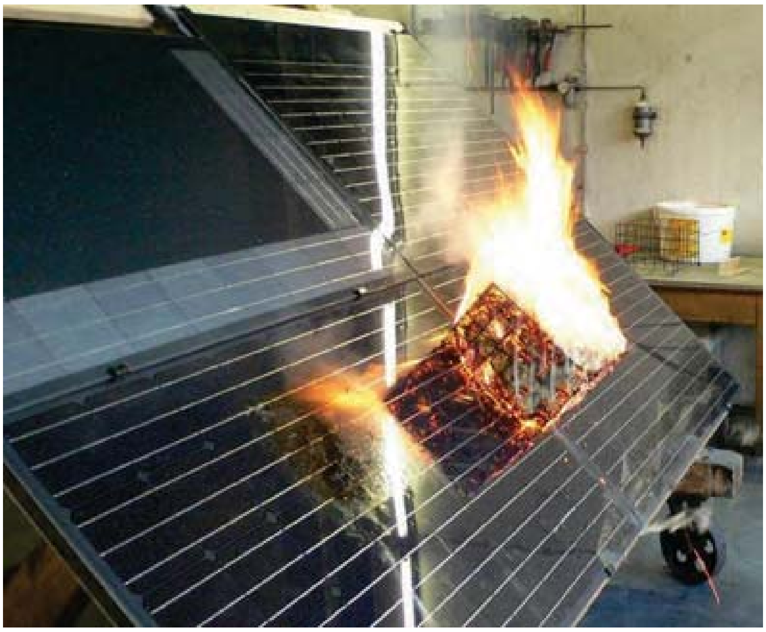

ABBILDUNG 3 BRANDPR FUNG

egendichtheit

Nach sieben Jahren Felderfahrung kann davon ausgegangen werden, dass MegaSlate®I über eine für zentraleuropäische Lagen ausreichende Regendichtigkeit verfügt. Da aufgrund der geringeren Überlappung bei MegaSlate®II in dieser Hinsicht Unsicherheit bestand, wurden entsprechende Prüfungen gemäss prEN15601:2008 am P+F Sursee durchgeführt. Abbildung 4 zeigt eine Aufnahme, die während diesen Prüfungen entstanden ist. Bei diesen Prüfungen wurde ein Dachmodell mit Wasser besprinkelt (bis zu 250 mm/h/m2), und gleichzeitig mit einem Ventiltor Wind simuliert.

ABBILDUNG 4 BEREGNUNGSPR FUNG

Mit diesen Tests wurde sowohl MegaSlate®I als auch MegaSlate®II eine für zentraleuropäische Lagen ausreichende Regendichtheit bescheinigt.

Neues PV- oduldesign und neue omponenten

MegaSlate®I ist ein bei Installateuren und Bauherren beliebtes Produkt, es weist aber einige Defizite in Bezug auf Produzierbarkeit (z.B. Automatisierung schlecht möglich), Preis, Integrationsmöglichkeit von thermischen Kollektoren und Dachfenstern, sowie Handhabbarkeit. Ziel der Entwicklung von MegaSlate®II war, diese Defizite zu beheben, möglichst ohne dabei die guten Eigenschaften des Vorgängerproduktes aufgeben zu müssen. MegaSlate®I war als Produkt für das eigene Projektgeschäft von 3S konzipiert. MegaSlate®II hingegen soll als Serienprodukt in Systemkits über Wiederverkäufer vertrieben werden.

Zur Erreichung des gesteckten Ziels wurde beispielsweise zur Verbesserung der Herstellbarkeit die interne Zellenverschaltung von horizontal auf vertikal (vgl. Abbildung 5) geändert, und damit die Notwendigkeit der aufwändigen Querverschaltung hinter den Zellen eliminiert.

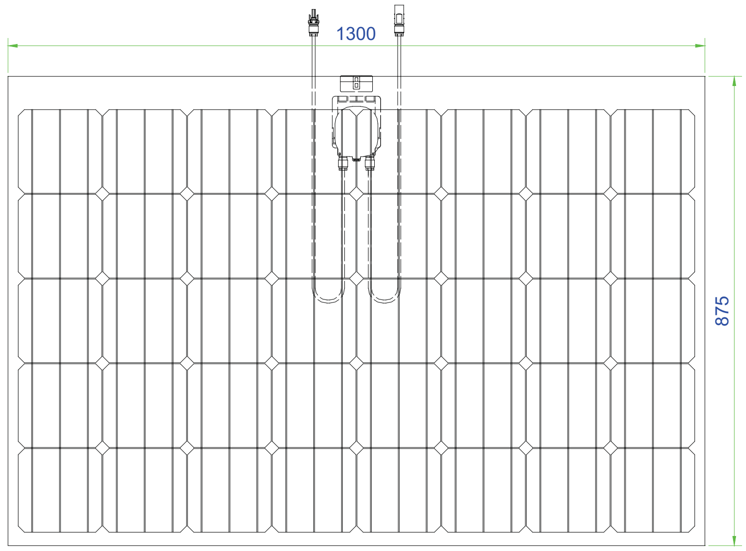

ABBILDUNG 5 ODULDESIGN EGASLATE II

Ferner wurde die Breite der Überlappung zwischen geschuppt übereinanderliegenden PV-Elementen von 150 auf 50mm verringert (Abbildung 6). Dank Verringerung der Glasgrösse unter Beibehaltung der aktiven Fläche konnte bei den Materialkosten eine Einsparung erzielt werden, und das geringere Gewicht erleichtert die Handhabung sowohl in der Produktion als auch bei der Montage.

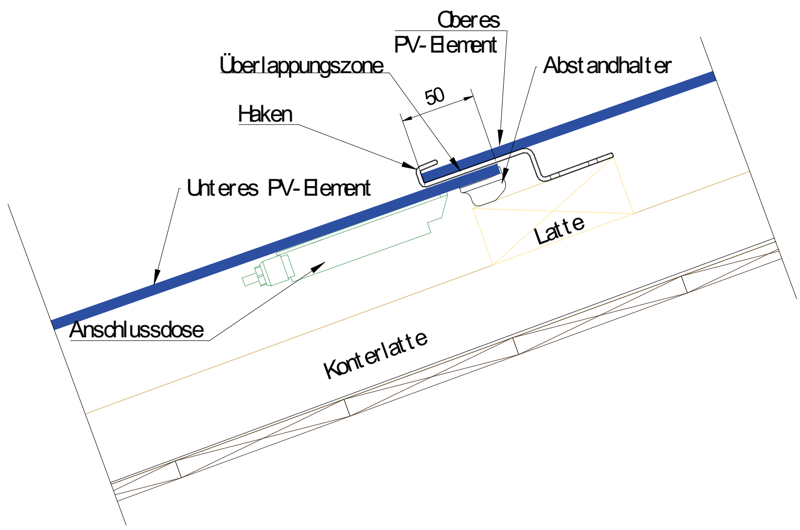

ABBILDUNG 6 DARSTELLUNG DER BERLAPPUNGS ONE WISCHEN BEREINANDER LIEGENDEN P -ELE ENTEN IN DER SEITENANSICHT

Die kürzere Spannweite erlaubt den Einsatz von dünnerem Glas (5 statt 6 mm), was sich positiv auf Gewicht, Kosten und Transmission auswirkt.

Bei MegaSlate®II kommen 3 Haken zu Einsatz anstatt 2 wie bei MegaSlate®I. In der Mitte des PV-Elementes (Abbildung 5 & Abbildung 6) Moduls ist zudem ein Abstandhalter aufgeklebt. Dadurch wird ein Durchhang vermieden, und die Spaltbreite zwischen überlappenden PV-Elementen bleibt konstant.

Aufgrund der weniger breiten Überlappung können kürzere Haken aus dünnerem Material (2.5 statt 4mm) verwendet werden. Dadurch verringert sich die Spaltbreite, denn diese wird im Wesentlichen durch die Dicke der Haken bestimmt. Dies hat ermöglicht, die breite der Überlappungszone zu verringern, ohne die Regendichtigkeit wesentlich zu beeinträchtigen.

Die Komponenten des Montagesystems wurden alle angepasst. Die Haken, Profile, Latten und Gummiauflager weisen eine optimierte Form auf, und durch eine geänderte Produktionsmethode konnten die Fertigungstoleranzen reduziert werden. Diese Komponenten werden nun mit eigens dafür konzipierten Werkzeugen in Serie hergestellt. Neu sind ferner Montagelehren zur effizienteren Anbringung der Haken verfügbar, sowie auch Firstanschlussbleche.

ABBILDUNG 7 FIRSTABSCHLUSS IT EGASLATE II FIRSTANSCHLUSSBLECHEN

Fun tionelle Erg n ungen

Als funktionelle Ergänzung wurden ins MegaSlate®II Rastermass passende thermische Kollektoren (Abbildung 8) und Dachfenster (Abbildung 9) entwickelt. Erste Projekte wurden bereits realisiert, die Entwicklung ist aber noch nicht abgeschlossen. Insbesondere die Integration der Dachfenster und deren Montage sind sehr anspruchsvoll.

ABBILDUNG EGASLATE II THER IEPANELE W HREND DER ONTAGE

ABBILDUNG 9 ANLAGE IT INTEGRIERTEN DACHFENSTERN

nderspe ifische ertifi ierungen

Um Photovoltaik-Indachsysteme in europäischen Ländern erfolgreich verkaufen zu können, sind teilweise länderspezifische Zertifizierungen erforderlich. Diese sind äusserst aufwändig und kostspielig. In Frankreich (CSTB) und England (MCS) wurden sie bereits initiiert. In Frankreich steht der „Avis Technique" noch aus, ein „Pass'Innovation" wurde bereits erteilt. Für das englische MCS-Zertifikat ist die Fertigungsstätteninspektion erfolgt, die Produktprüfung ist noch im Gange. In der Schweiz wurden die Thermiepanele durch das SPF zertifiziert. Ein solar Keymark ist noch in Bearbeitung.

usammenstellung Produ tanpassungen PV- odul

Pilotanlage

Im Frühjahr 2010 wurde eine MegaSlate®II Pilotanlage gebaut, welche zusätzlich mit der Prototypen der thermischen Kollektoren ausgestattet ist, um grundsätzliche Erfahrungen in Bezug auf Handhabung und Montage zu sammeln.

ABBILDUNG 10 EGASLATE II PILOTANLAGE IN L. THER IEPANELEN

Abbildung 10 zeigt ein Bild der Gesamtanlage, Abbildung 11 einen Ausschnitt, auf dem die Thermiepanele erkennbar sind. Diese sind in ihrem Aufbau vergleichbar mit Doppelisoliergläsern, bei denen die mittlere Scheibe durch den Absorber ersetzt ist, und eine äussere Scheibe durch ein isoliertes Blech. Dank der Pilotanlage – deren Montage gar nicht reibungslos verlief – wurde erhebliches Verbesserungspotential identifiziert, und in mehreren Schritten umgesetzt.

ABBILDUNG 11 AUSSCHNITT IT THER IEPANELEN

Im Rahmen des zum Pilotprojekt gehörenden Messprojektes wurden einige Sensoren installiert:

- Temperaturmessungen im Luftkanal im Unterdach bei Traufe und First (siehe Abbildung 12)
- Messung von Modultemperatur oben und unten
- Einstrahlungsmessung sowie Erfassung des Ertrags der thermischen Solaranlage.

Diese Daten werden mittels eines Dataloggers des Wechselrichterherstellers Fronius erfasst. Leider waren diese Komponenten erst mit einer Verzögerung von mehreren Monaten lieferbar. Daten sind erst ab Ende September 2010 verfügbar.

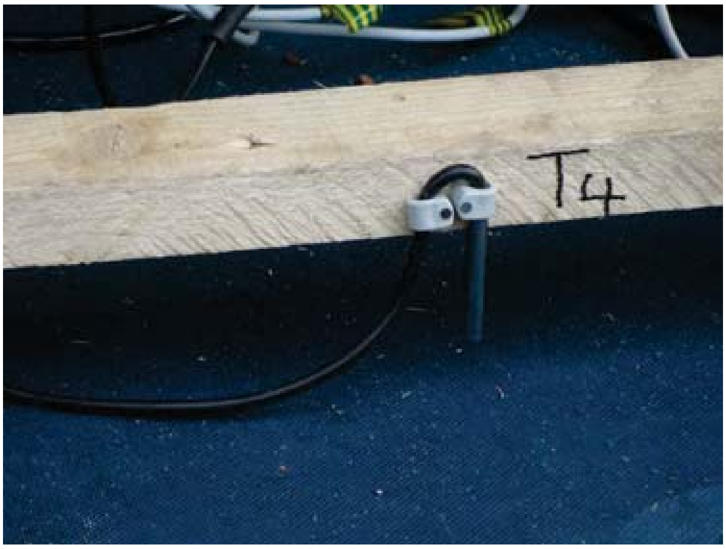

ABBILDUNG 12 TE PERATUR ESSUNG I UNTERDACH

Eine detaillierte Auswertung wird mit dem Schlussbericht zur Pilotanlage 2011 erstellt. Ein Grafik mit den spezifischen Novembererträgen ist angefügt (Abbildung 13), sowie ein Tagesverlauf mit Leistung und Temperaturen.

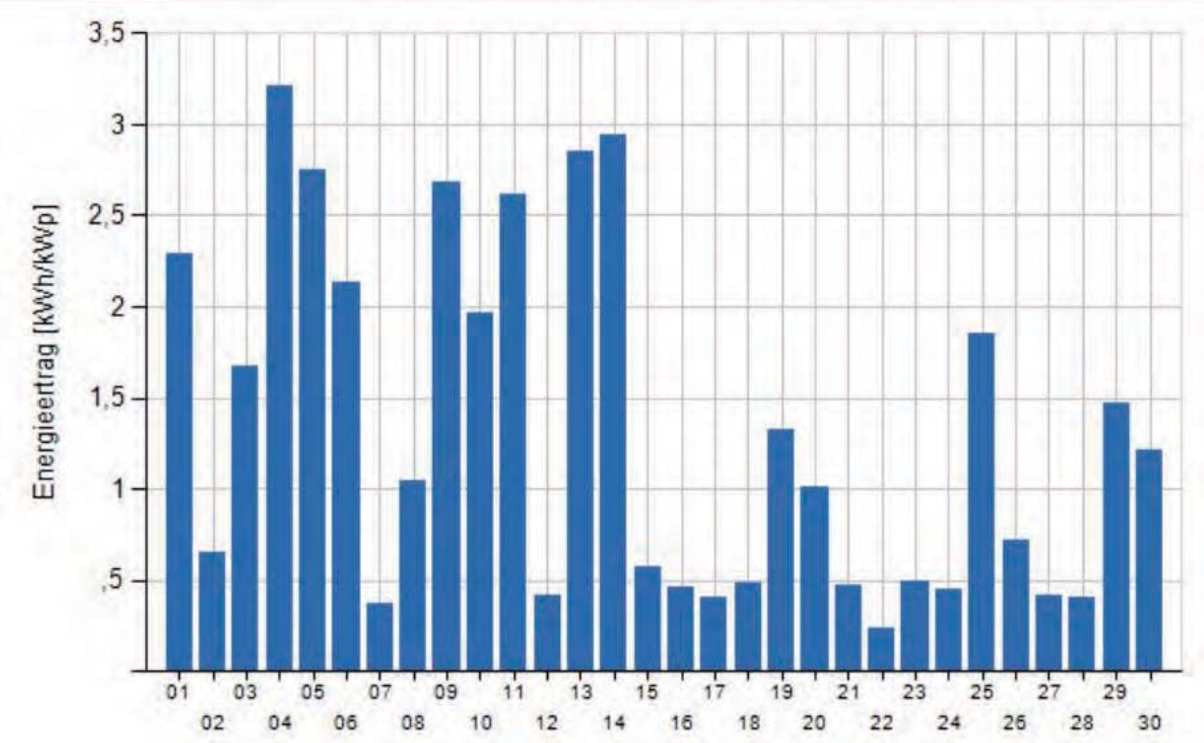

ABBILDUNG 13 SPE IFISCHE TAGESERTR GE I NO E BER 2010

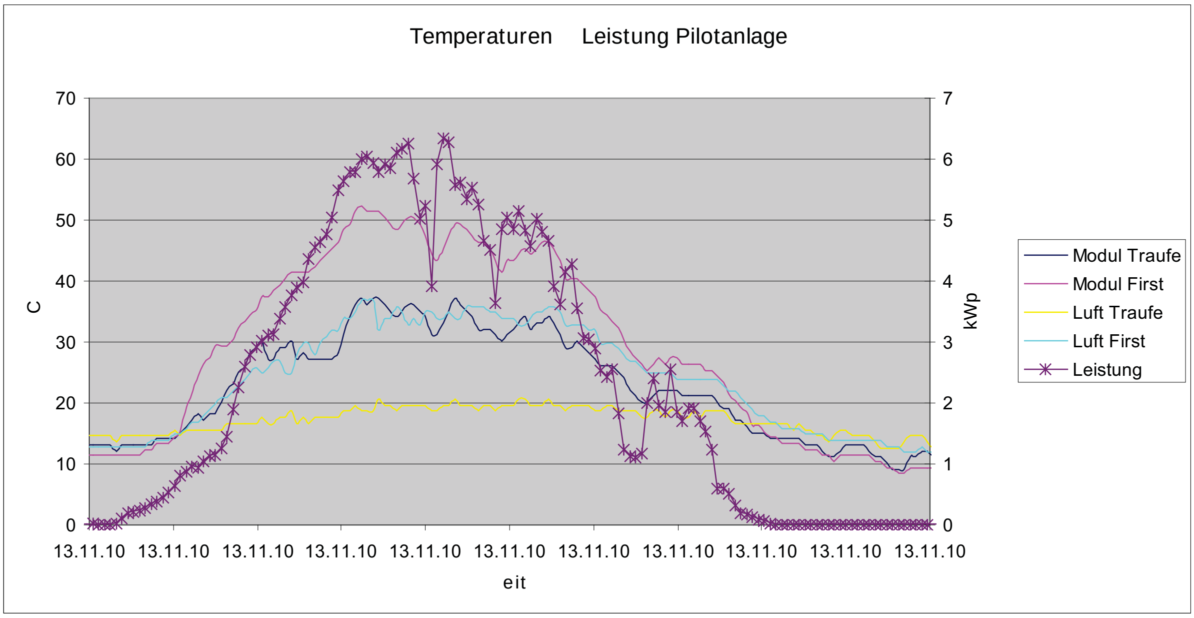

ABBILDUNG 14 LEISTUNG UND TE PERATUREN A 13. 11.2010

Aus der Grafik ist ersichtlich, dass sich am 13. November 2010 die Temperatur der Luft im Luftkanal zwischen PV-Modulen und Unterdach bis zu 15° erwärmt. Dies entspricht an diesem Tag in etwa der Temperaturdifferenz des obersten und untersten PV-Moduls. Mit einer besseren Firstentlüftung dürfte diese Temperaturdifferenz etwas geringer ausfallen.

10/11

usammenarbeit

Die Entwicklung der Integration der thermischen Solarkollektoren in das MegaSlate®II Dachsystem erfolgt in Zusammenarbeit mit der Firma H+S Solar in Rebstein. Für das Dachfenster ist die Firma Stebler Glashaus AG in Oensingen Kooperationspartnerin.

Be ertung und Ausblick

MegaSlate®II ist mittlerweile am Markt eingeführt, und auch einige Anlagen mit Thermiepanelen und integrierten Dachfenstern wurden bereits gebaut. Das Forschungsprojekt hat somit das wesentlichste Ziel – die Entwicklung des Solardachsystems MegaSlate®II zur Marktreife – erreicht.

Ein Rückstand besteht noch in Bezug auf die Zertifizierungen in England Frankreich und USA. Der Aufwand ist erheblich und die Bearbeitung eher schleppend, weshalb diese Aufgaben nach Beendigung des Forschungsprojektes erledigt sein werden. Auch die Optimierung der Dachfenster und Kollektoren, insbesondere im Hinblick auf die Montagefreundlichkeit, ist noch im Gange.

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BUILDING INTEGRATED PHOTO OLTAICS THER AL ASPECTS

LOW ENERGY HOUSE FOR TESTING BIPV SYSTEMS

Annual Report 2010

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Project- / Contract Number	103155/154147
Project Resp. at SFOE	Dr. Charles Filleux
Duration of the Project (from – to)	01.07.2009 – 01.07.2011
Date	09.12.2010

ABSTRACT

PV industries offering products that can be integrated as building materials represent so far a niche but promising market. At the moment only a few studies (see the references in the annual report 2009) have been carried out to assess the interaction between the PV modules and the building itself. This fact may represent a barrier not only for the PV industry, but also for the building industry that has yet to gain confidence in these new materials. The building sector must therefore possess a basic knowledge in relation to what is technologically available and how to properly employ photovoltaic integration in a building. Considering that in the near future PV will be used more and more often as a building material, the intentions of this project are to:

- Analyze building integrated PV products in order to define their electrical and thermal characteristics.
- Analyze the interaction between these materials and the building.
- Demonstrate what BiPV modules look like and how to integrate them into the building concept.

The real working conditions of a building-integrated PV system are generally different from those reproduced in a common outdoor test facility. For example, photovoltaic insulated glass will exhibit different electrical and thermal behavior compared to PV modules analyzed with a common outdoor test facility where ventilation, temperature, heat flux and structure are different. Consequently the photovoltaic components for building integration require a special test facility. To test BiPV modules closer to the real situation, a special stand was built on the roof of our institute with the objective of, on the one hand, analyzing new prototypes or already existing commercialized modules and, on the other hand, showing visitors what these new photovoltaic building elements really look like and which building components can be replaced with PV.

Aims of the project

The building integration photovoltaic sector becomes more popular day after day and consequently professional interest is increasing. The photovoltaic technology is the only mean to achieve integrated delocalized electrical production. The cost of the modules is decreasing more quickly than other building elements. In this case, the photovoltaic façades will become financially interesting in the near future. For this reason, this project analyzes several PV elements used as building components in façades. For further details on the facility construction and modules technologies, see the annual report 2009.

The main goals of 2010 ere the follo ing:

- Achievement of the outdoor test facilit see FIG.1
- Beginning of the data ac uisition
- Improvement of the test facilit functioning
- First anal sis reports after 3 and 6 months for manufacturers confidential
- Test facilit tour for building professionals, P specialists and students
- Presentation of the project and diffusion of the first results.

All the objectives were reached but with a delay of three months due to the delivery behind schedule of the BiPV modules by the PV industries and bad weather conditions (snow falls) at beginning of 2010 that delayed the finalization of the facility.

FIG. 1: Outdoor facilit for the testing of BiP s stems

Works carried out and results achieved

The BiPV simulator was finalized and the last modules installed, in March 2010.

Data ac uisition

The data acquisition began with the simulator completion in March 2010. All electrical and thermal data are daily registered with a frequency of 1 per minute during the daylight period. The module operating electrical specification (voltage and current), the meteorological data (irradiance, outdoor temperature), the ambient temperature inside the house and the module temperature placed on the bottom of each module are registered by 24 maximum power point trackers (MPPT) specially realized by ISAAC for this project. The one-year monitoring is still ongoing.

During the first months of monitoring, some improvements were made in order to improve the working conditions of the simulator.

- The data acquisition has been improved. The modules data have been filtered in order to eliminate the very low insolation days during which the tracking of the maximum power point is not very accurate.
- The temperature homogeneity into the facility was improved by adding a ventilator and a physical barrier in front of it which diffuses the hot or cold air. This because some modules were more exposed to the air-conditioner than others. The internal glass temperature is monitored to check the temperature uniformity.
- To increase the simulator lifetime, the wood surface was covered with a waterproof paint.

Intermediate anal sis reports for manufacturers

Two intermediate reports after 3 and 6 months were sent to each of the five manufacturers who collaborate within this project. The analysis reports only show the results of the PV modules provided by the producers itself. The comparison between the different technologies (without naming the manufacturer) will be shown in the final report after having monitored the installation for one year. This decision was taken in order to avoid the publication of values that don't allow a fair comparison due to the ambiguous choice of the nominal power between the different technologies. For scientific research, the Final Yield (FY) is used to compare the production of two modules having different nominal power but the same inclination and orientation (during a defined time period). The final yield is the ratio between the produced energy (E) and the nominal power (P_N) expressed in kWh/kW$_P$. It is noteworthy that due to its definition, the final yield strongly depends on the choice of the P_N value. The modules electrical characteristics under standard test conditions have been measured with a pulsed solar simulator (class A) before installing the modules on the test facility. The P_N value chosen for the intermediate report (that consider the initial degradation) was given by each manufactures. The P_N value will be measured again at the end of the project to quantify possible variations. When two modules with different inclination and orientation are compared, the Performance Ratio (PR) is the value that help to make the comparison. It is defined as the ratio between FY and the normalized irradiation (G/G_0) and in turn depends on the P_N given by the producer.

So far, some considerations have emerged, in particular:

- Opaque modules may be used as any building materials (paying particular attention to cables and fastening systems)
- Transparent modules: lower yield compared to standard modules, but natural light supply and reduction of summer overheating (facts that will be quantified at the end of the project)
- Insulating glazing facade with transparent modules in amorphous silicon → annealing effect
- Depending on the manufacturers and of the production line (how the transparency is obtained) different Power/m^2 values are obtained
- Standard PV laminates transformed in insulating double glazing: junction box at the edge, hermetically-sealed gap between the glass panes

Test facilit tour for building professional, P specialist and students

During 2010, many visits of the BIPV simulator were organized for planners, actors of the building sector, students, industries, associations. Considering the success of the demonstration stand, a Zoom out/Zoom in application (that was not include initially in the project) was realized in order to give the possibility to virtually visit the BiPV simulator on our website www.bipv.ch Ref. [1].

Presentations of the project and diffusion of kno ledge about the concept and first results

- 25th EUP SEC and WCPEC-5, Valencia, Poster and paper on “Low energy house for testing BiPV systems”, September 2010
- Status Seminar, Zurich, September 2010
- Energ forum - solar skins, Bressanone, Oral presentation on “Temperature and module efficiency: thermal and electrical behaviour of BIPV systems”, December 2010
- Supplemento del corriere del trentino e dell Alto Adige, article on “Stand di prova per elementi fotovoltaici integrati negli edifici”, November 2010
- etallglass, article on “Stand di prova per elementi fotovoltaici integrati negli edifici”, December 2010

National and international collaborations

- Verres industriels, Moutier
  Danilo Pirotta director, Bernard Cuttat R&D engineer, Pierre Stettler sales manager
- Galvolux, Bioggio
  Marco Jelmini director
- Swiss laboratories for materials testing and research EMPA, Dübendorf
  Mark Zimmerman, Bruno Binder, Mr. Vonbank and Stephan Carl
- PV producers (confidential)

2010 Evaluation and future prospects for 2011

In 2010, our project has received a great response by planners, actors of the building sector, students, industries and associations considering that tours of the BiPV stand were regularly organized. In fact, building specialists encounter difficulties when they have to choose among different technologies in relation to the application of PV into the building and are pleased to know that our project will give more "usable" information on this subject.

Considering that the construction of the stand was delayed, the measurements at EMPA will begin in March-June, in any case they should be finished on time for the analysis report and the conclusion of the project.

The BiPV stand was more expensive compared to the estimated costs, because of the decision to give more value to demonstration by making a real house instead of having boxes behind modules.

In the final report the following considerations will be analyzed:

1) Semi-transparent amorphous silicon modules (single, double junction o micromorph modules) have a lower nominal power compared to opa ue modules of the same technologies depending on how the transparency is made (during the manufacturing process). Nowadays the building standard request at least a double insulation glazing unit when the modules are manufactured with transparency characteristics in order to be used as a warm facade. In this case, the "annealing" effect (see study of our Institute), which occurs when the cells have a temperature of 40°C and more, has an important role and allows to increase the energy production during the summer period. This study will also analyze how the loss of energy production due to the transparency would be balanced by the increase of energy production in summer caused by the annealing effect. Would the application of amorphous silicon be more appropriate for ventilated facades rather than warm facades with good insulation glasses? (see Fig.2).

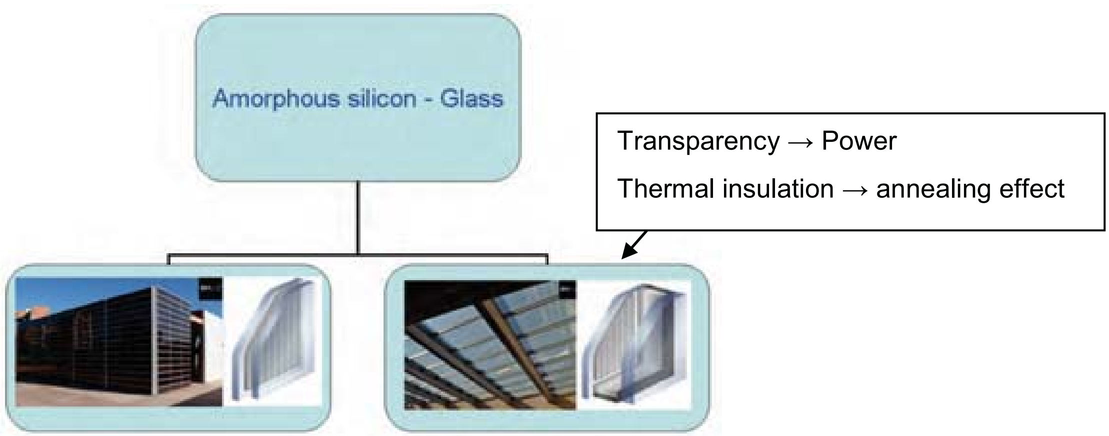

FIG. 2: The application of the amorphous silicon technologies ould be more appropriate for ventilated facades rather than arm facades ith good insulation glasses annealing effect

2) The study will analyze if the t pe of support ould influence the temperature of the modules laid on different metal roof (aluminum, zinc, steel) and membranes (black or white) and in turn also the modules production (see Fig.3).

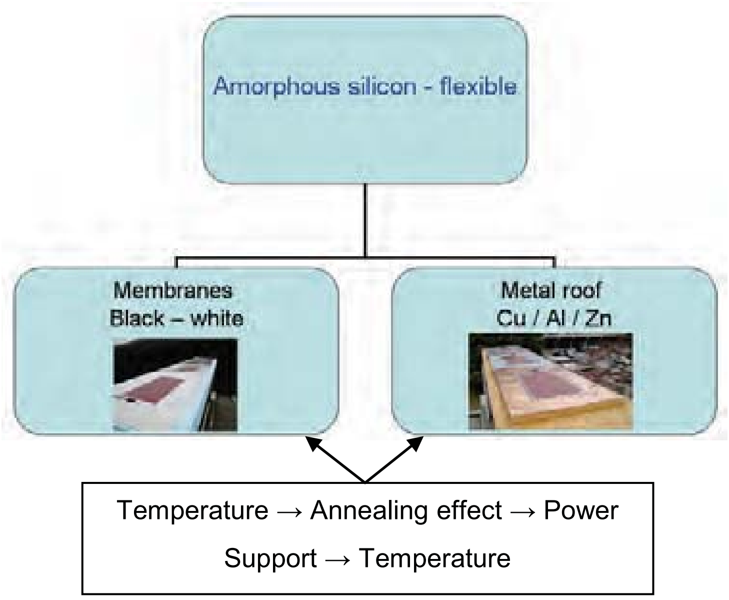

FIG. 3: The t pe of support ould influence the temperature of the modules and in turn also the modules production b means of the annealing effect

3) In a ventilated facade, the amorphous silicon and the crystalline silicon technologies don't have an interaction with the building in terms of heat exchange and light supply. Instead in the case of a warm facade, the study will analyzed how the modules influence the building itself. If and ho semi-transparent modules ould allo to reduce overheating hile ensuring a certain degree of natural lighting are aspects which will be analyzed at the end of the project with the measurements of the U and g values of the modules at EMPA (see Fig.4).

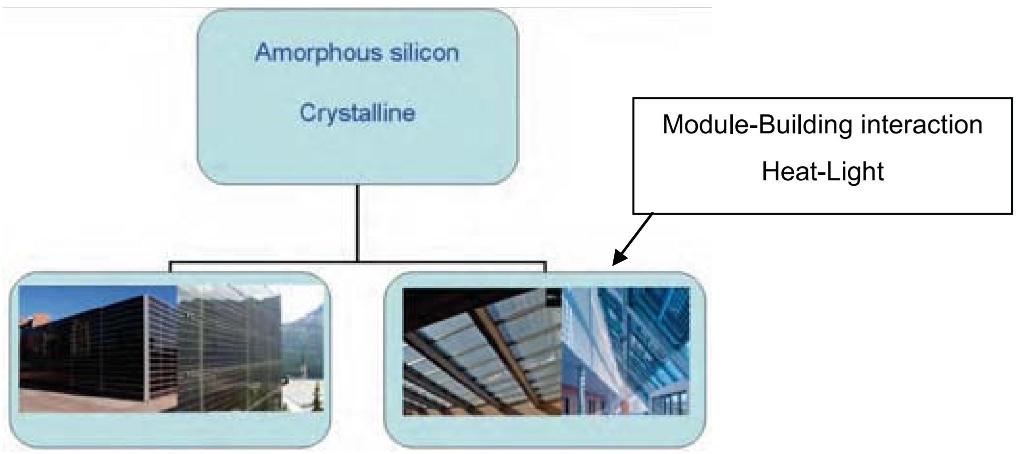

FIG. 4: utual module-building interaction considering heat e change and light transmission

4) The surface temperature of the front glass panes is hotter compared to traditional glasses. This specific behavior will be also studied before the end of the project.

References

[1] Zoom in / zoom out application on www.bipv.ch "materials" / "BIPV simulator"

UNI UE AND INNO ATI E SOLUTION OF THIN SILICON FIL S ODULES BUILDING INTEGRATION

ARCHINSOLAR

Annual Report 2010

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Project- / Contract Number	SI/500474 / SI/500474-01, Swiss Electric Research
Duration of the Project (from – to)	01.04.2010 to 31.03.2013
Date	22nd of December 2010

ABSTRACT

The Archinsolar project is based on the vision that, for a wide-scale development, photovoltaic (PV) products have to become "commodity objects". This project aims to develop a new generation of photovoltaic elements based on thin film silicon technology (single amorphous and tandem amorph/microcrystalline cells). These new elements will be ultra-reliable. They will make possible very low manufacturing costs and unique architectural integration, and be respectful of the environment, landscape, buildings and traditions.

During the year 2010, first "non functional" prototypes were developed.

A prototype molded in a composite material and integrating multi-functionalities like roof interconnection and water tightness was demonstrated.

In parallel a demonstration roof constructed by the PVLAB was demonstrated and some developments were also done on the aesthetic aspects by developing new colored filters (terra-cotta, grey) and textured patterns on top of the modules.

A survey was also submitted to more than 1800 architects with the aim of understanding the key features necessary for a well admitted product on the building integrated PV market.

Goals of the project

The project presented here aims at improving the architectural integration of PV cells, through the development of a new generation of photovoltaic elements based on thin film silicon technology (single amorphous and tandem micromorph cells), tailored color filters and multifunctional composite structures. The instigators of this project aim at developing the science, technologies and methodologies allowing to:

- conceive innovative elements, able to widely pass the norms of reliabilities IEC, with the objective of ensuring a lifetime of over 25 years (against 20 to 25 years as currently guaranteed).
- propose aesthetically revolutionary elements (in a variation of colors and textures) that will fit from an architectural point of view as well as being respectful of the landscape and environment.
- simplify to a maximum the interconnections on the roof while respecting their mechanical constraints and security, and increasing their functionality.
- demonstrate that, even with the mentioned constraints, prices as low as150-200CHF / m^2.

Short project description

The project is distributed in 3 main workpackages:

- WP1 ”PV engineering design of reliable elements“ establishes the design criteria, selects appropriate materials and carries out the first concepts of module design,
- WP2 ”Colored filters and multifunctionality“ develops the colored films and specific coatings and textures which will modify the visual aspect of the modules as well as the innovative electrical and roof interconnections.
- WP3 „Integration, design, architecture“ realizes the architectural implementation and identifies the various constraints (e.g. linked to mounting, security, certification).

Work performed and results achieved in 2010

1. Aspects of P -Design

In the beginning of our research we tried to define general terms like “attractiveness” related to the PV-market and its products. Therefore, a first survey was created and submitted to the architects’ community as it is obvious that they play a key role as consultants was also prepared and analysed to get a deeper vision on what is currently offered by the various producers. We stayed focused on products interesting by their way of being integrated into the roof as BIPV-solutions. There are at least around 20 suppliers and producers on the market which offer a variety of attractive installations but unfortunately staying as “niche products” and therefore not well represented on the market, essentially for question of cost. It appears that the not well defined “attractiveness” term is not solely related to mere superficial appearance but also to other well known key factors such as costs, yield (performance), reliability and aesthetics (appearance of the product).

In the framework of this project, there are many aspects, in the front and back part of the module where the general design could be improved (aesthetics as well as functionality) (Fig. 1). In the front side of the module, work on the size (in addition to the aesthetical appearance, most modules are too large and therefore too heavy to have them installed by one person only), on the colour (black, greyish, reddish, brownish) and on the glass texture (brilliant, matt finished, micro-structured) has been undertaken.

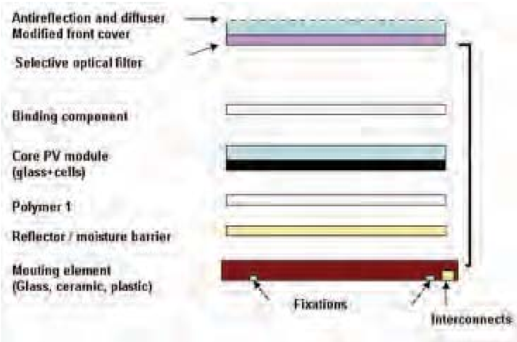


Fig ica st uctu a t in i i u an si n nts nt an ac a t

The back side of a traditional PV module is usually non functional (glass or foil). The junction box and the fixation systems are directly glued at the back of the module. 98% of this surface is therefore non functional. For example, horizontal and vertical water tightness has to be provided by a multitude of extra-elements. We work on the development of a moulded back encapsulation system able to integrate, by a specific design, several functions. In this purpose, a very first non functional prototype with innovative back solution design was realised which offers a solution concerning both, the horizontal and the lateral water tightness, by supplying specific profiles without using additional aluminium frame. The advantage of such a solution is evident: it will decrease the costs by an easier installation solution.

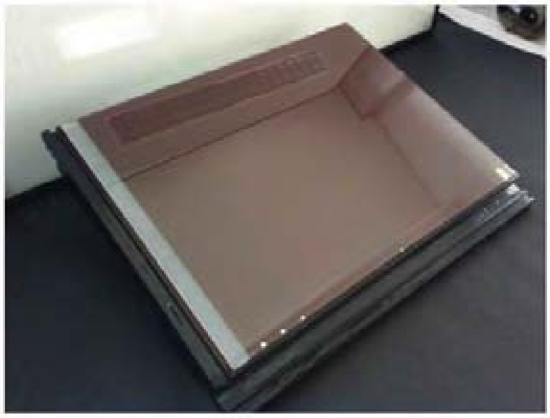
2. Demonstration roof

A demonstration roof was constructed at the PVLAB to present the advancement of the project all along its different stages (Fig.2). In a first step, some non functional modules have been installed on this roof to demonstrate the esthetical concept of the project. The demonstration roof has been fully covered with PV modules including “non-standard” elements (corner) done by cutting a non-active module (dummies). Some textured and anti-reflecting glasses have been laminated on some of these modules to show how the visual aspect can be improved by lowering the reflectivity of the glass.

Fig i st nst ati n at

3. ultifunctional composite back element

The objective of the work carried out at LTC-EPFL is to develop a multifunctional composite element as a backing structure for the PV devices. Activities include the selection of the material and of the process method, the analysis of the bonding between the composite backing and the glass module, and the production of prototype elements. During the reported period, a first generation prototype tile of dimensions 30 x 40 cm was produced and is shown in Figure 3. The module comprises a 3 mm thick single glass a-Si device bonded to a 24 mm thick sandwich backing structure made of glass-polyester composite faces and a foam core. The composite faces were made using a hand lay-up process in a homemade mold, and were subsequently coated with a black paint. Figure 4 compares the weight of the composite tile with and without the glass module, with a commercial concrete tile and a model aluminum tile of identical dimensions. A considerable weight reduction is demonstrated with the composite option, which represents an advantage for the manufacture of larger roof elements with optimized weight. The tile also includes in-molded fixation rails. Such a possibility to include additional structural and functional features (e.g., electrical connections, not realized on this first prototype) will be further explored in the production of the second-generation prototype.



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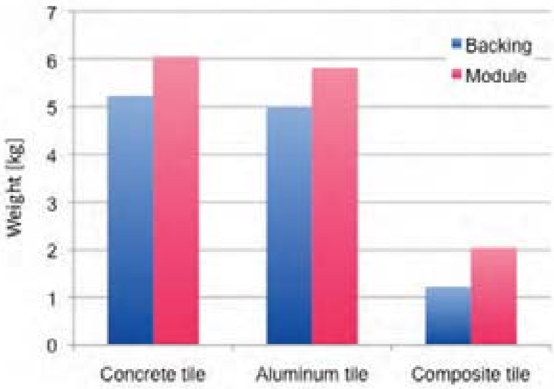

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4. Colored interferential filters and te tured glasses

The Archinsolar project aims at improving the architectural integration of photovoltaic cells. A novel glazing shall improve the appearance of PV modules. A special chemical treatment of the outer side of the novel glass element shall produce a textured appearance while decreasing light reflection. In order to vary the module’s color, an optically selective filter is applied to the inner side. Minimizing energetic losses, this filter should reflect only a selected part of the incoming radiation. The colored filters consist of multilayered thin films and have to be optimized to combine an intense color with a good energetic efficiency. These thin films are deposited by reactive magnetron sputtering. For the coating development in the laboratory, a new sputtering machine was designed, constructed, installed, and successfully tested. The new reactor was assembled from custom made components. In order to accurately control the deposition parameters, a quartz crystal microbalance was calibrated by precise ellipsometric measurements. The stacked thin films form an interferential filter between the outer glass pane and the polymer used for lamination. The neighboring media have to be correctly taken into account for computer simulation and design of the multilayers. The large range of available colors provides greater flexibility for architectural integration of PV devices. Some examples of samples produced by magnetron sputtering are shown in Figure 5. For roofs, especially orange-red color shades are of interest.

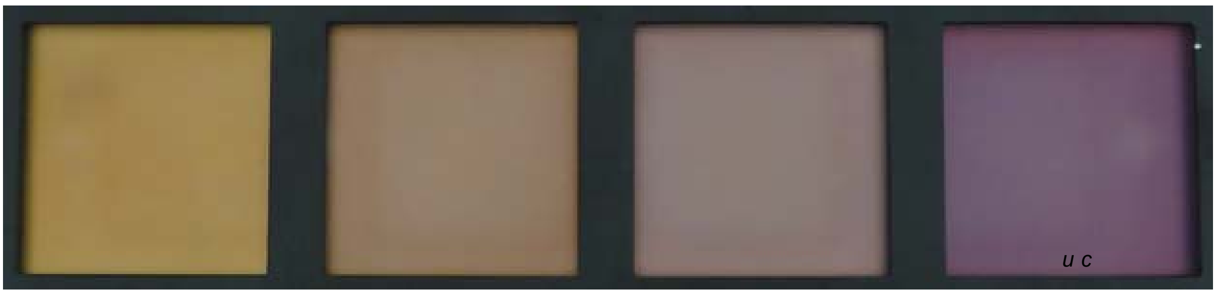

Fig a c tica s cti i t s

5. Report elements for architectural integration LESO-PB

One declared main goal of the project is to provide a solution for satisfactory integration of large amorphous and/or micromorph PV panels on tilted roofs, to achieve a broader diffusion of the technology in an architecturally acceptable way. Even using new colours, the target on "historical buildings" was questioned by our team in terms of acceptability, market size and feasibility within the specific constraints of size and low cost. To assess the readiness of the key actors in this market, the architects, to install photovoltaic panels on various building type, under different circumstances, with various panel sizes and appearances, a web survey has been prepared, launched and its results analyzed. More than 160 answers were collected from the 1800+ mails sent to practicing architects in Switzerland, France and Germany. The answers are still analyzed more in depth, but the first results have allowed the selection of key characteristics to be optimized in the developed products. A summary of these parameters and the resulting objectives for each project team will be prepared beginning of 2011, setting the target for the 2011 round of new prototypes. A parallel investigation on current tiles market and tiles systems has been started and is still underway.

Nationale and internationale Collaboration

Regular scientific academic contacts, discussions, meetings and sample exchanges are maintained throughout the project both with national (EPFL, ETH, EMPA, module producer) and international (module and polymer producers) entities.

Perspectives for 2011

The objective for 2011 will be to demonstrate a second medium size functional prototype (with defined electrical connections), integrating selected multi-functionalities (electrical connection, roof interconnection, water tightness). Further development will be done in the aesthetic aspects by developing new colored filters (terra-cotta, grey) and textured patterns for the glass. A strong effort will be done to understand the module reliability issues that still need to be deeply studied. Indeed the mechanisms and environmental influences that cause module performance degradation are yet poorly understood. Among them are the interlayer adhesion and cohesion within the layers, the glass instability in the thin film modules relative to the adhesion of the TCO layer on the glass, the effect of moisture, hot spot damage, encapsulant yellowness and interconnect failures. The emphasis of this research in the next year will be to develop a better understanding on what changes (use of new materials like composites, colors filters) may have impact on these different aspects (adhesion of the encapsulant, TCOs degradation…) and more generally, on the modules reliability over time. Finally, this second prototype will be presented on an outdoor demonstration roof.

Ackno ledgments

Swiss Electric Research (SER), the Services Industriels Genevois (SIG) and the Center of Competence Energy and Mobility (CCEM) are thanked for their co-financing support.

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CONFOR   AL PHOTO   OLTAIC   ODULES

Annual Report 2010

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Project- / Contract Number	KTI 9903.1
Duration of the Project (from – to)	March 2009-February 2012
Date	15 December 2010

ABSTRACT

The objective of this collaboration between EPFL and Flexcell is to develop a materials system and process for profiled encapsulation of thin film silicon photovoltaic devices with improved efficiency for structured roofing elements. The project started on March 1st, 2009. Two innovative concepts are explored and implemented in industrial demonstrators. Firstly, novel textured coatings to improve PV efficiency through enhanced light-trapping and simultaneously improved reliability are developed based on polymer nanocomposite resins. Secondly, full polymer low cost composite backing is developed to enable fast profiling into stable and complex shapes. With such lightweight prefabricated PV products Flexcell will offer a completely new product to profiled roof panel manufacturers and to system installers.

Project Goals

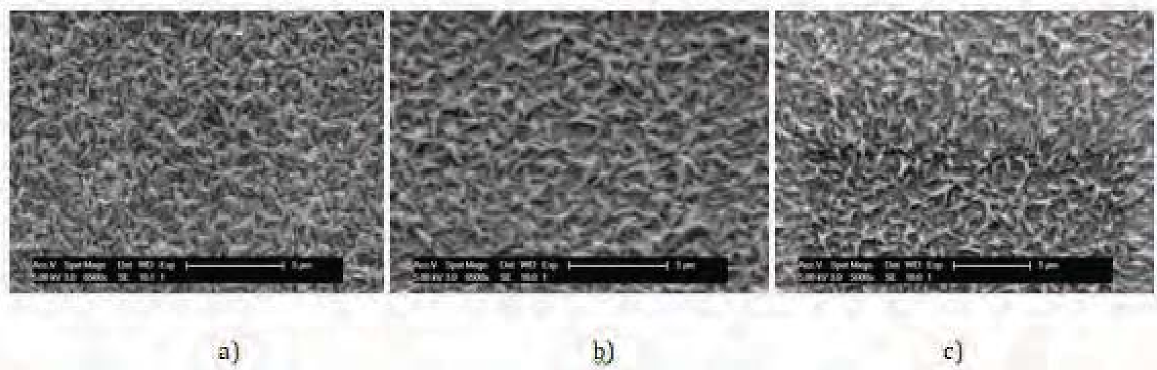
The main objective is to develop a materials system and process for profiled encapsulation of thin film silicon photovoltaic devices with improved efficiency for structured roofing elements. Two innovative concepts, namely a multifunctional textured coating and a full composite backing are explored with specific objectives :

i) Increasing cell current density (> 13 mA/cm^2) and module yield and durability with novel nano-textured photon-trap polymer-based coatings.
ii) Producing the photon-trap coatings in a roll-to-roll process (rate up to 10 m/min).
iii) Optimizing the forming of an appropriate composite material as structural backing with appropriate design freedom to be adaptable to a range of roofing geometries.

Key challenges are to avoid premature cracking of the brittle PV stack during forming and to achieve a high replication fidelity of thin organic coatings during photo-polymerization in a dynamic roll-to-roll operation. A further challenge is to guarantee the integrity of the layered structure with very high thermo-mechanical contrast between layers, and a high dimensional stability under severe durability conditions.

Photon-trap coatings

During the reported period the selection process of the UV-curable resin was finalized, based on i) haze tests (Flexcell) and electron microscopy (CIME-EPFL) of imprinted patterns using a Ni-shim template and a nano-imprint lithography process developed at LTC-EPFL (see OFEN report 2009), ii) adhesion tests of the cured coatings on PEN and iii) photo-conversion analyses of the resins with a range of photoinitiators. As shown in Figure 1, the replication fidelity of the textured coatings is very high (better than 95% based on roughness and correlation length data).



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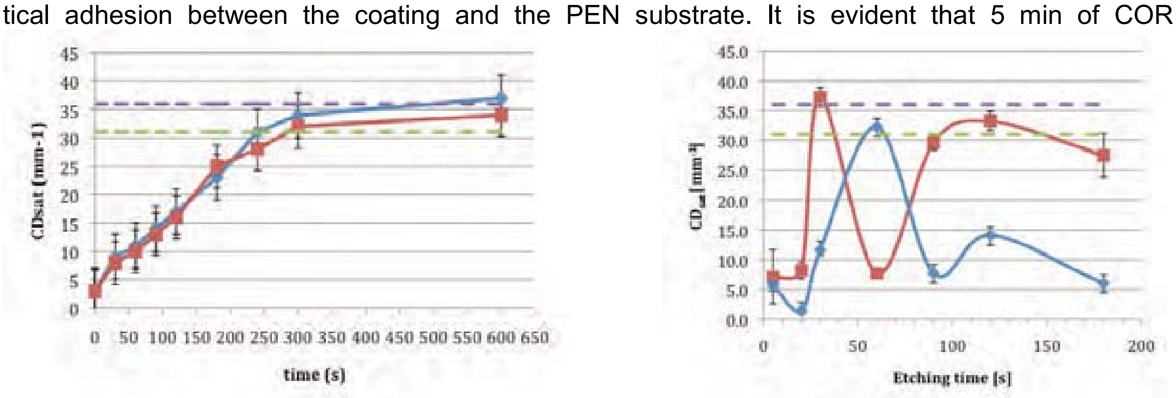
The analysis of the influence of surface treatments of the PEN substrate on coating adhesion was completed. Figure 2 compares the influence of corona discharge (COR) and acidic chemical etching (ACE) treatment time with the industrial plasma process on the crack density at saturation (CDsat) of two types of coating materials, measured using the fragmentation method developed at LTC-EPFL [1]. CDsat is proportional to the interfacial shear strength, which provides a quantitative value of the practical adhesion between the coating and the PEN substrate. It is evident that 5 min of COR or



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10-60 s of ACE enable to reach the same adhesion performance as the industrial plasma. The complex behavior observed in the case of ACE results from the concurrent action of oxidation and molecular weight degradation of the PEN surface layers.

Research work was also on the characterization of Ni shims supplied by Flexcell with extensive electron microscopy investigations at CIME-EPFL A systematic study of shunts was also undertaken in order to make a list of the different kind of shunt existing and their cause.

A roll-to-roll line has moreover been designed and constructed at LTC-EPFL to produce textured coatings on a 18 cm wide plastic substrate continuously (Figure 3). The work consisted mainly on motion control selection (motorization, tension control) and mechanical design of the machine itself and the various components (rolls, coating bar). The line is fully operational since November 2010 and initial tests have been performed to optimize the coating application step and UV-curing step.

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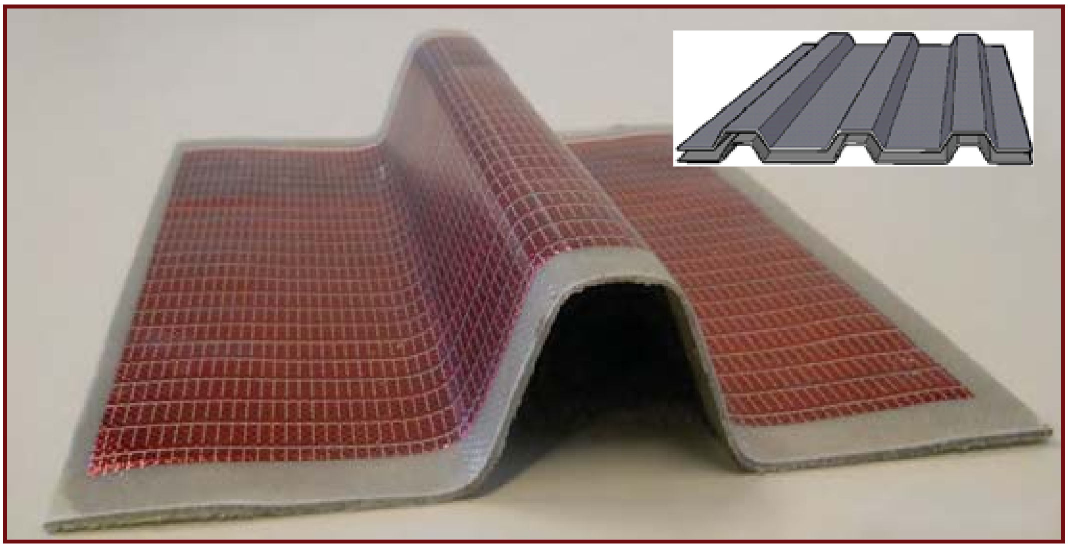
Conformal demonstrator modules

The production of laboratory prototypes (see report OFEN 2009) was continued during the reported period, in order to optimize the composite backing forming process. A series of flat functional modules was also produced for durability testing. Based on optimized material selection and process development [2], a first generation demonstrator of a functional conformal module was produced, using a standard roof profile (Figure 4).



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Evaluation 2010 and Outlook 2011

The project started in the Spring 2009 and the first two milestones on selection of composite backing (end of 2009) and on selection of UV-coating formulation (end of 2010) have led to decisions on materials and process routes. The first generation of profiled module demonstrators has also been produced in 2010.

Focus in 2011 will be on:

- Optimization of the coating and texturing processes
- Production of textured coatings with the LTC roll-to-roll pilot line, and production of PV cells on the textured coatings
- Production of second generation of industrial demonstrator module:
  - dimensions of profiled modules 0.6 x 1.5 m
  - Current density > 13 mA/cm^2
  - Reliability: 50 humidity freeze cycles with <5% power loss

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[2] Rion J., Leterrier Y., Månson J.-A.E., Blairon J.M., Ultra-Light As mmetric Photovoltaic Sand ich Structures Compos. Part A., 40, 1167-1173 (2009)

Ackno ledgements

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APPLICATION DE ODULES P FLE IBLES SUR LE SITE DE PRODUCTION

Annual Report 2010

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Project- / Contract Number	103202 / 154220
Duration of the Project (from – to)	15th may 2009 – 31th december 2012
Date	07/12/2010

ABSTRACT

The goal of this project is to develop, install and monitor various building integrated PV products and installation solutions based on Flexcell's technology on the buildings of Flexcell's production site in Yverdon. The type of installations include application on insulated metal sandwich panels, on corrugated metal sheets, on gravel covered flat roofs, on bituminous flat roofs, and an application as a stand-alone roof.

During the reporting period, the large 86.4kWp roof applied on the sandwich panels of the storage hall ("stock"-site) was monitored over a first full year of operation. In this initial installation, which was realized with production startup modules of 2008, a first batch of modules show still some quality problems, such that a section of this roof was shut down in order to monitor correctly the remaining part of this roof. As a result, this roof shows excellent performance ratios over the second semester of 2010.

Further, during 2010, 3 more installations were realized and connected to the grid, including an installation where MO-type modules were for the first time used to perform the actual water tightness of a roof ("cafeteria"-site).

Buts du projet

Sise à Yverdon-les-Bains, VHF-Technologies SA, développe, produit et commercialise des modules solaires flexibles connu sous la dénomination « Flexcell ». La technologie de déposition par plasma haute fréquence de silicium amorphe en couches minces sur substrat plastique initié à l'IMT de l'Université de Neuchâtel est unique au monde et s'adapte particulièrement bien à la production de module BIPV.

La diversité des toitures du site de production de l'usine Flexcell à Yverdon permet de réaliser différentes installations (de 1 à 85kWp) pour atteindre une puissance PV installée de 140kWp. Les modules Flexcell légers s'adaptent à de nombreuses nature de toiture: bac acier, panneaux sandwich, membrane bitumineuses et polymères. Ils sont installés sans nécessairement requérir de support spécifique, mais directement sur la toiture existante ou monté en remplacement de l'étanchéité.

Ce projet vise à caractériser les diverses modes d'installation et les différents type de modules photovoltaïques offert par cette technologie. Il s'agit plus précisément de :

1. Illustrer différentes nouvelles solutions BIPV
2. Etablir le détail des couts complets investis dans chaque toiture pv
3. Mesurer les productions d'énergie et calculer la performance de chaque site en fonction des particularités architecturales et des spécificités des modes d'installations
4. Disposer d'un site démonstratif fonctionnel

FIGURE 1: DECO POSITION DE L ENCAPSULATION D UN ODULE FLE CELL

Les objectifs pour l'année 2010 consistaient à procéder à la réalisation de plusieurs installations, de tester différents types de fixation, de tester le fonctionnement d'une installation branchée sur un onduleur sans transformateur et d'assurer le suivi énergétique des installations réalisées précédemment.

Br ve description du projet

1. <u>Abri cafétéria (#13)</u>

Le site # 13 de « l'Abri cafétéria » est né d'une volonté d'intégration optimale de plusieurs sources solaires. En effet, l'objectif était de proposer une toiture à l'aspect uniforme pour une installation solaire thermique et photovoltaïque. La collaboration avec l'entreprise Energie Solaire SA a permis de développer un module de dimensions et de fixation identiques à celles de leurs modules thermiques.

Le développement du produit a été réalisé durant le premier trimestre 2010, le montage des modules a eu lieu en mai et l'installation a été mise en service en juin 2010.

2. <u>Garages (#5)</u>

Le site # 5 « Garages » a été réalisé dans le courant de l'année 2010. Selon les calculs, les cellules photovoltaïques à couche mince sur support flexible mince présentent une capacité plus importante que les cellules sur substrat de verre et considérée comme potentiellement dangereuse pour les personnes et les choses. Par conséquent, ce type d'installation doit être branché sur un onduleur avec transformateur interne. Ce qui permet une isolation galvanique entre la source photovoltaïque et le réseau de distribution. L'objectif de cette installation était donc de disposer d'une toiture de test pour y connecter des modules Flexcell sur un onduleur sans transformateur.

3. Chaufferie (#11)

Le site # 11 de la « Chaufferie » est l'installation de test de colles sur une membrane d'étanchéité bitumineuse avec paillettes d'ardoise. 4 types de fixation ont été testés sur cette toiture : des modules laminés sur une membrane polyoléfine TPO bituminée et collée à chaud, des modules laminés sur plaques métalliques et collés avec colles froides ainsi que des modules laminés sur plaques métalliques fixés mécaniquement sur des plaquettes, elles-mêmes collées à chaud sur la membrane d'étanchéité de la toiture ainsi que des modules imprégnés de bitume puis collés à chaud en plein sur la membrane.

4. Stocks (#4)

L'installation # 4 du « Stock » a été mise en service l'année précédente (2009) et elle fait l'objet de suivi sur cette période d'évaluation (2010)

.

FIG. 1: REALISATION DE L'ABRI CAFETERIA (SITE #13, HAUT A GAUICHE), DES GARAGES (SITE #5, HAUT A DROITE), DU PROTOTYPE TPO COLLE A CHAUD (SITE #11, BAS A GAUCHE) ET DES STOCKS (SITE #4, BAS A DROITE)

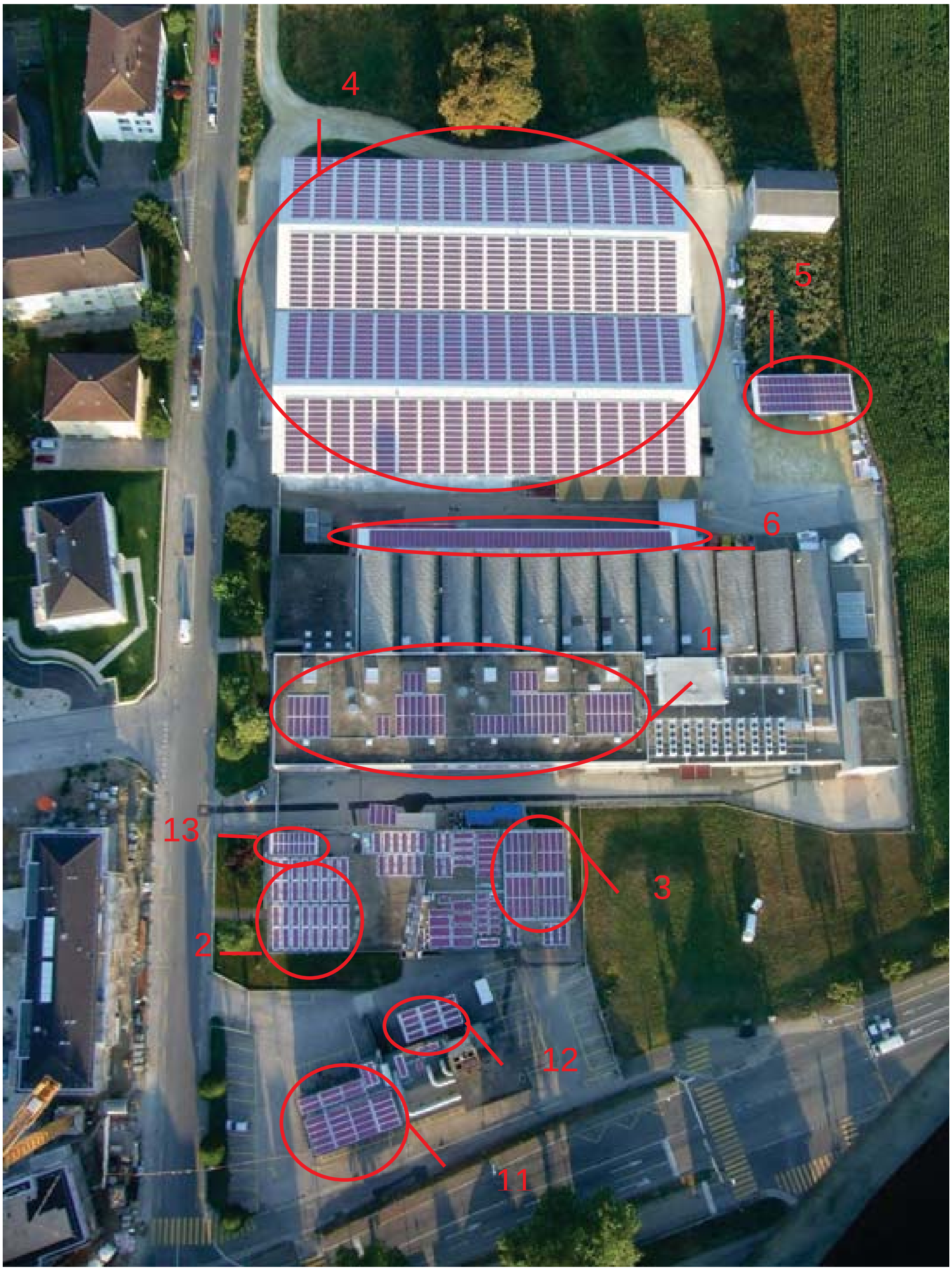


FIG. 2: PRISE DE UE AIRIAINNE DU SITE FLE CELL EN SEPTE BRE 2010. PENDANT L ANNEE 2010 ON ETE REALISEES LES INSTALLATIONS 5, 11, ET 13.

Travau effectu s et r sultats ac uis

1. Abri cafétéria

Le principe de fixation des modules selon la structure crée par Energie Solaire SA est le suivant :il s'agit d'un rail en aluminium à fixer directement sur la charpente à l'aide de taquet. Dans le profil des rails, est posée la tôle ondulée. Des joints en caoutchouc EPDM sont glissés dans les rails latéraux du profilé en aluminium. Ensuite, il faut placer les modules, à ras du bord des « T ». On vient fixer le tout avec un joint en EPDM, qui assure à la fois l'étanchéité et la fixation. Un nouveau module 1.5S11P a été développé pour satisfaire aux contraintes spécifiques des dimensions de ce système.

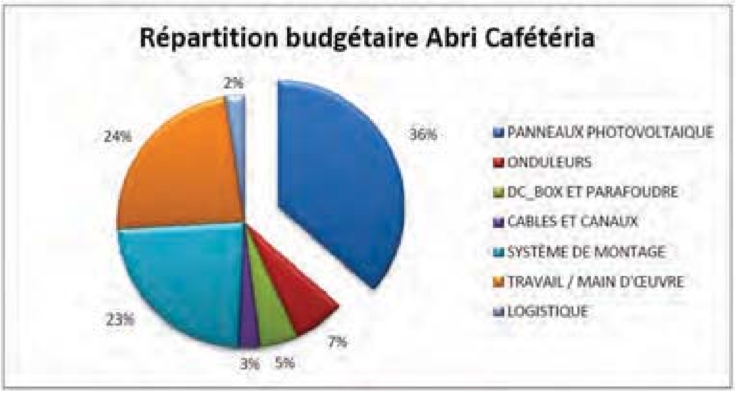
La puissance installée est 800 Wp, 4 strings de 4 modules. L'onduleur utilisé est un Synny Boy 700 de SMA. Le site a été mis en service le 23 juin 2010. Depuis ce jour, l'installation a produit 476 kWh au 10.12.2010.

Le planning de ce site fut le suivant :

Tâche	Terminé le :
Conception nouveau panneau	Le Lun. 12 Avril (*)
Lancement Production du panneau	Le Jeu. 15 avril
Production des panneaux	Prêt le Lun. 10 mai
Préparation du stand d'essai	Le Ven. 12 mars
Calepinage, Analyse	Le Mer. 17 avril
Commande du matériel	Le Lun.10 mai
wPréparation du chantier	Le Ven. 14 mai
Réception des marchandises	Le Mar. 18 mai
Pose des panneaux	Le Mar.18 mai
Pose des appareils électriques	Le Mar. 15 juin (**)
Branchement réseau (etps ext.)	Le Mar. 15 juin
Mise en route	Le Mer. 23 juin

FIG 3 : ABRI CAFETERIA

Le budget total pour cette installation a été de 9058 CHF dont la répartition est la suivante :Tous les éléments de construction, des joints d'étanchéité à la colle, sont strictement identiques aux prescriptions de l'entreprise « Energie Solaire SA ». Seul un trou de 10 cm de diamètre dans le plexiglas ondulé diffère, afin d'y glisser le boitier de jonction des modules PV. La toiture est parfaitement étanche et pourra être combinée avec aisance avec les capteurs thermiques de cette entreprise.



2. Garages

FIG 4 : GARAGES

Le site des garages a été sélectionné afin de tester un onduleur sans transformateur avec des modules photovoltaïques à couche mince. Une charpente en bois a été installée. Une toiture en bac acier trapézoïdal a été utilisée comme étanchéité. Celle-ci est reliée à la terre du réseau électrique. Des modules FLX-MO 1S11P ont été vissés sur cette toiture (de la même manière que le premier projet sur les toitures du Stock #4, cf le rapport annuel 2009). La puissance installée est de 4.86 kWp. Les modules sont câblés de la manière suivante : 3 strings de 8 modules sur le SB 2500 de SMA et 6 strings de 8 modules sur le SB 3000TL de SMA. Cela correspond donc à une puissance de 1620 Wp sur le premier onduleur avec transformateur et une autre puissance de 3240 Wp sur l'onduleur sans transformateur. L'installation a été mise en service le 10 septembre 2010.

Le résultat est sans appel : le transformateur utilisé Sunny Boy 3000TL détecte immédiatement un courant de fuite à la terre (I > 30 mA) et déconnecte l'installation.

Depuis la date de mise en service, la partie de l'installation branchée sur l'onduleur avec transformateur a produit 271.8kWh au jour du 08 décembre 2010. La deuxième partie a été débranchée au vu de son non fonctionnement avec l'onduleur sans transformateur.

Ce résultat pratique valide le calcul de courant de fuite des cellules à couche mince et nous appuie dans le choix d'onduleurs avec transformateur.

3. <u>Chaufferie</u>

Le site de la chaufferie est une toiture plate dont l'étanchéité est une membrane bitumineuse pailletée. Les toitures à membrane d'étanchéité bitumineuse couvrent une grande majorité des toitures plates industrielles. Deux sortes de fixation de ces membranes existent : soit elles sont lestées par du gravier soit elles sont collées en plein et fixées mécaniquement sur la structure de la toiture.

Flexcell avait développé en 2009 des supports pour les toitures lestées. L'installation test était le site #2 Admin présenté dans le rapport 2009. Cette année 2010 a fait l'objet de tests sur les membranes collées en plein et fixée mécaniquement.

Le site de la chaufferie s'y prêtait donc bien. Quatre groupes de fixation ont été testés :

a. Modules MO collés avec différents types de colles à froid
b. Modules DG (substrat enduit de bitume) collés à froid
c. Module TPO collé à chaud
d. Module MO vissé sur plaquettes de bitume collées à chaud

Les zones A et B sont raccordées au réseau électrique de distribution, les modules C et D ont uniquement faits office de test d'adhérence. La puissance installée est de 3.8 kWp branchés en 4 strings de 7 modules. L'onduleur est un Fronius IG 40. L'installation a été mise en service le 24 juin 2010.

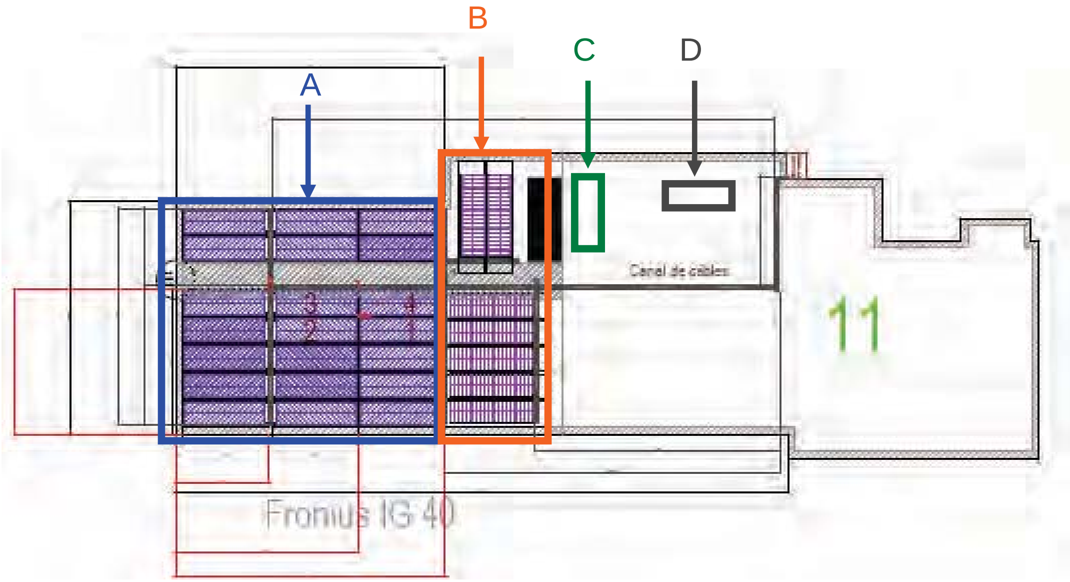


FIG 5 : SITE DE LA CHAUFFERIE

Sur la zone A, les colles Norco 604 et 60 ont été utilisées. Les modules ont été collés en plein. Le module a une surface totale de 4 m2. Il a été utilisé 6 kg de colle Norco 604 et 10 kg de colle Norco 60. La colle 604 collée en plein n'adhère pas sur l'ensemble de la surface du module. Ceci est dû aux différences de niveau de l'étanchéité de la toiture. La colle 60, par contre, adhère sur l'ensemble de la surface. Cependant la quantité utilisée fut de 10 kg pour 4 m2.

Colle 604 : 10.6 CHF/kg   Colle 60 : 11.75 CHF/kg

Sur la zone B, les modules ont été issus d'un développement conjoint entre Derbigum et Flexcell. La colle utilisée est la Derbibond. Les modules ont dans l'ensemble une bonne adhérence générale, cependant, quelques décollements ponctuels ont pu être observés. Son inconvénient principal, cependant, est son processus de fabrication ayant de multiples phases. Il est donc très coûteux et long à la fabrication.

Le module C est un module laminé avec du TPO. La colle utilisée est un mélange de bitume élastomère mélangé avec bitume oxydé (mélange 50/50). Le périmètre du module a été collé avec ce mélange de bitume à chaud. Lors du collage au bitume liquide des zones de débordement ponctuel ce son répartie à divers endroit sur le pourtour du module. Des tâches jaunâtres superficielles sont immédiatement apparues. Aucune adhérence ne se fait sur la membrane. Le décollement est immédiat.

Le module D sort du cadre de tests de colles sur bitume, mais reste dans le cadre de l'étude de fixation des modules sur membrane bitumineuse non lestée. Le principe ici est de fixer des plaquettes de bitume avec du bitume à chaud directement sur la membrane d'étanchéité. Ces plaquettes sont formées de deux couches de voile de polyester qui prennent une plaque de métal en sandwich. Une vis est fixée à cette plaquette.

Le module, pré-perforé, a ensuite été fixé avec des écrous sur les plaquettes.



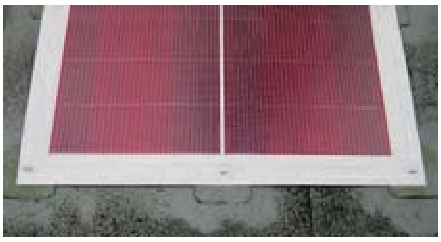


FIG 6 : COLLE NORCO (GAUCHE), TPO COLLÉ AU BITUME À CHAUD (CENTRE) MO VISSÉ SUR PLAQUETTES (DROITE)

Les conclusions qui peuvent être tirées de ces essais sont les suivantes : la colle 604 ne permet pas une adhérence du module sur la membrane. La colle 60 a une bonne adhésion, son désavantage est son prix de 117 CHF par module. Le procédé des modules bituminés Derbigum-Flexcell reste intéressant du à sa facilité de pose, le procédé de fabrication est en cours d'étude pour le rendre viable. L'adhérence du collage avec du bitume à chaud sur du TPO n'est pas du tout satisfaisante, cette solution a été rejetée. Le module vissé sur des plaquettes a une très bonne adhérence sur le bitume. Celle-ci reste très bonne même lors de températures extérieures supérieures à 35°C Son inconvénient est la pré-perforation en usine des modules. De même, la pose, au moyen d'un cadre, est longue et donc coûteuse.

4. Stocks

La toiture des stocks a été la première réalisation dans le cadre de ce projet, avec la construction en été 2009, et le branchement électrique en novembre 2009. Cette installation consiste de 864 modules de type MO de 100 Wp chacun, vissés sur éléments sandwich métalliques du toit du bâtiment des stocks. La puissance nominale est donc de 86.4 kWp. Comme le toit comporte deux orientations en quatre pans, deux onduleurs de 50 kW chacun groupent les strings est et les strings ouest (72 strings de 6 modules pour chaque orientation) (voir Figure 2, section #4).

Dans cette installation a montré un performance ratio (PR) de 90% dans les rares jours ensoleillés directement après le branchement en novembre 2009. Après, le PR le tombait rapidement en décembre et janvier, pour remonter en février et mars puis rechuter à partir du mois d'avril. Tandis que la chute hivernal du PR est normal pour une installation horizontale en silicium amorphe en Suisse, le ralentissement de la régénération (annealing saisonal) en mois d'avril et puis une rechute vers l'été n'est un aucun cas attendu. L'analyse des strings et puis des modules individuels a donnée comme résultat que les modules avec un premier layout des conducteurs de cuivre, qui était utilisé pendant le démarrage de l'usine, on augmenté leur résistance sérielle de façon à perdre pratiquement tout leur puissance. Après 6 mois d'opération, ce problème avait déjà touché au moins 20% des modules, et a donné comme résultat que pratiquement tous les strings équipés avec ce premier type de modules ont perdu au moins un des modules par string de 6, et n'arrivaient donc plus à injecter de la puissance à la tension de travail de 280 volt. Il a donc été décidé de déconnecter à la fin du mois de juin toutes les strings basées sur ce type de modules potentiellement défectueux, cad 64 strings de 600 Wp sur un total de 144 strings). La puissance DC connecté de l'installation a été donc réduite de 86.4 kWp à 48 kWp. Dans cette nouvelle configuration, comprenant uniquement les panneaux produites une fois le default de cuivre éliminé, un excellent PR est observé sur le deuxième semestre 2010. Les valeurs de 120% atteints en été donnent raison à dire que les modules ont en effet été sous-spécifié, et que leur puissance nominales siuterait plutôt vers 120 Wp (à comparé avec leur valeur nominale de 100 Wp).

Sur toute l'année 2010, l'installation à injecté 70453 kWh dans le réseau en 2010 (1.1.-15.12.), ce qui revient à 815 kWh/kWp (à base de 86.4kWp installés). Si on prends le deuxième semestre avec une production de 30500 kWh et une puissance de 48kWp installé, ca donne 635 kWh/kWp par semestre, voir, en extrapolant, potentiellement 1270 kWh/kWp par année (NB : ceci en prenant toujours une puissance nominale de 100 Wp par module).

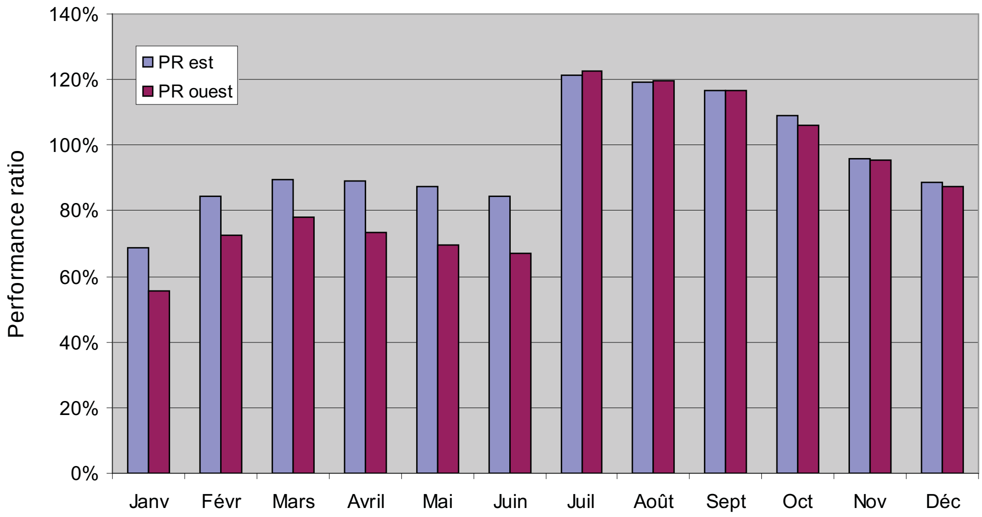


FIGURE 7 : PR DE L'INSTALLATION « STOCKS » EN 2010 : PUISSANCE CONNECTÉ JANV-JUIN : 86.4 KWP, JUILLET-DÉC 48 KWP. EXPLICATIONS : VOIR TEXTE CI-DESSUS

valuation de l ann e 2010 et perspectives pour 2011

L'année 2010 a permis de réaliser de réaliser trois installation supplémentaires : une installation comme étanchéité métallique, une installation sur bac acier horizontal avec des onduleurs avec et sans transformateur, ainsi que diverses solutions sur toit plat bituminé. Par ceci, toutes les solutions et systèmes Flexcell, sauf la membrane d'étanchéité TPO, sont maintenant installés et connectés sur le site Flexcell à Yverdon. Ceci permet à Flexcell d'analyser leur comportement, et aussi d'utiliser ces installations comme vitrine pour des clients et d'autres intéressés dans la technologie BIPV de couche mince flexible.

L'année 2011 sera axée sur la réalisation d'une dernière installation en TPO comme couche d'étanchéité, ainsi que sur des analyses de production plus approfondies de toutes les installations connectées.

R f rences

[1] *Site internet F E CE VHF-Technologies S* , www.flexcell.ch

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Bundesamt für Energie BFE

PHOTO OLTAI I ERBUND IT D - STOFF FOA GLAS

Jahresbericht 2010

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Telefon, E-mail, Internetadresse	
BFE Projekt-/Vertrag-Nummer	Foamglas
BFE-Projektleiter	Stefan Nowak
Dauer des Projekts (von – bis)	Dezember 2010 – Dezember 2013
Datum	13. Dezember 2010

USA ENFASSUNG

Als reiner Stromproduzent hat sich die Photovoltaik längst etabliert. Jünger, jedoch inzwischen bestens bewährt sind "Indachsysteme", bei welchen die Photovoltaikmodule nebst der Stromproduktion die Funktion der Wasser führenden Dachhaut übernehmen. Fast gänzlich unbekannt sind jedoch Systeme, bei welchen Photovoltaik nebst den oben genannten Funktionen die weitere Funktion der Wärme- und Schalldämmung übernimmt. Im Rahmen dieses Projekts soll diese dritte Funktion untersucht werden. Eine Demonstrationsanlage soll mit einem eigens dafür entwickelten Produkt aus PV und Foamglas errichtet werden.

Das Projekt "Photovoltaik im Verbund mit Dämmstoff Foamglas" wurde im Frühjahr 2010 in die Wege geleitet und im Dezember 2010 offiziell gestartet. Die Arbeiten im Jahr 2010 konzentrierten sich dabei intensiv auf die Projektvorbereitungen:

- Literaturstudium, Marktrecherche: In einer Literatur- und Marktrecherche hat sich gezeigt, dass bisher nur wenige Lösungsansätze in die Stossrichtung des Projekts untersucht wurden. Ein früheres vom BFE unterstütztes Projekt ("62 kW Flachdachanlage mit PowerGuard Solardachplatten") erzielte aufgrund der Eigenschaften des dort untersuchten Dämmstoffs nicht die gewünschten Resultate. Mit der Recherche hat sich die Projektumsetzung aufgedrängt.
- Finden von Lösungsansätzen: In einer ersten Kreativphase wurden verschiedene Lösungsansätze entworfen, PV mit Foamglas in Verbindung zu bringen.
- Formulieren einer Roadmap: In einem Projektplan werden die Meilensteine definiert, welche es zur erfolgreichen Projektabwicklung aus der heutigen Sicht zu erreichen gilt.

In den kommenden Jahren soll der Verbund von PV-Modulen mit dem Dämmstoff Foamglas intensiv getestet werden. Mit den Erfahrungen aus dem Projekt soll es möglich werden, für PV neue Anwendungsgebiete zu erschliessen.

Projekt iele

In diesem Projekt soll mindestens ein Produkt aus PV und FOAMGLAS entwickelt werden. Folgende Schritte Ziele werden dabei avisiert:

- erbund P -FOA GLAS
  PV-Module oder Zellen sollen dauerhaft (min. 25 Jahre) stabil mit FOAMGLAS verbunden werden können. Aus einer Reihe von Lösungsvorschlägen sollen die besten Optionen getestet werden. Parallel dazu werden Versuche und Testverfahren unternommen, insbesondere zu den Möglichkeiten der Verklebung von ungerahmten PV-Modulen (PV-Laminate). Die Kabelführung soll dabei derart geschehen, dass einerseits die Funktion des Dämmstoffes und andererseits die Möglichkeit zur Wartung der PV-Anlage bestehen bleiben.

  Hauptziel ist, ein Produkt auf den Markt zu bringen, welches von Beginn weg im Markt bestehen kann. Neben den technischen Funktionen sollen auch architektonische Aspekte wie Formgebung, Farbe, Randabschlüsse etc. berücksichtigt werden.

- Ertrags- und Unterhaltsprognosen
  Die Auswirkungen der Kombination PV und FOAMGLAS in Bezug auf Betrieb und Unterhalt sollen aufgezeigt werden. Folgende Fragen gilt es dabei zu beantworten:

  - Wie stark verändert sich der Energieertrag der PV-Module bei einseitiger Wärmedämmung der Module?
  - Welches sind die zulässigen thermischen und mechanischen Lastgrenzen?
  - Wie gestaltet sich der Unterhalt, namentlich das Austauschen einzelner Module, Kabel oder Stecker von Solarmodulen, die im Verbund mit FOAMGLAS eingesetzt werden?

  Des Weiteren soll die Umweltverträglichkeit sowie die Möglichkeit zur Rezyklierung geprüft werden.

- Poten ieller arkt / Einsat bereich
  In einer detaillierten Marktanalyse soll festgestellt werden, in welchen Einsatzgebieten bisherige Systeme nicht erfolgreich eingesetzt werden konnten, resp. wo mit der Kombination PV-FOAMGLAS Vorteile für den Anlagebesitzer zu tragen kommen. Die Gebäude- und Anlageplaner sollen auf die Möglichkeit der Doppelnutzung des Dämmmaterials als Dämmstoff und Unterkonstruktion für PV-Module aufmerksam gemacht werden.

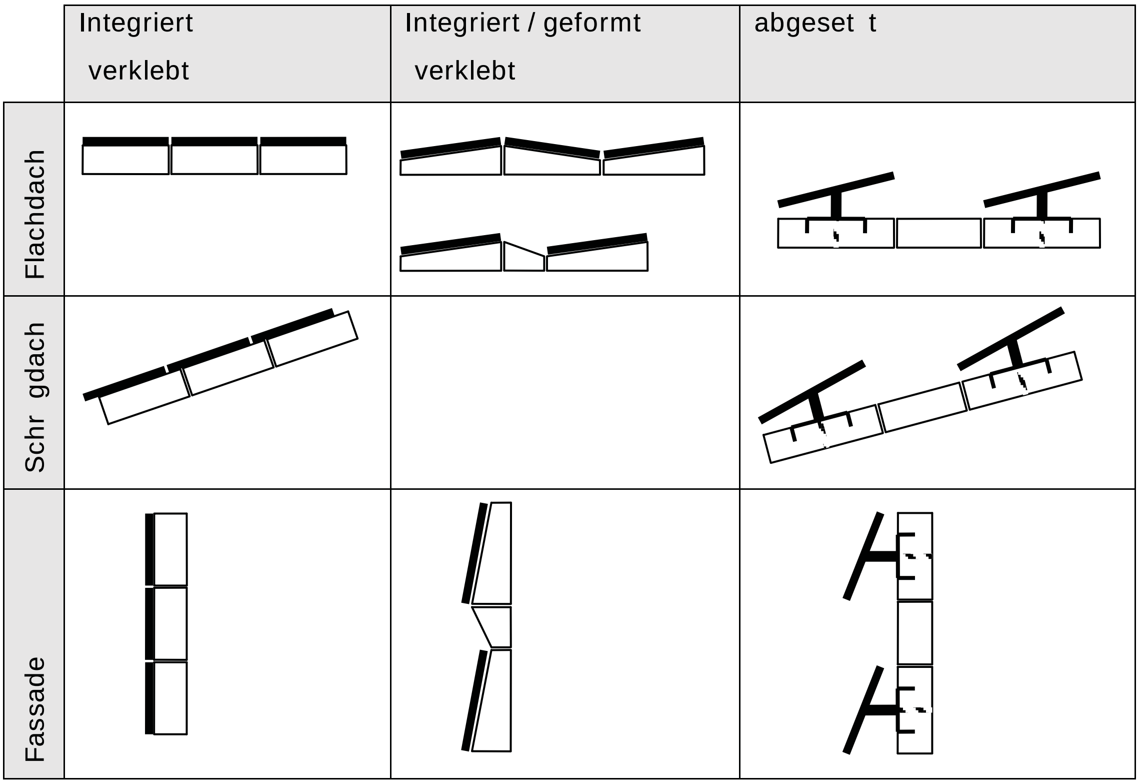
- gliche S nergien auf eigen
  Die Kombination eines Dämmstoffes mit Photovoltaik wirkt auf den ersten Blick paradox: Wird doch bei der Gebäudeintegration von kristallinen PV-Modulen meist darauf geachtet, diese möglichst gut zu hinterlüften. Im Verbund mit einem Dämmstoff kann diese Hinterlüftung gänzlich verloren gehen. Hingegen ist zu beachten, dass eine Vielzahl von integrierten PV-Anlagen an eine gedämmte Gebäudehülle gebaut ist. Und genau da soll dieses Projekt ansetzen. Synergien sollen aufgezeigt und genutzt werden.

  Welche Synergien ergeben sich aus der Kombination von PV und FOAMGLAS? Wie lassen sich Kosten derart einsparen, dass zwei hochwertige Produkte im Verbund Vorteile gegenüber herkömmlichen Systemen aufweisen?

- Wirtschaftlichkeit
  Durch die gefundenen Synergien sollen Kosten eingespart werden können. Mit einer Kostenanalyse soll das Einsparpotenzial aufgezeigt werden.

Durchgeführte Arbeiten und erreichte Ergebnisse

Die Ergebnisse der durchgeführten Arbeiten werden im Wesentlichen im Projektantrag widerspiegelt. Zentral dabei ist die Untersuchung über die Anwendungsmöglichkeiten von PV mit Foamglas. Die Integration von PV-Modulen in Gebäude resp. der Anbau von PV-Modulen auf Gebäude kann nach folgender Übersicht in neun Gebiete aufgeteilt werden:



Dabei zeigen sich zwei grundsätzliche Unterschiede in der Ausführung:

- PV-Module auf FOAMGLAS verklebt
- PV-Module abgesetzt an FOAMGLAS befestigt.

Nationale usammenarbeit

Das Projekt wird in Zusammenarbeit mit drei Partnern abgewickelt:

- Pittsburgh Corning (Schweiz) AG
  Schöngrund 26
  CH-6343 Rotkreuz

- Basler & Hofmann AG
  Forchstrasse 395
  8032 Zürich

- ISAAC-DACD-SUPSI
  Swiss BiPV Centre of competence
  Via Trevano CP 105
  6952 Canobbio

Dabei wird die hauptsächliche Projektarbeit von der Firma Pittsburgh Corning (Schweiz) AG ausgeführt, welche das Produkt Foamglas herstellt und damit mit dessen Eigenschaften sehr gut vertraut ist. Die langjährige Erfahrung mit Photovoltaik wird durch die Basler & Hofmann AG dem Projekt zugetragen. Das schweizerische Prüfzentrum für Photovoltaik ISAAC-DACD-SUPSI wird seine Kompetenzen im Bereich Modul- und Systemtest ins Projekt einfliessen lassen.

Internationale usammenarbeit

Für das Projekt ist keine internationale Zusammenarbeit vorgesehen. Experten der Firma Pittsburgh Corning werden bei Bedarf aus dem internationalen Raum für das Projekt hinzugezogen.

Be ertung 2010 und Ausblick 2011

Die Projektvorbereitungsphase konnte mit diesem Bericht erfolgreich abgeschlossen werden. Die Vorbereitungsziele wurden erreicht.

Für die kommenden Jahre ist das Vorgehen gemäss dem Meilensteinplan ("Fast Prototyping") vorgesehen:

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Referen en

Dieser Jahresbericht referenziert ausschliesslich auf den Projektantrag " Photovoltaik im Verbund mit Dämmstoff FOAMGLAS".

Systemtechnik

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P T PROJECT

MULTI PURPOSE PHOTOVOLTAIC MODULE TESTER

Annual Report 2010

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Project- / Contract Number	KTI-CTI project, 9626.1 PFIW-IW
Duration of the Project (from – to)	01.010.2008 – 31.03.2011
Date	13.12.2010

ABSTRACT

The aim of the P T ulti-Purpose P odule Tester project is to develop an extremely versatile measurement equipment for the indoor testing of PV modules by upgrading and integrating new functionalities into an existing solar-simulator (flasher) based IV measurement set-up.

The newly developed MPVT set-up should be able to realize IV measurements at standard test conditions, temperature coefficients (TCO's) and measurement at different irradiance levels. In addition, a set-up to measure spectral response (SR) of large-area module will be implemented in the system.

The MPVT system will be adapted to the needs of the different PV technologies present today on the market, which require a larger flexibility in terms of electrical measurement conditions (high-voltage/low-current thin film PV and high-current/low-voltage c-Si technologies).

Moreover, traditional or alternative solutions will be implemented to overcome problems - related to the short duration of the light pulse -which some technologies may encounter when performing power measurements with flashers, as for example, high efficient c-Si modules, which are characterized by high cell capacitances.

The status of the project is briefly reviewed.

Aims of the project

The P T ulti-Purpose P odule Tester project is funded by KTI-CTI (project number 9626.1 PFIW-IW) and has a duration of 24 months. The industrial partner is PASAN SA (Neuchatel) – manufacturer of solar simulators and measurement equipments for photovoltaic (PV) devices – and the research partners are two research institutes of SUPSI (Scuola Universitaria Professionale della Svizzera Italiana): SUPSI-DACD-ISAAC (www.isaac.supsi.ch) – and SUPSI-DTI-ISEA (www.dti.supsi.ch). ISAAC (Institute for Applied Sustainability to the Built Environment) is involved in the project with its Photovoltaics Sector (testing of PV devices and systems). ISEA is the Institute for Systems and Applied Electronics.
The main goal of the project is to adapt the measurement equipment (solar simulator set-up) for the current-voltage (IV) characterization under standard test conditions (STC: 1000W/m², 25°C, AM1.5) of PV modules and solar cells to the needs of the market, characterized by an increasing number of technologies commercially available – which require different measurement procedures and/or approaches - and by a continuously increasing size of the PV devices

Besides the flash lamp, the heart of a solar-simulator set-up is the electronic load, which has to respond to all requirements of a multipurpose solar simulator. The newly developed MPVT electronic load will be offered at testing and research laboratories worldwide and will be the basis for the development of a high efficient and cost effective in-line testing for PV module manufacturers.

The motivations to develop a new electronic load can be summarized as follows:

• Need for a larger range of electrical test conditions

The size of PV modules – both c-Si based and thin film (TF) technologies - is continuously increasing, challenging the existing test equipment, which was mainly developed for standard crystalline silicon PV modules. E.g. the largest thin film PV modules (5.2 m^2) present on the market are approaching powers close to 500 W.
There is therefore a need for more flexible measurement equipment able to test high voltage (TF) and high current (c-Si) devices.
The power unit of the new MPVT electronic load will be adapted to these requirements.

• Testing conditions different from STC

An increasing awareness in recent years about the need to optimize PV modules for their energy production (kWh) under real operating conditions rather just than for their power (Wp) measured at standard test conditions, has led to a growing demand for test equipment capable of characterizing a module under different irradiance, temperature and spectral conditions.
Very few of the existing solar simulator manufactures offer a light generator and electronic suitable for IV testing at STC, different temperature and irradiance levels in one solution; and none of these offers a system for the measurement the spectral response (SR) of the PV device.
The future adoption by IEC (International Electro-technical Committee) of an *n Ratin* standard (IEC 61853, currently under draft) will further increase these requirements.
The new MPVT electronic load (HW and SW) could easily be adapted to test TCO (temperature coefficients) and IV curves at different irradiances.

• Need for a commercial spectral response SR s stem for large-area P modules

The SR curve of a module is crucial for a correct calibration of PV devices and for precise energy predictions under real operating conditions where the spectral composition of the light changes continuously. Presently no existing solar simulator manufacturer offers a full solution for the testing of SR of large-area modules.

The new MPVT system (HW and SW) will offer the possibility to perform SR measurements on these devices.

• Need for specific solutions for thin film and high efficienc c-Si modules

Larger and more efficient PV technologies entering the market are challenging the existing test equipment, which was mainly developed for standard crystalline silicon PV modules.

Current equipment offered by manufacturers is not always capable of measuring these technologies.

E.g. one of the typical problems encountered with pulsed solar simulators is the difficulty to test high efficiency c-Si modules, which are characterized by high cell capacitances.
Standard measurement approaches do not allow the discharge of this capacitance within the duration of the light pulse, therefore, introducing strong measurements artifacts in the IV measurements of these technologies. This measurement artifacts may lead to strong over- or underestimation of the measured power (up or down to more than 20%, respectively).
Traditional approaches to overcome these problems – as sectional and point-by-point multi-flash IV measurement approaches - are generally time consuming and costly.

The newly developed MPVT system will implement these traditional approaches (as the multi-flash one) but also investigated specific alternative solutions to overcome these problems (as the measurement of dark IV curves or the use of modified voltage profiles) If these solutions will provide ease of implementation and will result in an increased time- and cost effectiveness they will be implemented in the final MPVT measurement set-up.

First results

The prototype of a novel electronic load (EL) – shown in Fig.1 - has been manufactured by PASAN and handed over to ISEA and ISAAC in July 2010 for integration tests.
The software (SW) is still under development at PASAN, though the first release is now ready and the EL can be governed by a low-level SW interface for testing purposes.

First integration test have shown that the prototype is working properly, though some oscillations problems still need to be solved.

ISEA is about to complete the new power board of the EL which should allow for example the testing of dark IV characteristics. Integration test of the power board into the EL will be carried out in January and February 2011.
The validation of the entire system – including for example the testing of modified voltage profiles for highly capacitive devices – will be carried out in the period January - March 2011.
Figures 2 and 3 show the results of initial testing of highly capacitive devices (SANYO HIT). By applying – during the duration of a single 10-ms light pulse - a triangular voltage profile at the terminals of the modules, it is possible to drive the module from short-circuit (Isc) to open-voltage (Voc) conditions and vice versa. The asymmetrical behavior of the measured current in Fig. 2 and the fact that the two IV curves in Fig. 3 do not overlap, are an indication that the module is capacitive.

Figure 1: prototype of the novel MPVT electronic load (EL) manufactured by Pasan SA.

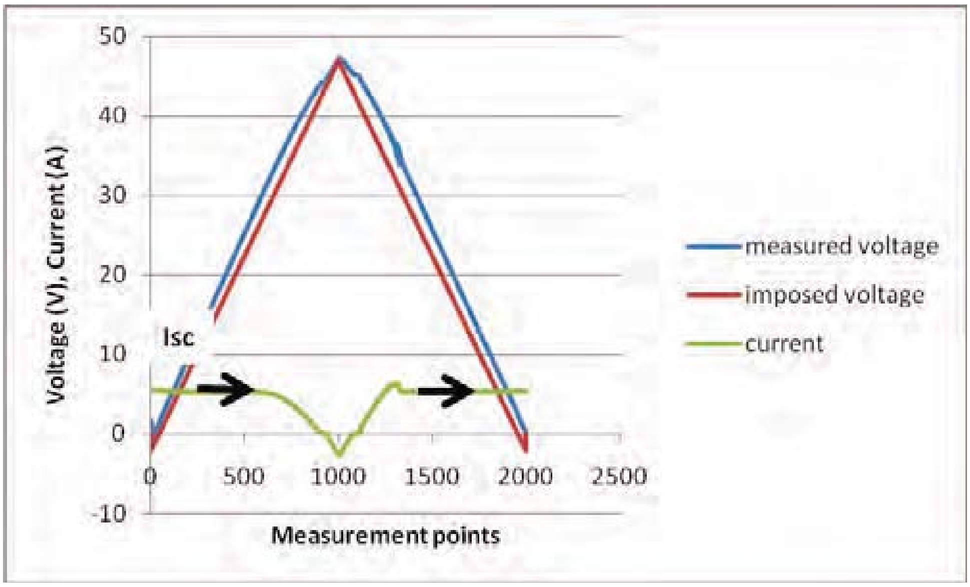

Figure 2: Imposed and measured voltage and measured current upon applying a triangular voltage profile at the terminals of a capacitive PV module.

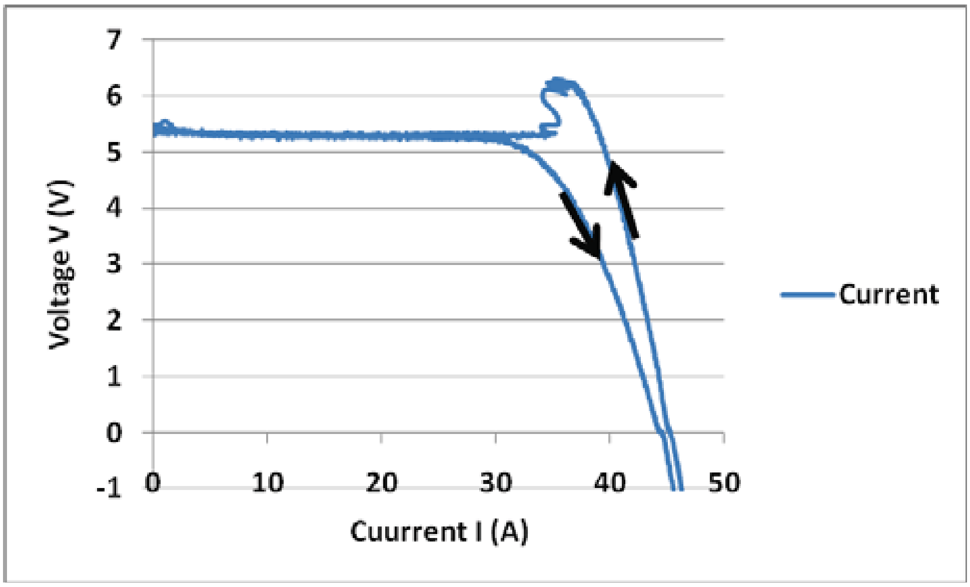

Figure 3: IV characteristics obtained by plotting data contained in Fig.2. By applying a triangular voltage profile at the terminals of the modules, during the duration of a single 10-ms light pulse - it is possible to drive the module from short-circuit (Isc) to open-voltage (Voc) conditions and vice versa. The fact that the two IV curves do not overlap, are an indication that the module is capacitive.

Dissemination

[1] A. Virtuani, G. Friesen, D. Chianese, G.C. Dozio, G. Rigamonti, M. Pegurion, P. Beljean, THE P T ULTI-PURPOSE P ODULE TESTER PROJECT - A HIGHL INNO ATI E AND ERSATILE SOLAR SI ULATOR, presented at the 25th European Photovoltaic Solar Energy Conference and Exhibition, Valencia 6-10 September 2010;

[2] C. Meza, A. Virtuani, D. Chianese, E ALUATION OF ODELS FOR THE INTERNAL CAPACITANCE OF A P OD-ULE FOR THE DESIGN AND SI ULATION OF POWER CON ERTERS, presented at the 25th European Photovoltaic Solar Energy Conference and Exhibition, Valencia 6-10 September 2010;

LIFETI E, ECHANICAL AND SAFET TESTING FOR P ODULE CERTIFICATION

Annual Report 2010

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Duration of the Project (from – to)	
Date	03.01.2011

ABSTRACT

In the expanding PV market testing and certification capacities constitute a serious bottle-neck. The institute ISAAC of Supsi has a long experience in PV module testing and intended with this project to set-up a laboratory, capable to respond to the growing request be the national and international PV industry. The project includes important investments in testing equipment reinforcing the position of ISAAC in the field of PV module characterization for services as well as for research.

The overall goal of this project was to set-up, in the course of 6-8 months, a new test centre to be accredited according to the ISO 17025 standard for testing laboratories and to dispose of the IEC tests cycles to carry out the PV module qualification. This goal has been reached in due time and within the limits of the budget.

The test centre is fully equipped to carry out the test cycles according to the three presently relevant testing standards for PV modules defined by the IEC norms:

- IEC 61215 – design qualification and type approval of crystalline PV modules
- IEC 61646 - design qualification and type approval of thin film PV modules

In addition this qualification tests will be completed by the security tests as requested from the

- IEC 61730 – safety qualification of PV modules.

The expected productivity of the laboratory is about 32 certifications in the first year and should reach after three years up to 40 certifications. About 15%-20% of the capacity of the test centre is dedicated to research purposes. The laboratory offers new opportunities for the development of the research activities at the ISAAC, increasing the range of topics and enhancing the relationship with the industry as expressed in the long term strategy of the institute.

The test centre has been presented at the 8th Nationale Photovoltaiktagung in Winterthur in February, and was present on invitation by OSEC with its own stand at the Hannover Energiemesse in spring 2010 and at the 25th European Photovoltaic Solar Energy Conference Exhibition and 5th World Conference on Photovoltaic Energy Conversion in Valencia (Spain) in September 2010.

Aim of the project

In the fast growing PV market the successful industries in this market are looking for new testing laboratories. The Institute of Applied Sustainability to the Built Environment (ISAAC) at the University of Applied Sciences in Lugano is the Swiss competence centre for the PV module characterization and an internationally recognized test laboratory for the electrical measurements. The institute already disposes of indoor testing facilities and outdoor test stands and has over twenty years of experience in the field of photovoltaic.

The overall goal of this project is to set-up a new test laboratory by integrating the accredited tests for the PV modules with new tests on lifetime, mechanical and security aspects according to the IEC standards for crystalline and thin film PV modules.

Project description

The project basically consisted in the set-up of a test laboratory from scrap including the planning of the layout and construction of the internal spaces of the laboratory. The building had to accommodate all the instruments for the lifetime and safety testing of PV modules as well as the sun simulators, which is determined by:

- Thermal cycling, damp heat and climatic test chambers
- Mechanical load tester – hail tester – module breakage tester
- UV resistance of the materials
- Steady state sun simulator and flash sun simulator

These lifetime and safety tests enable ISAAC to cover the complete certification according to the three presently relevant certifications standards for PV modules defined by the IEC norms:

- ➢ IEC 61215 – design qualification and type approval of crystalline PV modules
- ➢ IEC 61646 - design qualification and type approval of thin film PV modules

In addition this qualification tests will be completed by the security tests as requested from the

- ➢ IEC 61730 – safety qualification of PV modules.

The expected result of this project was to set-up, in the course of 6-8 month, a new ISO-17025 accredited test centre and to dispose of the IEC tests cycles to carry out the PV module qualification. This goal has been reached in due time and within to the limits of the budget. The expected productivity of the laboratory is about 32 certifications in the first year and should reach after three years 40 certifications. About 15%-20% of the capacity of the test centre is dedicated to research purposes. The laboratory offers new opportunities for the development of the research activities at the ISAAC, increasing the range of topics and enhancing the relationship with the industry as expressed in the long term strategy of the institute.

The new equipment of the laboratory can also be used for research purposes such as:

- Mechanical tests in particular for the BiPV group
- Lifetime of new lamination materials
- New design of modules
- New measurements and testing methods for thin film PV modules.

Work carried out and results achieved

In the following paragraphs the equipments for the most significant of the 29 tests will be shown, which can be carried out in the laboratory.

Building

A major challenge for this project was to find an adequate space. According to the plans and the layout of the laboratory a building with at least 1000 m^2 was needed. This space was not available in the school buildings. The search for an industrial building with the necessary surface was the first step in the realization of this project. The plan for the layout and the work for the internal division of the building was carried out by the ISAAC team, reducing significantly the time from the desk to the building. The empty building was ready on 1^{st} of May.

utsi i

nsi i t a at

Fig.1*: in ust ia ui in stin t n P t st a at in a n*

The building is located in a strategic position, with a good accessibility for the clients, about ten minutes from the institute and well served by public transport. The building also includes a large roof, which is supposed to be prepared next year for outdoor measurements. The building corresponds the new energy requirements of the Canton Ticino. The energy efficiency standards for buildings could be reached thanks to the use of residual energy of the climatic chambers.

Workflo

The testing and certification of PV modules needs a very tight management and workflow planning.
The testing process concerns from 8 to 11 different modules depending on the required IEC standard of different ongoing test procedures. Fig. 2 shows an example of the IEC 61646 flow.

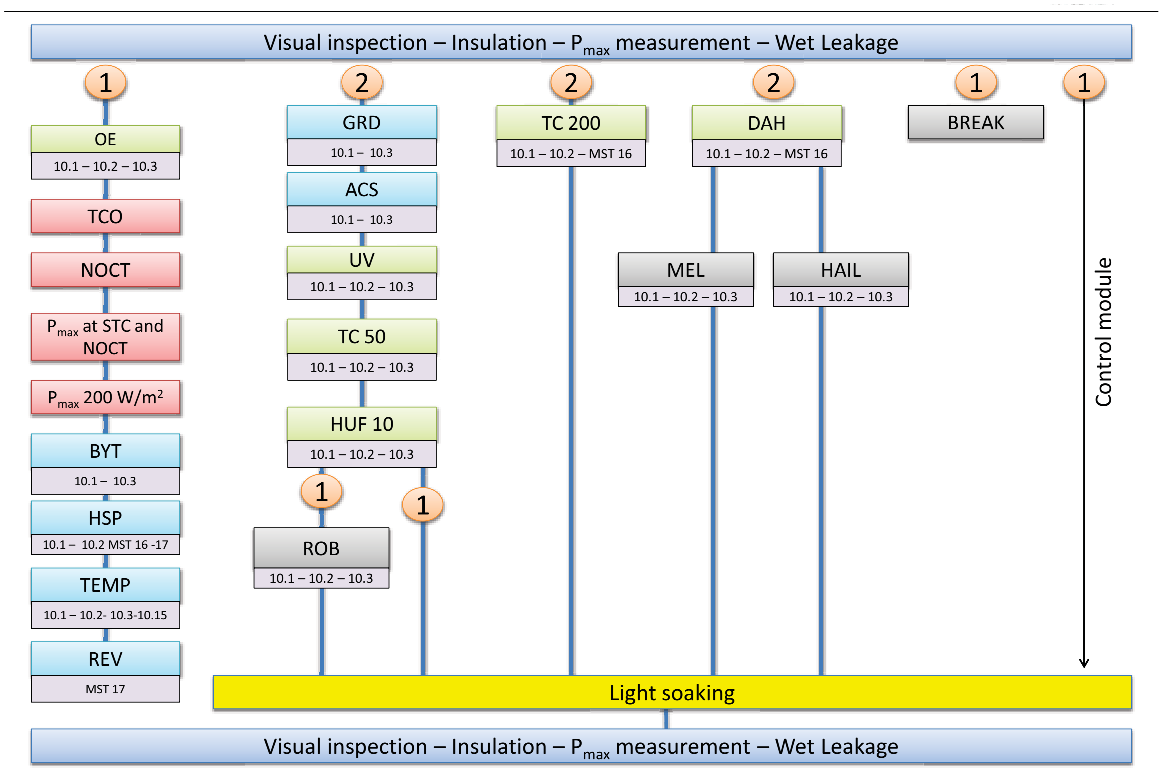

Fig : a t -

Database

In parallel to the equipment purchase and installation an intranet web portal was developed with a database to manage the ISO 17025 quality system and to stock all tests results. All tests results are acquired by PC and saved in the database. The single test reports and the final report are generated automatically by the web portal.

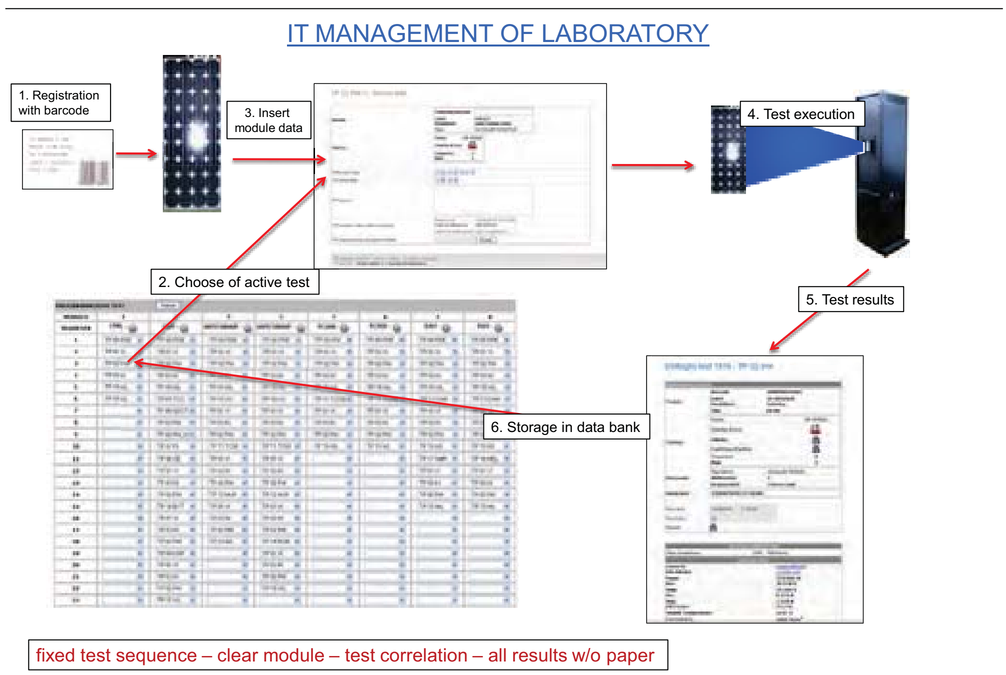

Fig : ana nt t u t stin s u nc an su ts

Where necessary the data acquisition system and the relative software to acquire the data automatically were created in-house. The database is also used for the PV module registration and all instrument and equipment quality control.

Lifetime

The major investment in the laboratory regards the lifetime and durability tests, carried out in three different climatic chambers, all designed to accommodate the latest PV modules with the dimension of 3.2 m x 3.3 m:

Thermal cycling (TC) chamber; humidity freeze (HUF) cycling chamber; damp heat (DH) chamber

Fig : t ci atic c a s

The two cycling climatic chambers are equipped with a condenser in order to recover the residual energy from the 100 kW compressors systems of each chamber. This allows heating the laboratory during the winter time. Recovering the residual heat was also a condition to comply with the new standards of the energy law in Ticino introduced on the 1st of January 2009 and is in line with the general concern of the Institute of energy efficient buildings.

It was the first time the German leader company for climatic chambers had to resolve the problem of energy recovery. Being an innovative company they gladly accepted the challenge and we succeeded together to face this problem in a very satisfactory way.

To simulate the UV exposure and aging of the PV modules a thermal chamber with UV lights was installed. The chamber can work at temperatures from 40°C to 90°C and the UV light is generated by UV lamps with a spectrum similar to the sun light.

Fig : t a c a

echanical tests

The mechanical tests for PV module certification constitute a new area for the PV sector of the institute.

Fig : c anica a

The mechanical tests include mechanical load test applied by pistons to the PV module (pressure and traction) to simulate the mechanical pressure from snow and wind (Fig. 5). The maximum pressure is 5400 pa.

Another important test is the hail test (shown in Fig. 6). We are equipped with a 25 mm according to IEC and a 35 mm gun for tests needed by the Swiss building insurances.

Fig   :   ai t st

The last important mechanical test set up is the PV module breakage test shown in Fig. 6.

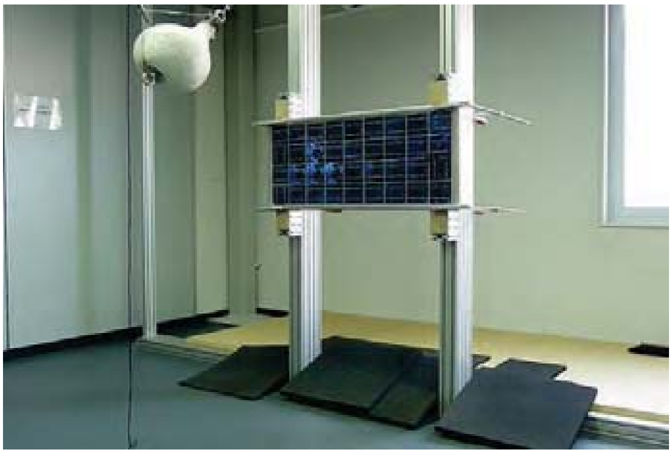

Fig   :   u   a a   t st

The other smaller mechanical tests for IEC testing as cutting test, robustness of terminals, conduit bending test and box knock out test were also installed.

Electrical safet

The following electrical safety tests are installed in the laboratory:

- Reverse current test
- Ground continuity test
- Insulation test up to 6000 V
- Wet leakage test
- Accessibility test (see fig. 7)

Fig cc ssi i it t st it a ti icia in an cuttin t st

Electrical measurement and sun simulators

On the roof of building B in Trevano we added to our existing test stands a NOCT stand to measure four modules simultaneously and a stand for the outdoor exposure of the modules. In addition we perform the preconditioning of the PV modules and measure the hot spot endurance test on the roof. All tests and the data acquisition on the roof are integrated the intranet web portal and the relative database.

Fig : tan

In the new laboratory in Lamone a dark room with the PASAN IIIa flasher (class AAA) was also set up and the ‘old’ thermal chamber for TCO measurements, which were used in the dark room in Trevano. In Trevano the flasher is a PASAN IIIb (class AAA) in combination with a new thermal chamber for TCO measurements. This chamber has a temperature range from 5°C to 100°C and is very useful even for research purposes.

In Lamone a steady state sun simulator class CCB for the light soaking of thin film PV modules and the hot spot endurance test was also installed. During the light soaking the modules are monitored by the MPPT developed by ISAAC (MPPT3000).

Fig : st a stat sun si u at c ass

Accreditation Process

The accreditation for product testing bodies is defined by the ISO Standard 17025 and conducted by the Swiss Accreditation Service (SAS) with the technical support of an expert. The technical expert comes from the JRC ISPRA (IT), where the test procedures were developed in the past. The pre-audit took place in August 2009 after the installation of the climatic chambers and the final audit on the 16th and 17th of November 2009. The required correction measures were implemented immediately after the audit in November besides the construction of a new parapet complying with the construction and safety norms on the roof in Trevano.

The accreditation was received on the 3rd of March 2010 with the registration number STS 531.

Conclusion

The set-up of the new testing laboratory was certainly a great challenge to the institute and the financial support of SFOE is kindly acknowledged. Thanks to the support of the School direction and the head of the department the important decision to create this new infrastructure providing the PV industry with testing services and amplifying our research activities in the PV sector was taken a year ago. All testing facilities, the whole management system, with a totally paperless management of all test reports, and the definition of all test procedures and quality manuals were successfully implemented due to a great team work, supported by the quality delegate of the School. The contacts with the industry ware taken during the whole year and with the end of the implementation period the efforts in marketing were intensified, in view of the accreditation in March.

References

IEC 61215 (2005): Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval

IEC 61646 (2008): Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval

IEC 61730-2 (2004): Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing

Public relation and publications:

Conferences and fairs:

- PV Tech Conference - Fair - Milan (Italy) – 25. – 27.11.2009
- 8. Nationale PV Tagung – Winterthur 04.-05.02.2010
- Hannover Messe: SWISS Pavillion Energiecluster OSEC 19.-23.04.2010

Publication – articles:

- PHOTON Newsletter 28.04.2010
- Energieforschung - März 2010
- Newsletter 105 – Energiecluster
- Photon 5/2009 (edition DE – IT – International) - New Testing Laboratories

CENTRALE DI TEST ISAAC-TISO

QUALITÀ E RESA ENERGETICA DI MODULI-FOTOVOLTAICI

Annual Report 2010

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Date	December 2010

ABSTRACT

In March this year, the Swiss PV Module Test Centre has been re-accredited ISO 17025 by STS (accreditation number STS 531) for 25 different tests related to the qualification of PV modules (IEC standard). The accreditation is valid both for measurements on crystalline silicon and now also for single junction thin film modules. The set of available reference cells has been enlarged to 10 reference cells, in order to reduce the spectral mismatch for the new thin film modules, single and multiple junction.

Repeatability measurements of the spectral irradiance of flash solar simulator and light soaking system have been performed with the new spectroradiometer in order to calculate the spectral mismatch factor. The new spectral response measurement setup has been completed and in particular includes a set of 18 customized optical interference filters with a bandwidth of 25 nm.

After 15 months of outdoor monitoring the test c cle 11 have been concluded in may 2010. 13 different technologies (mc-Si, sc-Si, back-contact, HIT, a-Si/a-Si, a-Si/µc-Si, CIS and CIGS) have been analyzed not only under real operating conditions but also indoors under different testing conditions. The energy output of the 8 standard c-Si modules differs not more than ±1% in kWh/Wp real power. In summer 2010 a selection of new module types have been defined and purchased for the next test cycle. For the first time a test cycle will concentrate on thin film technologies by covering most of the available technologies (a-Si, a-Si/a-Si, a-Si/µ-Si, CdTe. CIS, CIGS, CIGSS). Two additional c-Si modules will be used as reference.

The old (1982) TISO 10kW power plant had been temporarily removed. Visual inspection, I-V at STC and at low irradiance, wet leakage and insulation tests were performed on all the module of the plant in order to compare physical and electrical degradation during the last 10 years. The plant was re-mounted on the roof of Aula Magna in Trevano.

1 Aim of the project

The Institute of Applied Sustainability to the Built Environment (ISAAC) at the University of Applied Sciences in Lugano is the Swiss competence centre for PV module characterization and an internationally recognized test laboratory for electrical measurements. The institute already disposes of indoor testing facilities and outdoor test stands and has over twenty years of experience in the field of photovoltaics. The aim of the “ISAAC-TISO Test Centre” is to verify the quality, reliability and energy rating of photovoltaic modules. The goals for 2010 were:

- Maintenance of ISO17025 accreditation for I-V measurements with sun simulator; adjustment to the new quality system of the institute; and the integration of the new mechanical and lifetime laboratory in Lamone.
- Testing of the new flash sun simulator (PASAN IIIB) and relocation of the old simulator to the laboratory in Lamone.
- Validation of a tool for the measurement of the sun simulator spectrum.
- Setup of the spectral response (SR) measurement.
- Development of the tools for uniformity measurements of the sun simulator
- Module and cell measurements for industry.
- Completion and analysis of test cycle (nr. 11).

2 Project description

The main activities of ISAAC-TISO “Swiss PV Module Test Centre” are focused on the verification of quality and energy rating of PV modules, both with services for industry and with independent comparison tests.
In Lamone is located a new laboratory dedicated to mechanical and lifetime tests. It is added to the already existing laboratory in Lugano-Trevano where indoor measurements are carried out with a class AAA flash sun simulator and outdoor analysis of PV modules behaviour under real environmental conditions are carried out. Both laboratories have been re-certified ISO 17025 in order to perform IEC certifications of c-Si and Thin Film modules.
Systematic outdoor tests, under real operating conditions, are carried out on the most important modules currently on the market. Up to 18 modules for each test cycle were purchased anonymously. The modules were exposed for 15 months. Initial, intermediate and final I-V measurements at STC were performed. Each module is equipped with a Maximum Power Point Tracker (MPPT) adapted to its voltage and current range to optimize measurement accuracy. New outdoor stands, equipped with MPPT, have been set up for enabling the industry to compare new module technologies or prototypes with new solution of lamination or encapsulation.

3 Work carried out and results achieved

3.1 INDOOR EASURE ENTS WITH SUN SI ULATOR

3.1.1 easurement of cr stalline silicon and thin film modules

ISO 17025 accreditation

In 2001 the laboratory has been accredited ISO 17025 for STC IV measurements on crystalline silicon modules and then for temperature coefficient measurement. In March this year, the Swiss PV Module Test Centre has been re-accredited ISO 17025 by STS (accreditation number STS 531) for 25 different tests related to the qualification of PV modules (IEC61215, IEC61646, IEC61730). The accreditation is valid both for measurements on crystalline silicon and now also for single junction thin film modules.

Concerning indoor IV curve measurements, two new tests have been accredited additionally to the STC measurements and the TCO measurement. First the performance measurement at low irradiance levels (200 W/m^2) and the performance measurement at nominal operating cell temperature (NOCT).

Two new tests (performance at different irradiances and the power rating according to 61853-1) and a procedure for internal calibration of secondary reference cells have been implemented and are going to be accredited in 2011.

Solar simulators

With the new accreditation the old Pasan IIIA solar simulator (2ms) is dedicated to relative measurements of lower requirements, whereas the new Pasan IIIB (10ms) is used for all these measurements, where the best accuracy has to be reached, and for all thin film and capacitive module measurements.

This is thanks to its better spectral match to AM1.5G and its longer pulse length. For measurements under non-standard test conditions, its better control of temperature and irradiance is also an advantage.

The set of available reference cells has been enlarged to 10 reference cells, in order to reduce the spectral mismatch for the new thin film modules, single and multiple junction. Five reference cells have been calibrated as primary by PTB. The following table summarizes the uncertainties as declared on the measurement certificates.

	Po er Pma	oltage	Current I
PASAN IIIB 10ms c-Si ith primar reference cell	2.4	0.6	2.2
PASAN IIIB 10ms Thin Film ith primar ref. cell	3.4	0.6	3.2
PASAN IIIA 2ms c-Si ith primar reference cell	3.4	0.6	3.3

Table 1: Combined measurement uncertainty associated with the PV parameters measured with PASAN IIIB and IIIA and the relative IV measurement set-up (Expanded combined uncertainty k=2).

ualit control and metrological issues

Several metrological improvements have been introduced or continued within the new quality system.

- An entrance test, which all new module types has to undergo is introduced. This indicates if a module is capacitive or not and allows to define the best measurement procedure in order to guarantee the above specified uncertainties.
- A tool for the control and visualization of the stability of the two solar simulator set-ups through regular measurements of 7 different reference modules (3 for each solar simulator and 1 for cross validations). All relevant metrological events are registered into this tool and a statistical analysis is performed. A repeatability of ±0.5% have been reached on both systems.
- Periodical Round-Robin measurements with international test laboratories. In 2010 intercomparisons have been done with ISE laboratory (Fraunhofer, Germany), involving measurements on silicon, thin film single junction and multiple junction modules.

3.1.2 Spectral irradiance measurements

Spectral irradiance data are needed for the computation of the spectral mismatch factor (MM) used in performance measurement of PV modules according to the IEC 60904-7 standard. For this purpose, a rack containing three fiber-optic based spectroradiometers from Avantes has been purchased in 2009. In 2010, the post-processing of the raw data provided by the “Store To RAM function” of the Avantes instruments (for the storage of a large number of scans at high speed) has been automated. Repeatability measurements of the spectral irradiance produced by the short (2ms) and long (10ms) pulsed solar simulators have been performed. Also, the equipment was used for the control of the light soaking system located at Lamone and for external services (spectral irradiance of tabular flashers and of a dual-source steady state solar simulator).

easurement setup

The measurement setup consists in 3 spectroradiometers, the triggering electronics, and an input optics made of a cosine diffuser and of a triple-core optical fiber. The first channel is based on a silicon CCD sensor with 2048 pixels for measurement in the 250-770 nm spectral range (AvaSpec-2048-USB2); the second channel for measurement in the range from 600 to 1100 nm is identical and includes an additional filter for 2nd order filtering; the third channel is a near infrared (NIR) spectroradiometer. It is based on a InGaAs linear detector with 256 pixels sensitive in the spectral range comprised between 950 and 1700 nm (AvaSpec-236-NIR1.7-RM). For the spectral measurement of pulsed sun simulators, an integration time shorter than the light pulse is required. This parameter is critical for NIR spectroradiometers. Here, the NIR device provided by Avantes has a minimum integration time of 1.1 ms. The high spectral resolution offered by the system allows a clear distinction of the time evolution of the Xe-peaks and of the continuum spectrum produced by the short-pulse flash solar simulator located at Lamone.

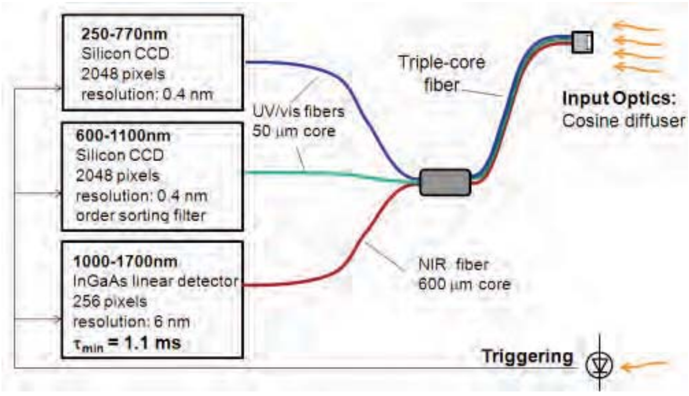

Figure : Schematics of the 3-channel spectral irradiance measurement setup in use at SUPSI. The input optics consists of a diffuser in transmittance and a triple-core fiber (2 UV/vis fibers with 50 µm cores and 1 NIR fiber with a core of 600 µm diameter. The 3 channels (2 silicon CCD sensors and 1 InGaAs linear detector) are synchronized by an external electronics.

Spectral irradiance measurement for the t o flash sun simulators used at SUPSI

Figure 2 shows the comparison of the spectral irradiance produced by the two sun simulators in use at SUPSI. The last generation flasher Pasan IIIB is equipped with four Xe flash tubes and an interferential filter for high-accuracy spectral match with AM1.5G. A comparison of the measured spectral irradiances clearly shows the improvement of the spectral match with AM1.5G for this class AA – AA – AA sun simulator.

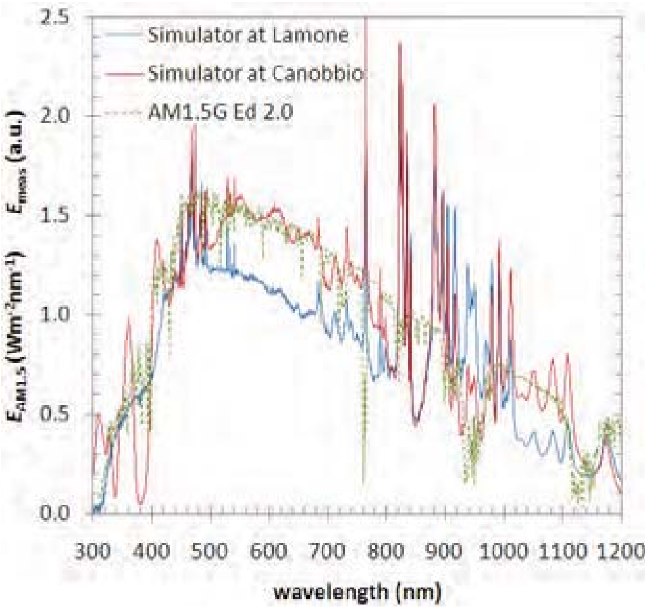

Figure : Comparison of relative spectral irradiance measurements of the two flash solar simulators used at SUPSI. In the laboratory at Canobbio, a class AA – AA – AA sun simulator Pasan IIIB is in use. It provides a stable 10 ms light pulse with a high fidelity spectrum w.r.t. AM1.5G. The measurements are compared to the AM1.5G Ed. 2 spectrum.

Spectral mismatch factor estimation

The influence of errors in spectral response (SR) and in the measurement of the experimental spectral irradiance (E_{meas}) on the computation of the spectral mismatch factor (MM) for PV modules has been studied in details since many years for the case of a steady-state illumination. King and Hansen stressed that the influence of wavelength-dependent error sources, such as bias errors, can be much larger than random measurement errors as calculated with Monte-Carlo analysis [1]. The measurement of E_{meas} when using a pulsed solar simulator is intrinsically much more challenging than with steady-state simulators. In the last EU-PVSEC we therefore presented a report on the influence of spectral irradiance measurement errors on the computation of MM [2]. If special care is not taken in the evaluation of the robustness of the computation of MM, a spectral correction in the wrong direction is not unlikely when using a well matched reference cell and a sun simulator with a high-accuracy spectrum as used at SUPSI (i.e. when MM is close to unity). Figure 3 shows a graphical analysis for the robustness of the computation of MM for ten different c-Si modules, when using the sun simulator located at Lamone and the c-Si reference cell REF02. In this figure MM is calculated taking into account systematic errors in E_{meas}, which are modeled by a linear error function of zero amplitude at 300 nm and maximum amplitude values (A_{max}) of up to ±25% at 1200 nm:

$$ErrorFct(\lambda, A_{\max}) = 1 \pm A_{\max} \frac{\lambda - 300nm}{1200nm - 300nm} \tag{1}$$

$$E_{meas,A_{\max}}(\lambda) = E_{meas}(\lambda) \cdot ErrorFct(\lambda, A_{\max}) \tag{2}$$

For a given experimental E_{meas}, the functions $MM(A_{max})$ for different modules are calculated with the relation:

$$MM(A_{\max}) = \frac{\int s_{ref}(\lambda) E_{AM1.5}(\lambda) d\lambda \cdot \int s_{sample}(\lambda) E_{meas,A\max}(\lambda) d\lambda}{\int s_{ref}(\lambda) E_{meas,A\max}(\lambda) d\lambda \cdot \int s_{sample}(\lambda) E_{AM1.5}(\lambda) d\lambda} \quad (3)$$

where s_{sample} and s_{ref}, are the relative spectral response of the module and the reference cell, respectively; $E_{AM1.5}(\lambda)$ is the reference spectrum AM1.5G; and $E_{meas,Amax}(\lambda)$ is calculated according to eq. (2).

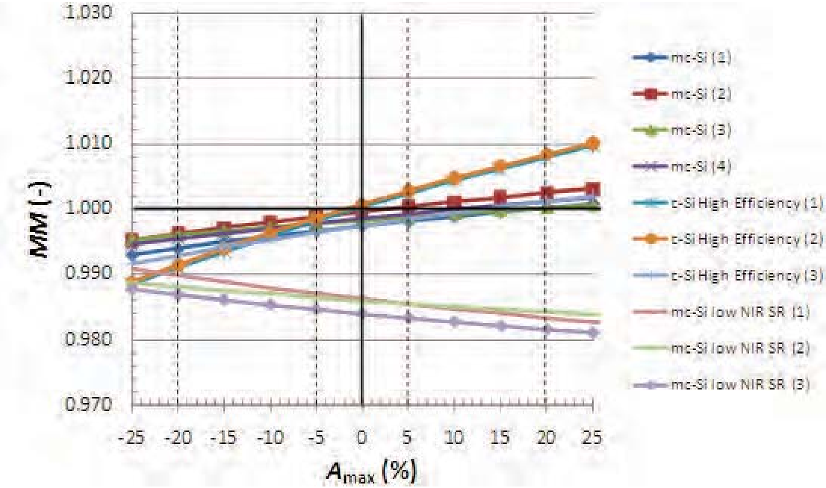

Figure : Effect of the linear error function given by eq. (1) on the mismatch factor (MM) calculated according to eq. (3) for 10 c-Si PV modules, when the maximum amplitude at 1200 nm of the error (A_{max}) ranges from A_{max} = -25% to A_{max} = +25%.

When A_{max} increases, the spectral mismatch of the modules with a lower relative spectral response in the red and infrared part of the spectrum (modules labeled mc-Si low NIR SR) follows an opposite trend than the other modules. Assuming negligible errors in E_{meas} (i.e. A_{max} = 0), a spectral mismatch of about -1.5% affects the measure of $I_{sc,STC}$ of these modules. For the other modules MM is close to unity with (MM – 1) ranging from -0.26% to 0.07% when A_{max} = 0. The slope of the curves in Fig. 3 is a quantitative indicator of the sensitivity in the computation of MM to errors in E_{meas}. Assuming that the uncertainty in the spectral irradiance measurement corresponds to $|A_{max}| \leq 5\%$, the sign for the correction of the spectral mismatch is undetermined for 3 modules over the 10 modules under consideration. Taking into account a more conservative uncertainty with $|A_{max}| \leq 20\%$, the sign of MM becomes undetermined for 7 over the 10 modules. But even in this conservative case the absolute value of spectral mismatch is smaller than 1% for those 7 modules.

3.1.3 Spectral response setup

The spectral response (SR) measurement setup includes the Pasan IIIB flasher; a dual channel transimpedance amplifier with selectable conversion factors; a reference cell ; and 18 sets of customized optical interference filters with a bandwidth of 25 nm. Each set consists of four filters mounted in a black-anodized aluminum holder which can slide in front of two lamps of the Pasan IIIB, the two other lamps being shadowed. This insures the spatial homogeneity of the monochromatic irradiation, because a pair of lamps which are orthogonal must be active. The system covers the spectral ranges from 360 to 1170 nm with 18 data points.

The filters are secured in the filter holders with dedicated H- and U-profiled pieces of silicone. Those parts have been injected in molds specially designed for the different thicknesses and widths of the filters.

As an example of measurement with the SR setup, the relative spectral response of a multi-crystalline Si module SolarWorld SW165 (160 x 80 cm^2) is shown in Fig. 5.

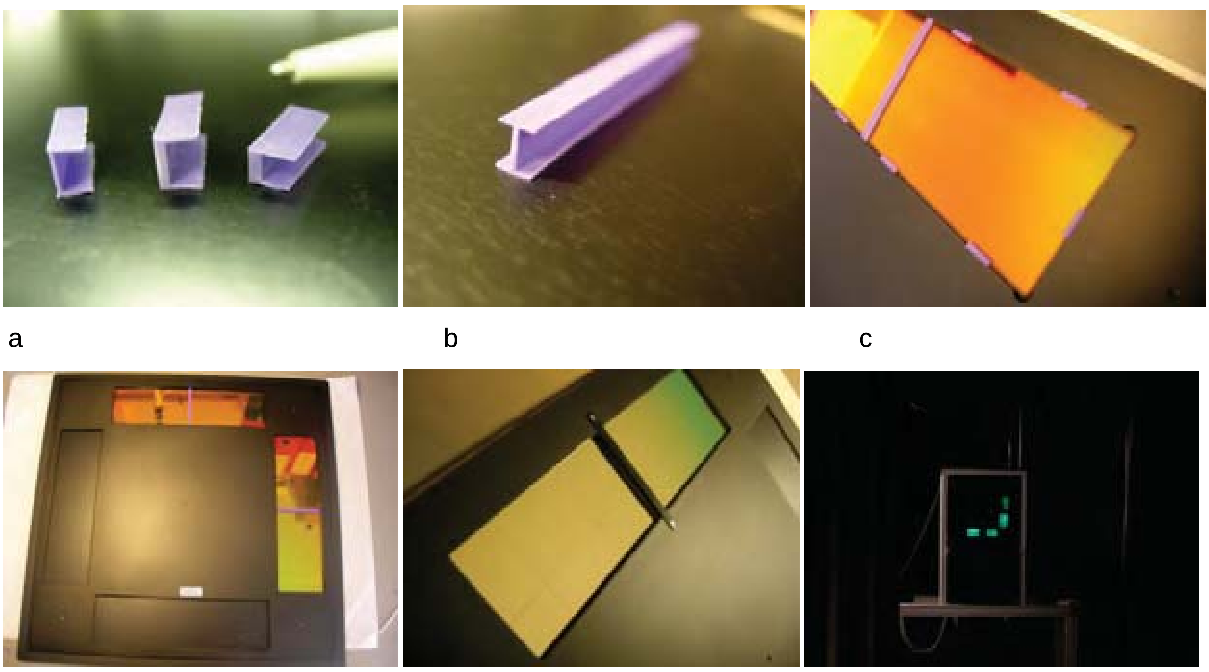

Figure : (a) Three different types of U-profiled silicone parts for glass-aluminium protection. (b) H-profiled silicone part for glass-glass protection. (c) Detail of the mounting in the filter holder (viewed from the side of the PV module). (d) One set of 4 interference filters (600 nm) mounted in orthogonal position (viewed from the side of the PV module). (e) Detail of the filter holder viewed from the side of the lamps. (e) Another set of filters (450 nm) engaged into the light box of the Pasan IIIB.

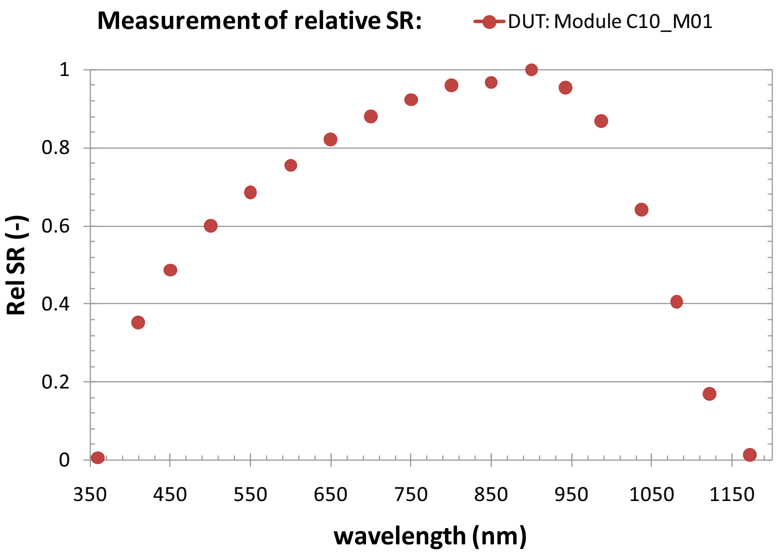

Figure : Measurement of the relative spectral response of a SW165 multi-crystalline Si module from SolarWorld (160 x 80 cm^2).

3.2 NEW I PRO E ENTS IN EASURE ENT E UIP ENT

3.2.1 Tools for uniformit measurements:

A new procedure for irradiance uniformity verification was developed and one module with 96 separated cells has been realised. The short circuit current of each PV cell is measured separately and simultaneously. The electronic part was built at the ISAAC in collaboration with the Department of electronics (DTI - ISEA) at the SUPSI. It is possible to obtain measurements with a scanning speed of up to a maximum of 100kHz (10 μs) with a 14 bit resolution.

During 2010 a Windows C# software interface was developed. This software communicate through USB and permits device calibration and data acquisition. Using this interface is possible to define a virtual test surface bigger than the actual sensor module. With a sequence of flashes and different positions for the sensor module, it is therefore possible to aggregate the data in an enlarged virtual test surface. Uniformity and solar simulator classification are calculated accordingly to IEC 60904-9. Data export is currently available in CSV file format.

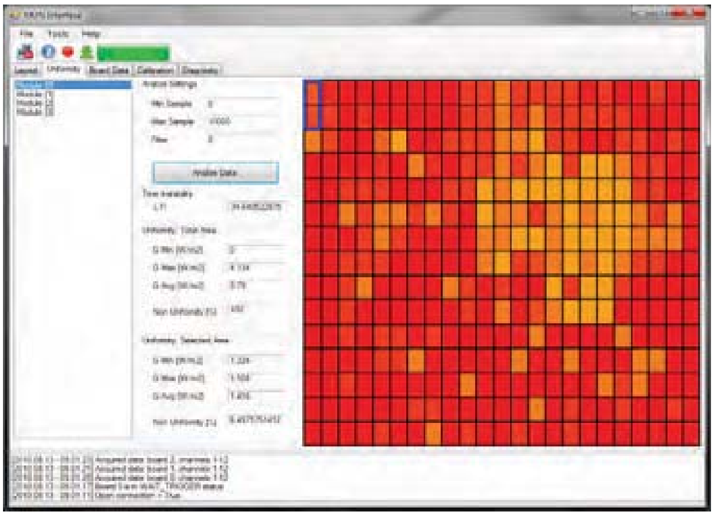

Figure : Software interface for uniformity measurement equipment

Measurement boards were mounted in the back of a 96 module. All system is powered solely by a normal laptop through the USB cable. Embedded software and interface software are stable. The system was tested on the pulse simulator and the trigger mechanism was verified. Integration within ISO 17025 accreditation are currently ongoing.

3.3 OUTDOOR EASURE ENT AND TEST C CLE

3.3.1 Outdoor energ ield measurements

The ISAAC operates two different outdoor test stands for energy yield measurements. One is dedicated to research purposes with the so called test cycles and a second one for measurement campaigns on behalf of industry, distributors, installers or any customer interested into energy inter-comparisons.

The major difference within the two tests stands is that in the second case all data are treated confidentially. The results of the test cycles and the respective test procedures are instead published at national and international conferences and data are shared with other research institutes or industry with the objective to increase the understanding of differences within technologies, to improve the overall measurement and energy prediction accuracy. Another important objective of these test cycles is to disseminate the state of the art of current module quality and fulfillment of data sheet declarations. The following paragraphs summarizes shortly some of the achievements within 2010.

Test c cles

After 15 months of outdoor monitoring the test *cycle* have been concluded in may 2010. The final results have been published at the EUPVSEC in Valencia [3]. 13 different technologies (mc-Si, sc-Si, back-contact, HIT, a-Si/a-Si, a-Si/μc-Si, CIS and CIGS) have been taken under the loop not only under real operating conditions but also with the indoor testing equipment available at ISAAC.

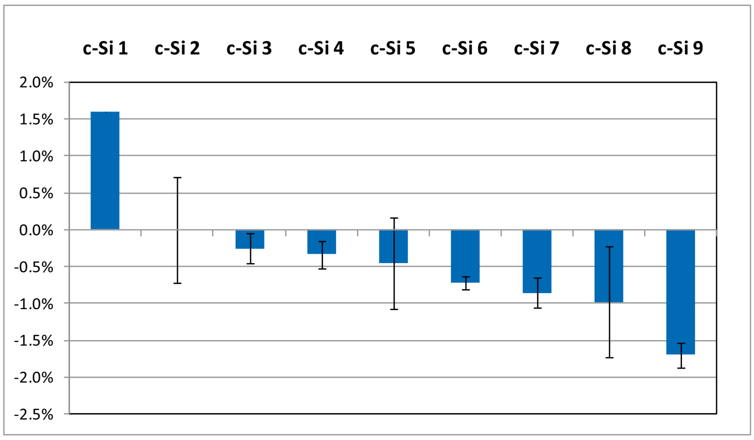

Figure : Difference (average of 2 modules) in annual energy production [kWh/Wp], of 9 different c-Si module types compared to the best-performing standard c-Si module (c-Si 2). The c-Si 1 module is a high efficiency module (HIP). The error bars represents the difference between the two modules of the same type. The real stabilised power, as measured by ISAAC, is taken as reference.

Some of the major outcomes related to the module performance, testing procedures and manufacturer declarations are here summarised:

1. The energy output of the 8 standard c-Si modules differs not more than ±1% in kWh/Wp real power. Only the HIP technology slightly outperforms the others (see Figure 7).
2. 3 of 13 module types (all c-Si) did not respect declarations. The initial power (out of box) or stabilized power was below the name plate value. All modules were stable over the first year. In 3 of 9

cases the temperature coefficients differed from the declared ones. The information about low light performance is generally very poor.

3. The introduction of a powerful data handling and quality control procedure allowed to significantly increase the accuracy of our energy yield inter-comparisons. The operator is alerted automatically via e-mail about any malfunction, such: missing data, out of range, negative values, blocked signal, snow, disconnected module, single erroneous peaks, short term phenomena (e.g shadows, MPPT malfunctions), signal below MPPT switching on threshold, signal drift (e.g. maintenance problems, malfunctions), bad temperature (e.g. detached sensor).
4. A good correlation between indoor measured module parameters (temperature coefficient γ and low irradiance performance) and energy output have been achieved both qualitatively as well as quantitatively.
5. Following needs for improvements have been identified for the thin film technologies with a major need for multi-junction modules: the understanding and modeling of degradation effects, the lack of information about production stability and tolerances and last but not least some remaining calibration issues, which are mainly related to spectral problems.

In summer 2010 a selection of new module types have been defined and purchased for the next test *c c* . For the first time a test cycle will concentrate on thin film technologies by covering most of the available technologies (a-Si, a-Si/a-Si, a-Si/μ-Si, CdTe. CIS, CIGS, CIGSS). Two c-Si modules will deal as reference. Modules of 12 different thin film manufacturers are involved. The modules are currently undergoing the initial indoor characterisation. The first installation on the test stand is foreseen for January 2011. The first weeks will be focused on the analysis of the initial degradation or stabilisation process followed by a second indoor measurement campaign to quantify the changes in module performance. After this all modules will be mounted again outdoors for the monitoring of the energy yield. New features as spectral irradiance measurements and irradiance stability have been implemented for 2011.

Industr Test Stand

In 2010 nineteen different modules have been monitored within 4 different contracts. The scope ranged from more straightforward inter-comparisons of standard commercial crystalline silicon modules up to prototype testing for enhanced energy output; and the evaluation of the influence on energy yield of changes within the manufacturing process of a thin film technology.

3.3.2 Refurbishment of TISO 10kW - 19 2

The old (1982) TISO 10kW power plant had been temporarily removed to make room for the test stand for the industry, the test stand for IEC certification and for a BIPV project. Visual inspection, I-V at STC and at low irradiance, wet leakage and insulation tests were performed on all the module of the plant in order to compare physical and electrical degradation during the last 10 years. The plant was re-mounted on the roof of Aula Magna in Trevano.

Figure : TISO 10kW -1982 - power plant on the new roof location in Trevano.

4 References

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[2] D. Dominé et al., The influence of measurement errors in spectral irradiance of flash solar simulators on the spectral mismatch factor of P modules ; 2010, 25th EUPVSEC, Valencia.

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Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

OBILES SOLAR ODUL ESSLABOR

Annual Report 2010

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Project- / Contract Number	Financed by EKZ
Duration of the Project (from – to)	2009 to 2011
Date	15.01.2011

ABSTRACT

The Swiss Mobile Flasher Bus (SMFB) was developed in July 2009 and is equipped with a standard high-quality Pasan flasher. In 2010 several measurement orders were carried out and a very high throughput of up to 200 PV modules per day could be reached at customer site. The measurements of the SMFB are calibrated with a set of four 230W standard polycrystalline silicon modules, each tested at ISE, Freiburg by a precision performance measurement with an uncertainty level of 2% (95% confidence level). A calculation of the SMFB measurement uncertainty budget resulted in an expanded combined uncertainty of ±3% at a 95% confidence level for standard crystalline Silicon modules (between 15°C and 35°C). This uncertainty value is about 1% larger than values of the best stationary test labs but enables still very accurate measurements at ambient temperature conditions with the advantage to make more measurements directly on customer's site.

Since summer 2010 the SMFB offers the measurement of the spectral response characteristic on module scale. This is realised by placing optical band pass filters of 50nm spectral width, in front of the flasher light source in steps of also 50nm from 400nm to 1100nm. The spectral response measurement will allow even more accurate measurements of the power performance because the spectral mismatch factor can be quantified und thus this spectral uncertainty contribution will be minimised. Successful spectral response measurements could be performed using single junction devices like standard cr-Si modules CdTe and CIS module

The mobile PV laboratory SMFB was also successfully used for teaching PV basics at the University of Applies Science Zurich, as well as at ISU Energy 2010, a two weeks, International Summer University program on Energy Renewable Energies hosted in Falera, Switzerland.

Einleitung / Projekt iele

Für eine 5kW Hausdachanlage entsprechen 3% Unterschied in der Nennleistung der Module auch 3% Unterschied im Ertrag der Solaranlage und damit einem Geldwert von ca. 700 Fr bezogen auf die gesamte heute typische Investitionssumme. Mit letzterem Betrag können nicht einmal die Kosten für eine Präzisions-Nennleistungsmessung, mit einer Messunsicherheit von 2%, an einem einzigen Solarmodul der Anlage in einem unabhängigen Testlabor bezahlt werden. Für einen 5 MW Solarpark sind die Verhältnisse anders und Referenzmessungen der Module für die finanzierende Stelle unumgänglich. Dazu werden für den obigen Solarpark typisch 20 bis 50 Module zu einem stationären, unabhängigen Messlabor geschickt und vermessen. Für diese baugleichen Module können dann auch Kosten für diesen Stichprobenumfang von ca. zehntausend Franken veranschlagt werden, bei Messunsicherheiten von 2% bis 3%. Wohlgemerkt, sind diese Messdienstleistungskosten wesentlich unterhalb des geldwerten Betrages von 3% einer 5MW Anlage, der dann deutlich über einer halben Million Franken liegt. Eine Neuerung stellt der hier beschriebene Swiss Mobil Flasher Bus dar, der es ermöglicht auf den Transport der zu messenden Module zu verzichten, da das mobile Labor direkt am Ort des Solarkraftwerks die Flashermessungen durchführen kann. Dies verkürzt den Zeitraum bis die Messresultate vorliegen, wobei bei gleichen Gesamtkosten für die Messung eine höhere Stichprobenzahl untersucht werden kann, bei geringfügig höheren Messunsicherheiten. Zusätzlich kann der Kunde noch ein, zwei derselben mit dem Messbus vermessene Module an ein stationäres Messlabor schicken, um eine zweite unabhängige Vergleichsmessung verfügbar zu haben. Auch in der Schweiz, wo ja bekanntlich kaum MW PV Anlagen realisiert werden, kann diese mobile Dienstleistung beispielsweise auch von Solarmodulgrosshändler oder PV-Modul Einkaufsgemeinschaften genutzt werden.

Realisierung mobiles esslabor und Status

In Rahmen eines gemeinsamen Projektes der Züricher Hochschule für Angewandte Wissenschaften, ZHAW und dem Energieversorger des Kantons Zürich, EKZ wurde im Jahr 2009 ein kommerzieller Sonnensimulator der Firma Pasan, Neuchatel Schweiz, in einen Mercedes Sprinter Transporter eingebaut. Im Sept. 2009 wurde dieses international erste, mobile Flasher Messlabor für Solarmodule (SMFB Swiss Mobile Flasher Bus) auf der Europäischen Photovoltaik Tagung in Hamburg vorgestellt.[1] Die EKZ führen im Kundenauftrag Messungen durch, während die ZHAW den Messbus zu Forschungszwecken aber auch für die Ausbildung einsetzt und die Messtechnik weiterentwickelt.[2]

Der Pasan 3c Flasher Simulator mit einer Distanz von 5.5 Meter zwischen Lichtquelle und zu messenden Solarmodul, machte den speziellen Einbau einer ausziehbaren Plattform auf der Rückseite des Trägerfahrzeuges nötig. Auf das Ende dieser Plattform wird das jeweilige zu messende Solarmodul montiert, wobei die Modulabmessungen innerhalb der Fläche von zwei mal zwei Meter Platz finden müssen. Der Aufbau vor Ort, direkt beim Kunden (siehe Bild 1) benötigt ca. eine halbe Stunde Zeit und es konnten an einem Tag bisher bis zu 200 Module vor Ort vermessen werden.

Im Jahr 2010 wurden ausführliche Arbeiten zur Bestimmung der Messunsicherheit des SMFB umgesetzt und weiter wurden auch einige Kundenaufträge, meist im Ausland ausgeführt.

Abb. 1 Seitenansicht Mobiles Messlabor (Swiss Mobile Flasher Bus) beim Einsatz auf einem Bauernhof in Süddeutschland

essunsicherheit des mobilen Solarmodul esslabors

Etablierte, führende Messlabors in Deutschland, geben für Standardmodule aus kristallinem Silizium Messunsicherheiten von 2% bis 3% für die Bestimmung der Nennleistung an. Für den kleineren Wert ist die Messung des spektralen Verhaltens des zu messenden Solarmoduls eine wesentliche Voraussetzung, was auch mit entsprechenden Messkosten verbunden ist. Dies deshalb, weil stets eine systematische farbliche Abweichung der künstlichen Lichtquelle vom genormten Sonnenspektrum AM 1.5 vorliegt und daher die Messung der auf das Modul eingestrahlten Leistung, welches nach Standard Test Bedingungen 1000 W/m^2 entsprechen soll, auch vom spektralen, farblichen Verhalten des eingesetzten Einstrahlungssensors abhängt. Nur wenn der eingesetzte Einstrahlungssensor, wie z.B. eine kleine Referenzsolarzelle, die neben dem Modul in der gleichen Ebene angeordnet ist, exakt die gleiche spektrale Empfindlichkeit wie das zu messende Modul selbst hat, kann die eingestrahlte Lichtstrahlung ohne weitere Abweichung bestimmt werden. In der Praxis ist dies jedoch nie der Fall und bei Verwendung eines kristallinen Silizium Referenzsensors, für kristalline Silizium Standardmodule ist typisch mit systematischen Abweichungen von bis zu 1% für diesen spektralen Mismatch-Faktor zu rechnen. Das mobile Messlabor ist auch in der Lage diese spektrale Empfindlichkeit des zu vermessenden Moduls zu bestimmen und so obigen Mismatch-Faktor als systematische Abweichungen entsprechend der Norm IEC 60904-7 zu korrigieren.[3]

Die erste umfassende Analyse der Einflussfaktoren für die Unsicherheit bei der Leistungsmessung von Solarmodulen wurde vom Europäischen Forschungszentrum JRC, ESTI in Ispra vorgelegt. Dabei kamen die Wissenschaftler der EU Kommission zu dem Schluss, dass etwa die Hälfte der Messunsicherheit von gesamthaft 2%, bei einem Vertrauensniveau von 95%, auf die Genauigkeit der verwendeten Referenzsensoren zu veranschlagen ist, wenn die Leistungsbestimmung allein auf diese Referenzsensoren zurückgeführt wird.[4]

Auch bei der hier in Tabelle 1 angeführten Messunsicherheitsberechnung ist die Unsicherheit des Referenzmoduls der dominierende Faktor, gefolgt von der inhomogenen Verteilung der Lichtstrahlung über der Modulfläche. Die resultierende Messunsicherheit des mobilen Testlabors ist mit 3% etwas höher wie in den besten stationären, klimatisierten Testlabors.

Das hier eingesetzte Referenzmodul wurde am Fraunhofer ISE kalibriert mit 2% Unsicherheit für k=2 womit eine 1% Unsicherheit für k=1, der einfachen Standardabweichung abgeleitet wird. Dieses Referenzmodul gehört zur permanenten Ausrüstung des SMFB und wird regelmäßig eingesetzt, um den gesamten Messaufbau zu kalibrieren. Die kleinen, im Messaufbau unmittelbar neben dem zu testenden Solarmodul integrierten Referenzzellen (2cm x 2cm) hingegen übernehmen nur die Aufgabe die Leistungsschwankungen innerhalb eines Flashes von 10 Millisekunden zu korrigieren.

Tabelle 1:

Budget der Messunsicherheitsanalyse des mobilen Messlabors SMFB mit einem resultierenden Vertrauensniveau von 95% (k=2) für Standardmodule aus kristallinem Silizium im Temperaturbereich von 15°C bis 35°C. Die dritte Spalte gibt den angenommen Typ der Verteilung der jeweiligen Unsicherheit an, wobei G für Gauß-Verteilung und R für Rechteckverteilung steht und letztere zur Berechnung der Varianz die angegeben Unsicherheitsgrenzen durch 3 dividiert werden müssen.[5]

Unsichheitsbeiträge	Unsicherheit k=1	Verteilung	Varianz
Referenzmodul	1.00%	G	1.00
Temperaturmessung	0.50%	R	0.08
Optische Inhomogenität	0.89%	R	0.26
Fehlausrichtung Modul	0.60%	R	0.12
Fehlausrichtung Monitorzelle	0.12%	R	0.005
Elektrische Reproduzierbarkeit	0.09%	G	0.01
Spektrale Unsicherheit Mismatch	0.50%	G	0.25
Weitere unbekannte Unsichheiten	1.25%	R	0.52
	Summe der Varianzen=		2.25
Gesamtunsicherheit (k=2), 95%	3.0%	←2* √2.25	3.00

Der wesentlichste Unterschied in Bezug auf die erzielbare Messgenauigkeit des mobilen Messlabors SMFB und dem stationären Labor mit dem gleichen hochwertigen Pasan Flasher ausgerüstet, liegt im Einfluss der Modultemperatur. Die Anwendung des SMFB, vor Ort um an einem Tag ca. 100 Module zu vermessen, bringt es aktuell mit sich, dass es in dieser Zeit nicht möglich ist, jedes Module auf die Standardtemperatur von 25°C zu kühlen um dann zu messen. Die Module sind typisch im Schatten gelagert und haben somit Umgebungstemperatur angenommen.

Da die STC Nennleistung stets auf die Modultemperatur von 25°C bezogen ist, wird bei der Messung mit dem mobilen Messlabor die Modultemperatur auf der Rückseite des Moduls mit einem PT1000 Temperatursensor ermittelt. Zur Kontrolle wird ein weiterer PT100 Temperatursensor eingesetzt, der in der Referenzelle untergebracht ist (Abweichungen typisch kleiner 0.2°C). Mit der Kenntnis des Temperaturkoeffizienten der Leistung des zu messenden Solarmoduls kann so auf die Nennleistung bei 25°C rückgerechnet werden. Die Qualität dieses Verfahrens wurde in einigen Experimenten überprüft, bei dem z.B. ein Modul in der Sonne auf über 45°C erwärmt wurde und nach der Montage auf der rückseitigen Plattform des SMFB, während des natürlichen Abkühlvorganges, wiederholt im 30 Sekunden Intervall die Leistungsmessung vorgenommen wurde. Bild 3 zeigt als Ergebnisse, dass bei polykristallinen Modulen (Tabelle 1) die verbleibende Abweichung bis 39°C kleiner als 0.5% ist. Dabei lag die Unsicherheit des Temperaturkoeffizienten bei 0.03%/K. Daher wird die resultierende Messunsicherheit bei der Messung von Standard kristallinen Silizium Modulen mit 3% (Vertrauensniveau 95%) für einen Temperaturbereich der Module von 15°C bis 35°C angegeben.

Weitere Detailanalysen der Unsicherheitsbeiträge, wie Fehlausrichtungen der Module bzw. Referenzzellen, sind in den angegebenen Fachpublikation nachzulesen (siehe F. Baumgartner unter Referenzen)

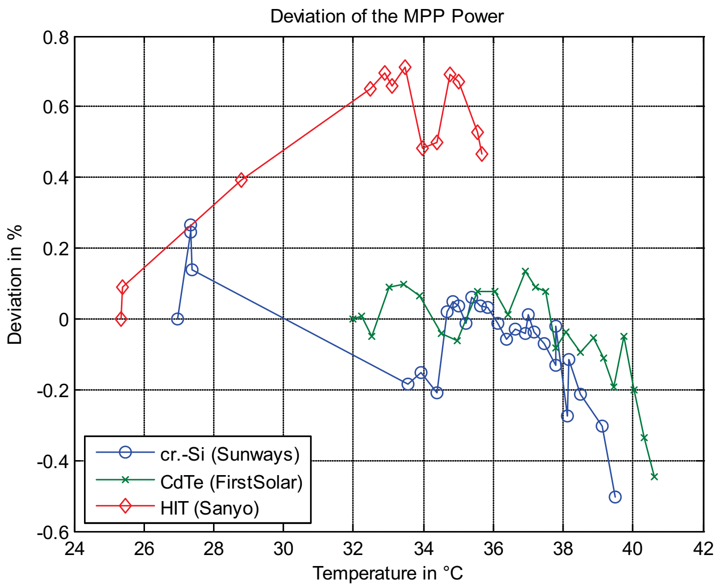


Abb. 2 Verbleibende Unsicherheitsabweichung in Prozent nach erfolgten automatischen Temperaturkorrektion der Leistung für den angegebenen Modultemperaturbereich.

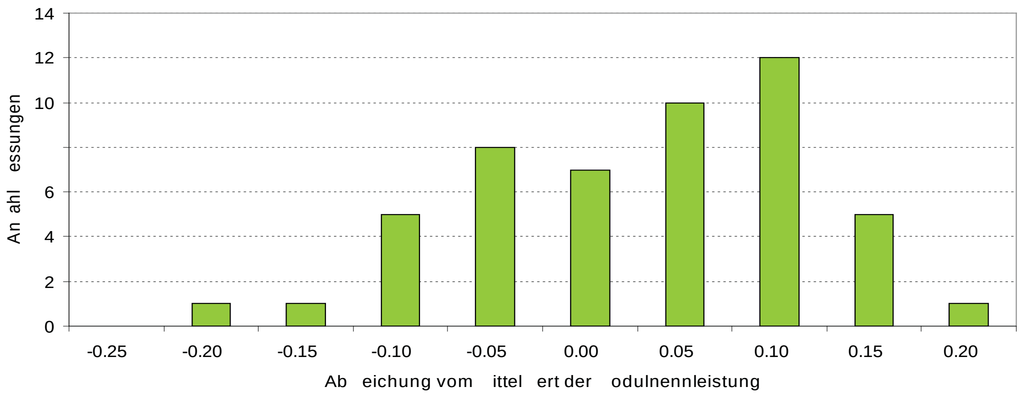


Abb. 3 Histogramm der Abweichung von fünfzig hintereinander ausgeführten Nennleistungsmessungen mit dem SMFB am gleichen Modul ohne Veränderung der mechanischen Modulmontage bzw. elektrischen Anschlüsse. (Standardabweichung 0.09%; die Messung wurde am 12. Nov 10 an der ZHAW ausgeführt)

essung des spektralen Photostroms auf odulebene

Wie bereits erwähnt, ist die Kenntnis des spektralen Photostroms jenes Moduls, von dem die Nennleistung gemessen werden soll, eine entscheidende Voraussetzung um die minimale Messunsicherheit erzielen zu können. Damit ist es möglich, die spektrale Missmatch Korrektur nach IEC durchzuführenden. Auf der Europäischen Photovoltaikkonferenz in Valencia, im September 2010 konnten erste erfolgreiche Messergebnisse der Bestimmung des spektralen Photostroms mit dem mobilen Messlabor SMFB vorgelegt werden.(siehe Abb. 4) Der SMFB ist mit 15 Bandpassfiltern ausgerüstet, die wahlweise vor die Blitzlampe geschoben werden können, um so nur z.B. grünes Licht im Wellenlängenbereich von 525 bis 575 nm zum Solarmodul passieren zu lassen.(siehe Abb. 5) Die anderen Farben werden herausgefiltert.

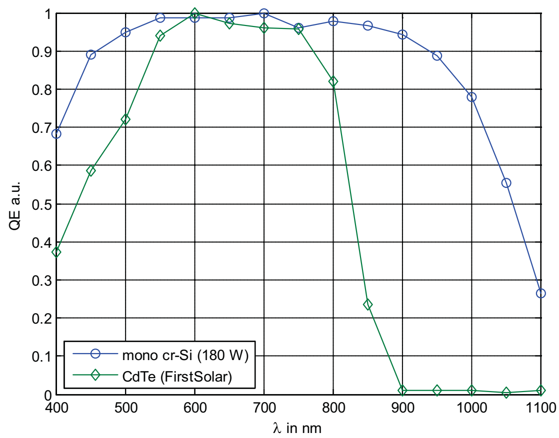


Abb. 4 Messresultate der spektrale Effizienz der Lichtausbeute bei Standardmodulen aus kristallinem Silizium und Dünnschichtmodulen aus CdTe (siehe Tabelle 1) gemessen mit dem mobilen Messlabor SMFB.

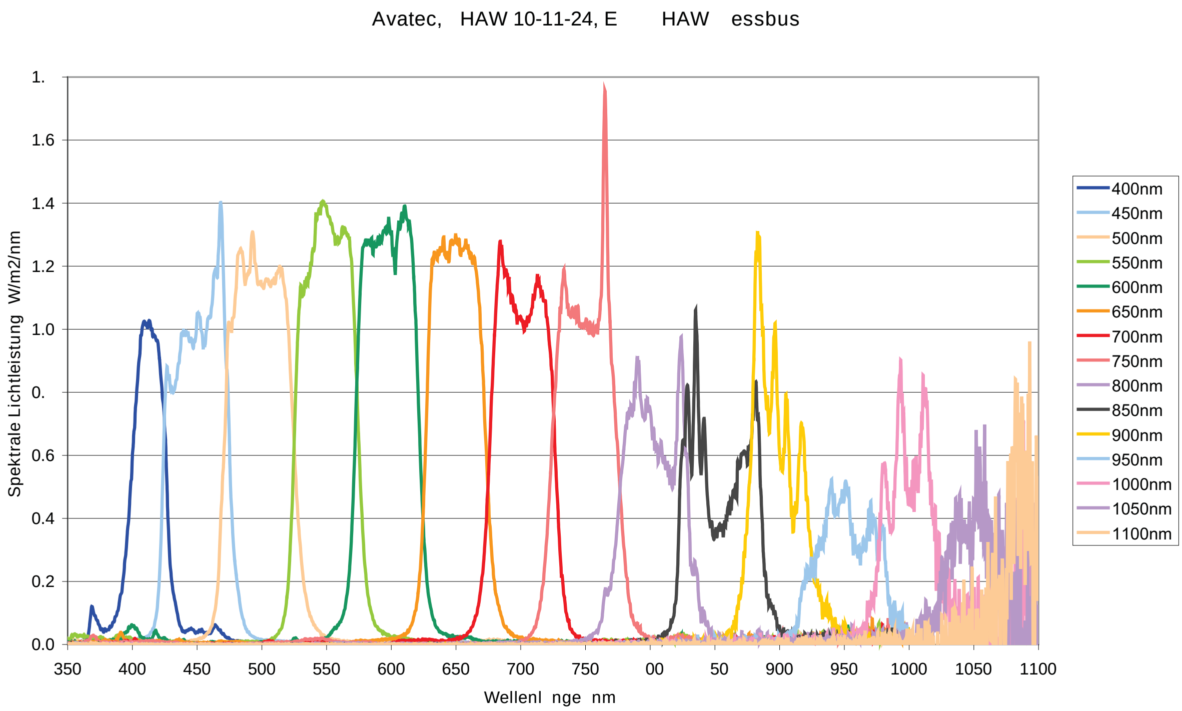


Abb. 5 Lichtspektren des Pasan 3c Flashers mit den 15 unterschiedlichen Bandpassfiltern die im mobilen Messlabor zur Messung des spektralen, Farbverhaltens von Solarmodulen eingesetzt werden. (Die Messung am Pasan 3c Flasher wurde am 24. Nov 10 mit dem Spektrometer AvaSpec-2048 USB2-UA-50 ausgeführt)

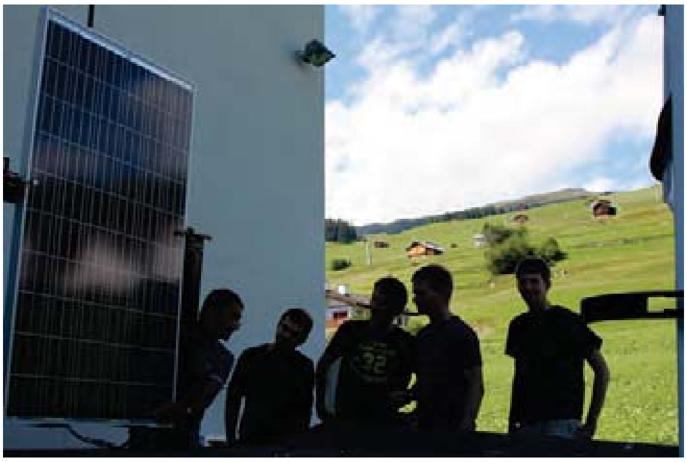
usammenfassung

Zusammenfassend kann festgestellt werden, dass für Standardmodule aus kristallinem Silizium, die bei Temperaturen zwischen 15 bis 35°C mit dem mobilen Messlabor SMFB vermessen werden, Unsicherheiten von 3.0% erreicht werden. Bei Dünnschichtmodulen können Unsicherheiten bis ca. 4% oder mehr folgen, da dort auch auf die Stabilität und die Vorbehandlung der Module geachtet werden muss. Spezielle Anpassungen des Messverfahrens waren erfolgreich um nicht nur Standardsiliziummodule, sondern auch hocheffiziente HIT Module und auch CIS Module zu vermessen. Mit dem mobilen Messlabor ist selbst die Messung des spektralen Verhaltens von Solarmodulen vor Ort möglich, sowie auch die Messung des Schwachlichtverhaltens im Bereich von 100 W/m^2 bis 1100 W/m^2.

Gilt es für einen grossen Solarpark den Prozentsatz der fehlerhaften bzw. leistungsschwachen Module, unterhalb der garantierten Leistungsgrenze zu ermitteln, so reicht die Stichprobenzahl von 10 bis 20 Stück pro MW nicht mehr aus, da es sich dann nicht um eine einzelne homogene Grundgesamtheit handelt, aus der eine einfache Stichprobe gezogen werden kann. Auch dort ist der Einsatz des mobilen Messlabors, mit einem hohen Stichprobenumfang von etwa 100 Solarmodulen pro Tag, ohne aufwendige Logistik und Ertragsausfall über mehrere Wochen bis Monate, eine attraktive Ergänzung zu den bestehenden stationären Messlabors.

Weiterer Einsat des mobilen esslabors in der Sch ei

Im Rahmen des Gemeinschaftsprojekt der Elektrizitätswerke des Kantons Zürich (EKZ), der Zürcher Hochschule für angewandte Wissenschaften (ZHAW) und Oerlikon Solar, Trübbach werden fünf unterschiedliche Modultechnologien auf dem Dach des EKZ Gebäudes in Dietikon im Outdoor-Betrieb getestet. Dabei wurde der SMBF für die jährlichen Flashermessungen aller 100 Module erfolgreich eingesetzt.



Fünfzig Masterstudenten aus fünfzehn verschiedenen Ländern trafen sich im September 2010 zur zweiten ISU Energy, der Summer University in den Schweizer Bergen in Laax/Falera, um sich intensiv rund um die Solartechnik weiterzubilden.[5] Neben Vorlesung von Dozenten und Fachexperten aus verschieden Ländern und Hochschulen, konnten die Studierenden auch praktische Übungen und mit dem mobilen Solarmodulmesslabor SMFB der EKZ/ZHAW durchführen und so industrienahe Erfahrungen sammeln.

Daneben kommt der SMFB selbstverständlich regelmässig bei der Ausbildung von Ingenieuren an der ZHAW zum Einsatz.

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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

BISOL

BUILDING INTEGRATED SOLAR NETWORK - BRENET

Annual Report 2010

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Project- / Contract Number	SI/500339 / SI/500339-01 (103049 / 153948)
Duration of the Project (from – to)	
Date	02.12.2010

ABSTRACT

The BiSol project is specifically addressed to architects, engineers, building material manufacturers, solar system manufacturers, designers, contractors, public sector and researchers. Its aim is to create a competence network between specialists (stakeholders) so to maximize solar energy integration into the built environment and overcome the related technical and non technical issues.

In order to encourage communication between these professionals of different sectors and to identify the issues linked to building integration of solar systems and their possible solutions, thematic multidisciplinary workshops are planned and carried out.

Between February 2010 and August 2010, the 3rd and 4th (out of 5) workshops have been organized. Indeed, under the auspices of the working group BiSol, an “Opportunities of collaboration between the BUILDING and SOLAR sectors” Workshop was held in Trübbach on the 1st and 2nd of February 2010 and a “Quality and reliability of building integrated photovoltaic modules and thermal collectors” Workshop was held in Lugano on the 23rd and 24th of August 2010.

The outcomes of each workshop are the encouragement of collaborations between the different actors and the identification of problems and their resolution trough eventual new projects and the creation of one or more working groups that will develop and manage these projects.

Aims of the project

Introduction

The market of solar systems as photovoltaic modules and thermal collectors is increasing very fast. This increase has encouraged producers, installers and designers to develop products that are more adequate for building integration. However, barriers to the dissemination of solar thermal and PV integration are numerous and concern various aspects: architectural, planning, constructive, economical and educational.

Aim

In order to confront and overcome the different aspects of these barriers, the BiSol Workshops aim to act as the platform that brings together the different sectors and encourage communication among them creating a competence network between specialists (stakeholders) for maximizing solar energy integration to the built environment.

ethodolog

Between March 2009 and February 2011, the BiSol group organizes 5 multidisciplinary workshops specifically addressed to architects, engineers, building material producers, solar system producers, designers, contractors and researchers.

Specific 2010 goals

Specifically, the goal for 2010 was the organization of the 3rd and 4th BiSol Workshops. BiSol can be designed as the main Swiss platform for new collaborations in the active solar field considering that it enabled to successfully bring together specialists of various sectors.

Work carried out and achieved results

3rd BiSol Workshop (Trübbach, 1st and 2nd February 2010): Opportunities of collaboration between the building and solar sectors.

The goal of this workshop was to give a chance to specialists from the building and solar sectors to get together and discuss the issues and wishes, concerns and solutions related to the integration of solar systems in buildings. Particularly, the importance that PV and STH become a more used building material was stressed.

The Workshop was attended by 35 professionals from different Swiss Cantons, Germany and Italy. These professionals were mainly architects and engineers working in different fields such as the private sector, industry and university related research centers. The main outcome of this particular workshop was the identification of a series of issues and observations concerning the difficulty of obtaining a compromise between standardization (producer's wish) and flexibility (architect's necessity) (Annex 1). Also, a list of actions to be taken was produced (Annex 2). Among these, the possibility that CSFF proposes 10 architecturally ideal standard PV module sizes for façade integration (see answers Annex 2).

4th BiSol Workshop (Lugano, 23rd and 24th August 2010): Quality and reliability of building integrated PV Modules and thermal collectors.

The goal of this workshop was to illustrate the variety of issues linked to solar product quality and reliability and the state of the art regarding norms and regulations on these same products.

The Workshop was attended by 31 professionals from different Swiss Cantons and Italy. These professionals were mainly engineers and architects working in different fields such as the private sector, industry and university related research centers. The main outcome of workshop 4 was the highlighting of the need of tests on the whole system (modules + fastening system) rather than single parts; the need of more collaboration between the producers, the installers and researchers for defining the necessary tests; and the need of product development such as modules with diode bypass, modules with MPPT (maximum power point tracker), back sheet + integration of other functions, colored encapsulation and more types of dummy modules (Annex 3).

For each workshop, a detailed report was written. These are available on request through info@bipv.ch

All the PowerPoint presentations presented during the orkshops are available at www.bisolnet.ch

National collaboration

For the organization of Workshop 3:
EPFL LESO-PB and OERLIKON SOLAR

Evaluation of ear 2010 and perspectives for 2010

Thanks to constructive observations obtained during year 2009, the BiSol Team was able to improve certain logistic details and was able to optimize the management of the two events planned and carried out during 2010. Indeed, both workshops held during 2010 have been a success. A survey shows that most of the participants appreciated the combination of presentations, group work and group visit (respectively to the Oerlikon Pilot Plant in Trübbach and to the Swiss PV module Test centre in Lamone / BiPV simulator). It was very difficult, but extremely interesting to gather people from different backgrounds and speaking different languages. The language issue was overcome by the simultaneous translation and partly by the "language" flexibility of the participants. Participants were generally motivated and took part to the discussions and group work; most of them were interested in participating in and developing future projects.

The positive results of the orkshop are ithout doubt the creation of an important net ork bet een e perts from different sectors in S it erland, the proposition of ne project ideas and the development of collaborations bet een participants.

The downside is that the BiSol Team has found some difficulty to concretize the ideas and propositions highlighted during the workshops. More time and resources are needed to organize kick-off meetings with the interested parties and launch new projects. Hence, discussions, propositions, etc. fall short after the Workshops have taken place.

The last workshop will be held on the 11th of February 2011. This encounter will principally focus on the economic aspect of photovoltaics. Will PV technologies ever be affordable? Will the dissemination of the technology, the learning curve of mass production and the increase of conventional energy cost be a sufficient cause? Is political support adequate? Are the electricity companies and the industrial services prepared to handle the mass arrival of this technology?

Anne es

Anne 1: Main outcomes of discussion held during the 3dr BiSol Workshop :

- Architects would like to maintain some kind of "artistic" flexibility when working with PV and STH as a building material
- Producers would like to standardize the products especially for reducing the fabrication process and costs
- Crystalline silicon modules are available in different sizes from different producers. On the contrary, amorphous silicon modules on glass are proposed in standard sizes (1.3 x1.1m / 2.2 x 2.6m)
- Fastening systems should be compatible to all PV module size to allow, with the use of interface elements and dummies, more flexibility for completing the façade and/or roof raster
- BiPV modules are dealing with electrotechnical and building codes
- Lack of tests for flexible PV modules (problems of compatibility with existing norms)
- Lack of uniformity for electrical security and fire tests at the international level
- Need of research/state of the art on building material tests for proposing similar tests on BiPV systems (ex. tests on waterproofing membranes could be reproduced on PV waterproofing membranes)
- Lack of tests on fastening systems
- For further information on tests on new PV products: www.pv-performance.org (SP 6); a brochure are available on the website

- The function/position of STH and PV façade planner does not yet exist
- It is essential to form STH and PV façade planners!
- CSFF and Swissolar could co-organize courses for professionals

Anne 2: List of actions to be taken following the 3dr BiSol Workshop

CSFF member will discuss with CSFF about proposing 10 ideal standard PV module sizes for façade integration

Answer from CSFF:

The façade builder are mostly very interested in the PV systems. But they are still not very good informed about the general PV products. In this case they have really not a clear idea about the PV products.

In the other hand you have the planers and architects. But also this group of people cannot say what sizes of PV modules they want to have.

Our experience is following:

More than 30% from the designed PV façade projects we can realize with standard framed PV modules. Maybe for 30% of the projects we need standardize frameless modules. And this projects we are able to realize with products from Pramac or other thin film PV producer or even we can use frameless modules from Sunways or for example from the company Solon in Berlin.

The rest of the PV façade projects we have to use customized modules from Ertex in Austria or GSS in Gera and so on. These companies are able to produce modules with any kinds of cells - transparent, colored and so on. And this to an acceptable price.

I don't think the PV façade integration is limited by the available products. I believe, the extensive PV façade integration is limited by the little knowledge about the PV opportunities from the architects, engineers, planers and façade builder.

I showed for example some architects the pictures from some pavilions from the solar decathlon from Madrid and they most told me, if I know about the PV possibilities, one of my next projects will receive a PV facade.

- Swissolar would like to contact CSFF for co-organizing courses on solar façades for professionals
- Following the discussion on BiPV certification, a meeting will be organized by 3S on this theme, including flexible PV modules
- The importance of education/formation was yet again highlighted (has been an important part of the discussion in all 3 BiSol workshops!). A teaching network within schools and institutes with sharing of academic material, education experiences and tutorials would be welcome
- Producers have to realize that architects require a certain product flexibility; architects need to understand that size standardization allows cost reduction
- It's essential to clarify responsibilities among the different actors involved (architects, façade planners, builders)

Anne 3: Main outcomes of discussion held during the 4th BiSol Workshop :

- Lack of tests on: modules together with fastening systems, waterproofing systems, how the temperature influence the module lifetime and modules characteristics. Necessity of tests on the whole system (modules + fastening system) rather than single parts = more security; separated tests and norms for BAPV and BIPV; more collaboration between the producers, the installers and researchers to define tests requested; Lifetime test with higher temperature; lifetime: define when a module is “dead” and need to be changed; need for testing changes in characteristics: color, transparency, form, weight, dimensions.

- Need of product development. Modules with diode bypass; Module with MPPT (maximum power point tracker); back sheet + integration of other functions; colored encapsulation, more type of dummies modules.
- Lack of research on shadowing effect (in relation to technologies and application). Necessity of developing research, type of technology less sensitive in shadow (longer and thinner cells rather than larger cells), standardized measurements, results use by dimensioning tools (PVSyst).
- Risks for firemen when dealing with PV. Necessity of fireproof norms including PV (as a building component); specific PV (DC) training for firemen; mapping of buildings with PV.
- Lack of training: ventilation, building standard, inverter configuration. Necessity of training; stages and collaborations between industries and research institutes; change the mentalities: PV is a building element!

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BIP TOOLS

INTERACTIVE TOOLS AND INSTRUMENTS SUPPORTING THE DESIGN OF BUILDING INTEGRATED PV INSTALLATIONS

Annual Report 2010

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Project- / Contract Number	103220 / 154244
Duration of the Project (from – to)	01.07.2009 – 01.07.2011
Date	02.12.2010

ABSTRACT

The BiPV Tools project is addressed specifically to architects. Its aim is to provide information and tools which will allow a correct and appropriate integration of photovoltaics into the building design concept. Its purpose is to define and analyze a series of needs especially pertaining to architects (and architecture students) who don't have a strong technical knowledge of PV but who would like to be able to integrate photovoltaic systems into the architectural design.

The backbone tool will be the website www.bipv.ch. It was developed with the intent of making it an informative website specifically for architects. With this project it will be possible to move up to a following phase of development where the contents of the website will be examined, updated and optimized with a list of examples of BiPV installations and with a CAD library which will include an implemented 3D parametric CAD whose development was also included in this project object.

Aims of the project

In order to prevent an indiscriminate use of photovoltaic applications and to invest economic and spatial resources in the most effective way possible, it is necessary to offer to architects and specialists of the building sector tools and information which are effectively developed considering their specific needs and requests.

Consequently, the distinctive qualities of this project are the contributions of ideas, remarks and advice by different partners. Part of the project will be carried out following the direction of the Solares Bauen Committee constituted of members of Swissolar (Swiss Association of Solar Energy Professionals). The Swiss BiPV Competence Centre will also collaborate with the University of Applied Sciences of Southern Switzerland and with the Architecture Academy of Mendrisio. Thanks to this collaboration, it will be possible to test the material developed within this project on architects, students and specialists of the energy field through one-day courses, workshops and practical assignments. Moreover, considering that some of the objectives are similar, an exchange of information and knowledge with the IEA SHC Task 41 “Solar Energy and Architecture”[1] is also envisaged.

The main objectives of the project are the following:

- elaboration of a list of high quality BiPV installations in Switzerland and in Europe;
- updating and development of the website www.bipv.ch;
- development and improvement of a PV CAD parametric object (determination of characteristics and dynamics);
- configuration of a CAD library (nine standard PV modules were developed using the 3D CAD object; it will be possible to download them together with the 3D CAD object);
- analysis of various software.

BiP e amples

Considering the increasing number of solar installations in the region, it is necessary to avoid an architecturally and constructively indiscriminate use of PV technology. It is consequently indicated that all the actors within the building sector should take advantage of supporting tools which are not generally technical, but rather focus on general aspects, such as examples of various possibilities of PV integration in new buildings or in cases of renovation.

Several examples of existing BiPV plants in Switzerland and in Europe have been analyzed in order to gather architectural, technical and electrical details.

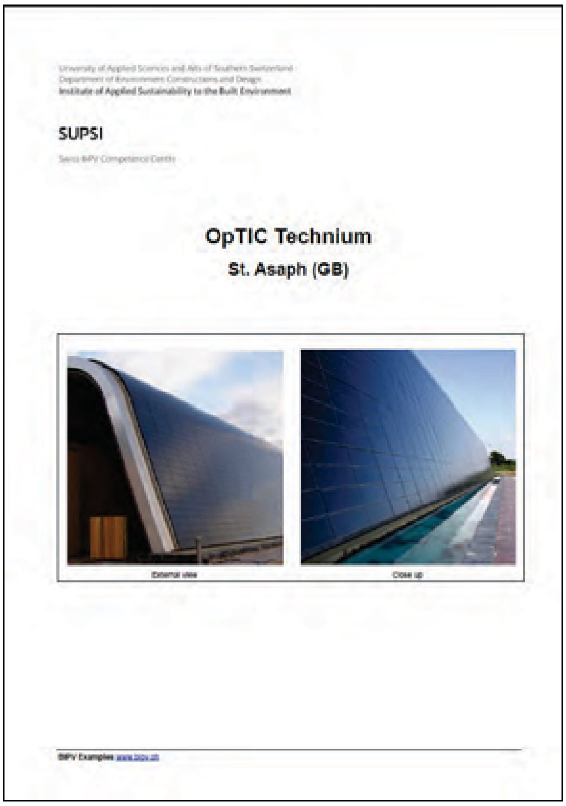

Figure : ayout of the datasheet here all the data regarding an installation are collected n the first page three or more pictures are inserted, hile on the second page the most important information regarding the specific iPV plant is indicated
Source: Isa anetti, IS C-D CD-S PSI

The most significant characteristics of every example are collected in five tables (contacts, building, location of PV plant, specifications, architectural evaluation). As the characteristics of the BiPV plant are presented in summary form, when possible additional information will be provided, for example articles, papers and presentations previously elaborated (either in .pdf format or just by indicating a web link).

In order to assess personal experiences regarding building integration and identifying barriers related to technical and economic aspects, a survey was sent out to some architectural firms who, in these last years, have developed remarkable BiPV installations. Unluckily only few architects completed the whole survey. It was consequently not possible to collect a series of empirical considerations in relation of practical experiences with the integration of photovoltaic modules in high quality architecture buildings.

BiP Website

The website www.bipv.ch is presented in four languages: Italian, German, English and French. Its purpose is to give a general insight into building-integrated photovoltaics (BiPV). Even though the structure and the contents of the website are well established, the web hierarchy and the information displayed in the website were reorganized in order to improve the management and the updating process. In fact there are an increasingly amount of information and data that need to be input almost daily.

The old running software didn’t allow to make the required revisions and because of that it has been necessary to find an adapted CMS operating system (Content Management System).

The website also presents the official list of PV modules and fastening systems that allow the construction of a BiPV plant. This inventory list determines the types of modules that correspond to the category "building integrated photovoltaic plants" for the (Swiss) compensatory feed-in remuneration (see page “products”).

Figure : Homepage bipv ch
Source: im Nagel, IS C-D CD-S PSI

The website is divided in six main pages whose contents are the following:

1. Home – BiPV, integration, news & events, prejudices & FAQ
2. PV Technology – photovoltaic, requirements, energy aspects, characteristics, legal aspects, quality, potential
3. Examples – residential, administrative, industrial, other
4. Products – BiPV criteria, BiPV modules, BiPV fastening systems, other, add products
5. Material – publications, software, glossaries, tables, archiCAD PV object, guidelines, feed in tariff
6. Contact

CAD 3D object

GDL (Geometric Description Language) intelligent object technology offers the optimal way of describing building components to use in construction design and facility management applications. The ability to select building components before and during the design phase will benefit both the designer, who can design by using real objects, and the component manufacturers, who can successfully market their product at an earlier stage in the design process.

The physical characteristics of a PV product (mono- and multicristalline, thin film, opaque surface, partially transparent) such as colour (cells, background, frame), shape (cells and modules), typology of the electrical contacts (standard, back contact), transparency and reflection, have been analyzed. Each of these factors correspond to GDL information which carries 2D and 3D geometry, product logic and behaviours, parameters, material definitions and a specific user interface.

These features allow an effortless customization of the CAD object to the requirements of every user, reproducing most of the products currently on the market using CAD and CAD-compatible software.

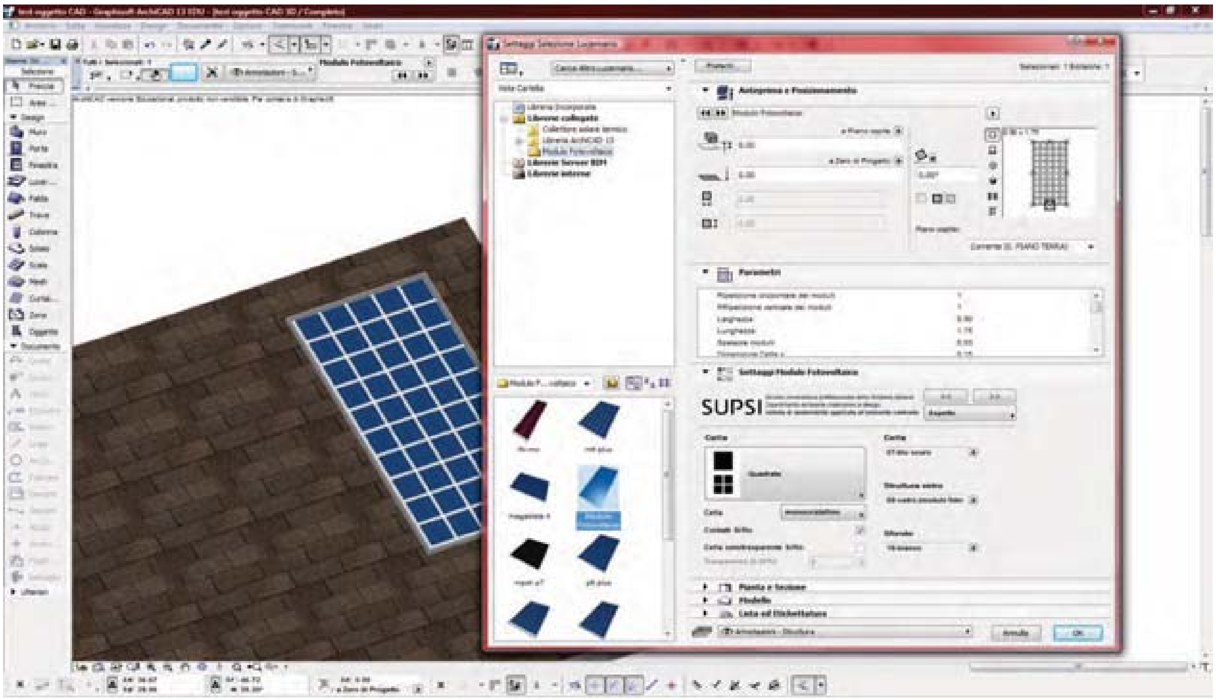

Figure : archiC D D photovoltaic module object indo
Source: Isa anetti, IS C-D CD-S PSI

Using this tool, it was possible to generate a series of virtual PV modules that were subsequently collected into a CAD library.

Figure : nine fixed archiC D D objects
Source: Isa anetti, IS C-D CD-S PSI

CAD 3D objects are very standard tools which are commonly used by architects in the design phase of a project. This tool allows to quickly create building elements as walls, roofs and windows, but also to implement the building rendering with accessories such as pieces of forniture or technical elements. If, as it should be, a photovoltaic module is considered as a constructive element, it is important to have it in the same library of all the other components of a building project. The making of a render of a building with a PV installation will then follow a more logic and efficient process.

A simplified parametric CAD object reproducing standard solar thermal collectors was also developed.

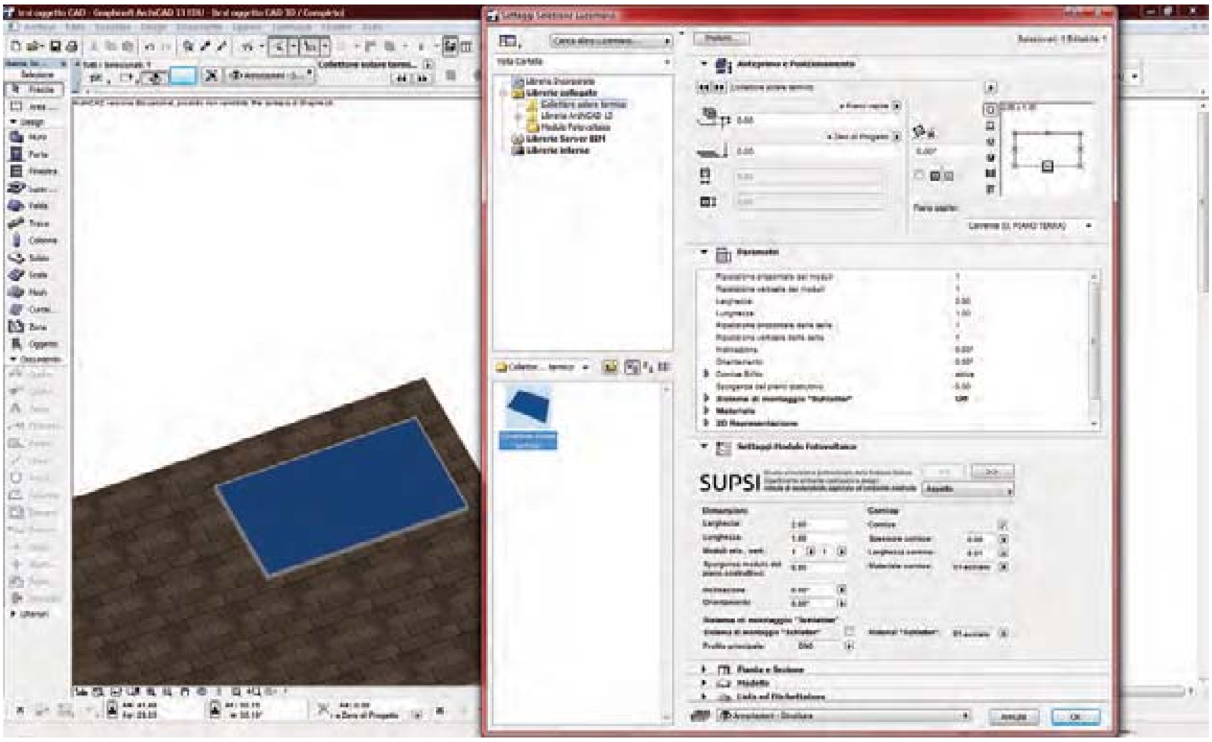

Figure   : archiC   D   D solar thermal collector object   indo
Source: Isa   anetti, IS   C-D   CD-S   PSI

Work carried out and achieved results

The collection of several “referential” BiPV examples is a good way to encourage architects and consequently their clients, to use PV modules into the architectural design. Case studies are an important basis to gain experience regarding the level of successful building integration and to identify barriers related not only to technical and economical aspects, but also to a lack of knowledge/information.

The research of referential case studies has been consistent throughout 2010. On the BiPV website 27 examples of BiPV installations are currently listed. Considering that using PV modules as part of the architectural and constructive concept of a building is getting more and more common, this list will be constantly updated.

The updating and development of the website took place in the second half of the year, concomitantly with the replacing of the operating system. The new software allows a easier and faster management of the website.

Concerning the 3D CAD object and library, both tools are in their latest testing phase in order to make them more user-friendly and to eliminate possible bugs. The 3D object has already been used with success by some of the SUPSI architecture students.

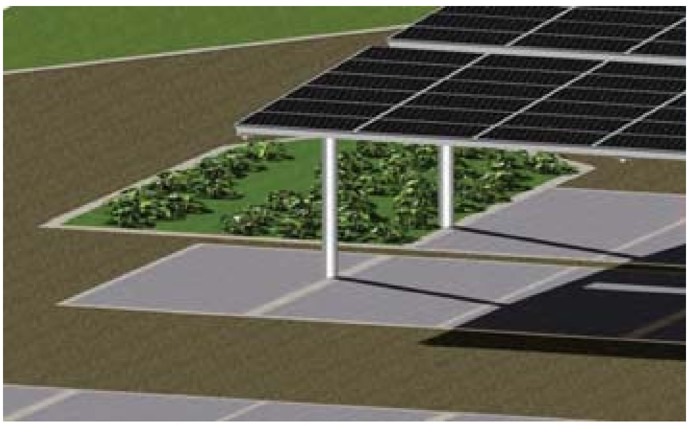

Figure   :   rchiC   D   rendering of a   iPV car shelter
Source: Isa   anetti, IS   C-D   CD-S   PSI

Figure : rchiC D rendering of a iPV sun shading element, the D as refined ith the soft are rtlantis
Source: Isa anetti, IS C-D CD-S PSI

National collaboration

SWISSOLAR - Commission “Solares Bauen” (reference person: Peter Dransfeld)

One of the most interesting aspects of this project is the collaboration with Swissolar and especially with the members of the “Solares Bauen” Commission. In fact, as it was emphasized in the previous pages, BiPV Tools is a project that deals with the significant lack of communication between the actors of the building sector, the general public and the PV sector. Having professionals with expertise in different field working together from the very first phase of solar integration and developing a common and adapted jargon is by itself a success.

SUPSI / DACD - University of Applied Sciences of Southern Switzerland / Environment Construction and Design Department

The Swiss BiPV Competence Centre actively collaborate with the University giving specific course in two laurea bachelor courses (architecture and civil engineering) and one DAS (Diploma in advanced studies - Energy Management) course.

On request, specific lessons on the topic (Bi)PV are also given (e.g. AAM – Architecture Academy of Mendrisio)

IDC AG Luzern - Swiss ArchiCAD distributor

IDC AG was the professional partner who developed the parametric CAD 3D tool.

International collaboration

IEA SHC Task 41 – Solar Energy and Architecture

Some of the subjects (collection of BiPV “good” examples, 3D CAD object) that will be covered by this project have already aroused the interest of the IEA SHC Task 41 “Solar Energy and Architecture”. The task 41 and the BiPV Tools project (which started first) deal with very similar arguments and consequently for both of them is very important to define tools and informative supports that will help the achievement of high quality architecture for buildings through a correct integration of solar energy systems.

Evaluation of ear 2010 and perspectives for 2011

Overall the objectives of the project for 2010 have been accomplished.

The development of the website has been very successful, especially considering that the new operating system enable to optimize resources and time. The new layout of the website allows to consistently implement in the website all the subject that are being/have been elaborated in the BiPV Tool project, thus leading to a better and faster dissemination of the results achieved.

A paper and oral presentation regarding the project named "*ui in -int at P t taic - nt acti t s an inst u nts su tin t si n ui in int at P*", was presented at the EUROSUN 2010 (International Conference on Solar Heating, Cooling and Buildings) which was held in Graz (Austria) from the 28th September to the 1st October.

Concerning the development of a CAD 3D tool (parametric object + library), the programming phase is over. It is still not possible to consider finished the object mainly because the testing part is taking more time than expected, Indeed it is not always straightforward to find a proper way to communicate with our professional partner (IDC), due to their almost non-existent knowledge of the requirements, characteristics, limitations regarding solar technologies (in the specific case: photovoltaic and solar thermal).

As soon as the testing phase is over, the tool will be translated in English, French and German and inserted into the website where it will be possible to download it free of charge.

The elaboration of a list of high quality BiPV installations has been only partially successful, on one hand it was possible to find several very interesting case studies that were more or less exhaustively displayed in internet. On the other hand only few architects have answered to the short survey which was sent out in different languages (English, German and French) at the end of April. The aim of the survey was to collect a series of professional experiences of architects working with BiPV. Considering the very limited feedback that came from non-Swiss architects, it was decided to concentrate on those projects whose architects who have already collaborated with the Swiss BiPV Competence Centre (e.g. Reto Miloni, Beat Kämpfen, Peter Dransfeld, Grab Architekten, etc.).

Finally, concerning the analysis of various software, this is the only task that has been only marginally worked on. In 2011 a number of software that can be used when planning, sizing or simulating a PV/BiPV installation will be tested and then presented through the website.

The BiPV tool project will be concluded in July 2011, consequently in the next six months all the unfinished tasks will be finalized. All the information and data collected will be shown on the BiPV website.

References

[1] IEA SHC Task 41 "Solar Energy and Architecture" - www.iea-shc.org/task41

PHOTO OLTAI S STE TECHNI 2007-2010 (PVSYSTE 07-10)

Annual Report 2010

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Duration of the Project (from – to)	01.07.2007 – 30.06.2010, extended until 31.10.2010 (subproject monitoring from 01.01.07 – 31.12.2010)
Date	21. January 2011

ABSTRACT

Purpose and goals of the project during 2010

- Continuation of long-term monitoring of PV plants.
- Test of further inverters in the power range up to 100 kW according to prEN50530.
- Update of the examination of long-term behaviour of all PV plants monitored until at least 2009.
- First steps for the development of a PV array simulator for higher voltages (1000 V and more).

ost important results in 2010

- Continuation of the long-term monitoring projects (partly since 1992) without any interruption. Evaluation of the long-term behaviour of all PV plants monitored until at least June 2010.
- Development of automated fault-current tests on the DC-side of PV inverters without transformer according to VDE 126-1-1 in a bachelor thesis. After some improvements successful first tests at prototypes of new inverters.
- Confidential (paid) tests of static and dynamic behaviour according to prEN50530 and automated tests of fault current behaviour according to VDE 126-1-1 at prototypes of several inverters.
- Paid test of an inverter NT 5000 (published on www.pvtest.ch after authorisation by Sunways).
- Confidential (paid) tests of EMC behaviour of a prototype of an inverter of 100kW.
- As in the media the problem of firemen safety in case of a fire at a building with PV was intensely discussed, some studies and practical tests with the fire brigade of the city of Burgdorf were carried out.
- The energy yield of a PV plant with solar tiles on the roof of the regional hospital in Burgdorf decreased significantly in the last years. Measurements showed a considerable reduction of MPP-power, MPP-voltage and even some mechanical problems.
- Development of a large resonant circuit (33 kVar) for islanding tests according to VDE126-1-1.
- Introduction of designated successor (Urs Muntwyler) into past and current activities of the PV laboratory.
- Studies of possible future and new activities (e.g. inclusion of PV plants with new technologies (Solyndra) into long-term monitoring project, new CTI projects).
- 3 conference contributions at 25th EU PV conference in Valencia, 3 contributions at the 25th PV symposium at Staffelstein, a talk about PV safety at the 8th Swiss National PV Conference in Winterthur and 2nd edition of updated and extended book "Photovoltaik" [1].

Projekt iele für 2010

- Fortführung des Langzeit-Monitorings an den Anlagen des Projektes (mit kristallinen und Dünnschichtzellen-Modulen). Auswertung der Langzeit-Messdaten und der Wechselrichter-Ausfallstatistik bis mindestens Mitte 2010.
- Weitere Tests an Wechselrichtern bis 100 kW nach prEN50530 mit unseren PV-Simulatoren.
- Realisierung vollautomatischer Fehlerstromtests nach VDE 126-1-1 für trafolose Wechselrichter.
- Entwicklung einer neuen, frei programmierbaren Kennlinienerzeugung für die vorhandenen Simulatoren (mittelfristiger Trend in internationaler Normierung) und erste Schritte für Ausbau auf 1000 – 1200 V.

ur beschreibung der 2010 durchgeführten Arbeiten

Die teilweise seit 1992 ohne Unterbruch durchgeführten Langzeitmessungen an nun 73 PV-Anlagen wurden auch 2010 unterbruchsfrei weiter geführt. Bei der in Zusammenarbeit mit der ADEV Burgdorf in den Jahren 2007 und 2008 erstellten Modulvergleichs-Anlage beim APH Burgdorf mit nunmehr 6 verschiedenen kristallinen Modultypen ist die normierte Gesamtproduktion aller Anlagen nach den Ablesungen auf den Zählern insgesamt sehr hoch, allerdings ist eine genaue Aussage über die einzelnen Teilanlagen noch nicht möglich. Deshalb wurde mit der Planung einer erweiterten, genaueren Messtechnik begonnen. Nachdem in der Anlage ″Stade de Suisse″ im Laufe von 2009 die fehlerhaften AC-Leistungssensoren ersetzt worden waren, traten ab August 2010 wieder neue Probleme auf, diesmal an den verwendeten Strahlungssensoren. Diese immer wieder auftauchenden Probleme reduzieren leider die Qualität der Daten und der daraus möglichen Auswertungen bei dieser Anlage. Die weiter geführte Ausfallstatistik der Wechselrichter bei allen Anlagen zeigte auch im vergangenen Jahr wieder eine erfreulich tiefe Anzahl der registrierten Ausfälle.

Da der Energieertrag der PV-Anlage auf dem Regionalspital Burgdorf seit der Inbetriebnahme im Jahre 1999 kontinuierlich abnahm, wurde diese im Sommer 2010 im Auftrag der Localnet AG eingehend untersucht. Dabei wurde eine bedenkliche Abnahme vom P_{MPP} und U_{MPP} der dafür verwendeten, seinerzeit von der Firma Atlantis hergestellten Solarziegel "Sunslates" festgestellt und auch mögliche mechanische Probleme dieser Ziegel bemerkt.

Anfang 2010 wurde beim neuen 100kW-Solargenerator-Simulator bei grösseren Spannungen ein geringfügiges Stabilitätsproblem entdeckt. Die gemessene Spannung veränderte sich in den ersten Minuten nach dem Einschalten um etwa 0,07%. Da eine sehr hohe Stabilität ein wichtiges Entwicklungsziel unseres Simulators war, wurden weitere Verbesserungen vorgenommen und es besteht nun nur noch ein sehr kleiner Restfehler von 0,03%.

Neben einem (bezahlten) Test des Wechselrichters NT5000 für Sunways wurden mit dem 100kW-Solargenerator-Simulator für die Firma Sputnik auch einige (bezahlte) Messungen an Prototypen von Geräten mittlerer und grösserer Leistung vorgenommen. Ergebnisse solcher bezahlter Tests sind im Prinzip vertraulich; die Firma Sunways hat aber der Publikation des Testberichtes auf unserer Homepage www.pvtest.ch zugestimmt.

Im Rahmen zweier Semester- und Bachelorarbeiten in den Jahren 2009 und 2010 wurde ein Gerät entwickelt, das unter Computersteuerung einen automatischen Fehlerstromtest auf der DC-Seite von trafolosen Wechselrichtern nach VDE126-1-1 durchführen kann. Nach einigen Anpassungsarbeiten konnten damit erfolgreich weitgehend automatische Fehlerstromtests durchgeführt werden, die viele langwierige (tagelange) Handmessungen ersetzen.

Um auch bei grösseren Wechselrichtern Inselbetriebstests durchführen zu können, wurde ein grosser 33 kVar-Resonanzkreis entwickelt (Q_{max} = 37 kVar). Mit drei dieser Geräte können an Wechselrichtern bis 100 kW nun Inseltests nach VDE 126-1-1 und IEC 62116 durchgeführt werden.

Auch Ende 2010 hat sich nach verschiedenen Brandfällen an Photovoltaikanlagen ein weiterer interessierter Hersteller unter einem Non-Disclosure-Agreement über Aufbau und Funktionsprinzip des am PV-Labor entwickelten Lichtbogendetektors informieren lassen.

Da im Sommer 2010 vermehrt Berichte über die mögliche Gefährdung der Feuerwehr durch PV-Anlagen erschienen, wurde dieses Problem etwas näher untersucht und erste Messungen durchgeführt. Insbesondere wurden unter Mitwirkung der Feuerwehr Burgdorf nächtliche Kennlinienmessungen an Teilgeneratoren von 5 kW und 21 kW der PV-Testanlage in Burgdorf durchgeführt, ein Vortrag bei der Berufsfeuerwehr Bern gehalten und ein Beitrag für das 26. PV-Symposium in Staffelstein eingegeben.

Neben je drei Beiträgen am 25. PV-Symposium in Staffelstein und an der 25. EU PV Konferenz in Valencia erschien im Mai 2010 auch die zweite, wesentlich erweiterte Ausgabe des vom Projektleiter verfassten Buches über Photovoltaik-Systemtechnik [1]. Die beiden 2007 und 2010 erschienenen Bücher werden inzwischen von vielen PV-Fachleuten bereits als Standardwerke betrachtet.

Durchgeführte Arbeiten und erreichte Ergebnisse

Lang eitmessungen

P -Anlage "Stade de Suisse" Wankdorf

Die PV-Anlage "Stade de Suisse" (Wankdorf), deren Messdaten im Rahmen dieses Projektes seit April 2005 vom PV-Labor der BFH-TI ausgewertet werden, wurde im Sommer 2007 auf eine neue Gesamtleistung von 1,342 MWp ausgebaut. Die verwendete Messtechnik hatte leider verschiedene hartnäckige Probleme, welche die Auswertung der Messdaten teilweise wesentlich erschwerte. Da bei der Messtechnik mehrere Parteien involviert sind, erweist sich die Behebung dieser Probleme als relativ mühsam. Schon zu Beginn traten Probleme mit falsch montierten Meteosensoren auf und wegen lang anhaltender Probleme mit den AC-Wirkleistungssensoren Star3 konnten die Wirkungsgradmessungen lange nicht mit der gewünschten Genauigkeit durchgeführt werden. Abhilfe brachte erst der im Sommer 2009 erfolgte Austausch dieser Sensoren durch ein anderes Fabrikat. Ab August 2010 traten leider wieder neue Probleme an der Messtechnik auf, diesmal an den verwendeten Strahlungssensoren.

Wechselrichter-Ausfallstatistik

Die bezüglich Zuverlässigkeit kritischste Komponente bei netzgekoppelten Photovoltaikanlagen ist der Wechselrichter. Das PV-Labor der BFH-TI führt bereits seit 1992 eine Ausfallstatistik über eine bisher stetig steigende Anzahl von Netzwechselrichtern. Diese wurde auch 2010 weiter geführt. Gegenwärtig werden 73 Wechselrichter überwacht. Das Durchschnittsalter aller Wechselrichter, welche im Moment im Monitoring-Programm sind, beträgt ca. 8 Jahre (siehe Fig. 1). Dieser Durchschnitt blieb in den letzten Jahren wegen der Integration neuer Anlagen (Wankdorf/Stade de Suisse und auf dem Alterspflegeheim in Burgdorf) und durch den Ersatz alter defekter Wechselrichter annähernd konstant. Im Jahr 2010 lag die Ausfallrate bei etwa 0,08 Wechselrichter-Defekten pro Wechselrichter-Betriebsjahr (Stand Ende August, hochgerechnet auf Ende Jahr), also wieder etwas tiefer als 2009. Sie liegt damit auch deutlich unter dem langjährigen Mittelwert von 0,122 in den Jahren 1997 – 2010.

In den Jahren 1992 – 1994 lag die Anzahl Wechselrichter-Defekte pro Betriebsjahr (siehe Fig. 1) noch im Bereich 0,7 bis 1, sank dann in den folgenden Jahren kontinuierlich ab und stabilisierte sich in den Jahren 1997 bis 2010 im Bereich 0,07 bis 0,21 . Im Jahre 2001 erreichte dieser Wert in dieser Periode ein relatives Maximum von 0,21 , bedingt durch den Ausfall von zumeist älteren Geräten. Im Jahre 2002, in dem keine schweren Gewitter beobachtet wurden, sank er dagegen wieder auf einen Rekordtiefstand von 0,07 und stieg 2004 wieder auf 0,14 an. Im Jahr 2006 wurde der Minimalwert der Ausfallrate aus dem Jahre 2002 nochmals ganz leicht unterboten. 2007 - 2009 lag die Ausfallrate immer ganz wenig über 0,1 und in den ersten 8 Monaten von 2010 etwa bei 0,08.

Interessant ist die Beobachtung, dass sich die Defekte bei den trafolosen Geräten alle auf den gleichen Gerätetyp konzentrieren, der bei vielen Anlagen in Burgdorf eingesetzt wurde.

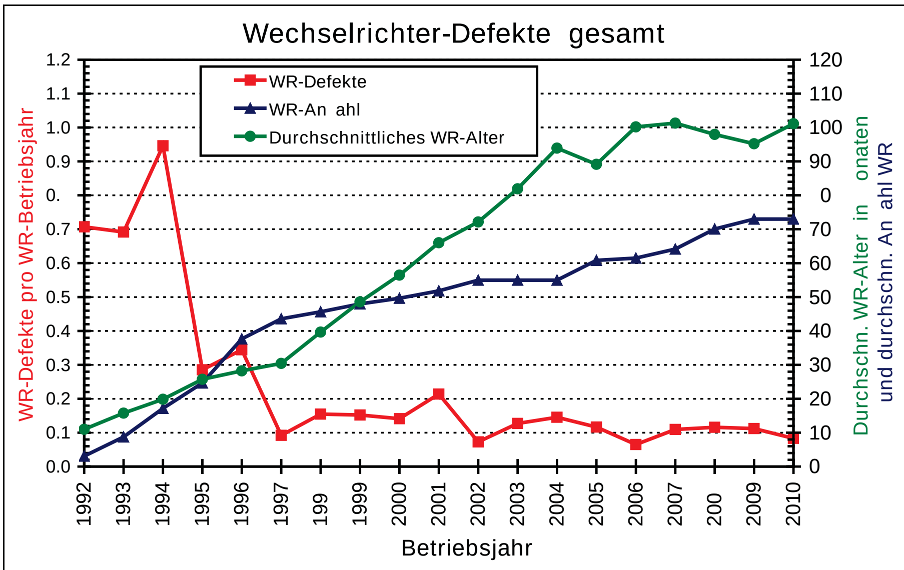

Fig. 1: Wechselrichterdefekte (Daten bis August 2010)

Wechselrichterdefekte pro Wechselrichter-Betriebsjahr und durchschnittliche Anzahl von der BFH überwachter Wechselrichter in den Jahren 1992 - 2010.

Dank dem Einsatz von neuen und Ersatz von alten Wechselrichtern (11 in 2005, 9 in 2007, 8 in 2008 und 6 in 2009 und bisher 2 in 2010) ist das Durchschnittsalter der überwachten Wechselrichter seit 2006 etwa konstant.

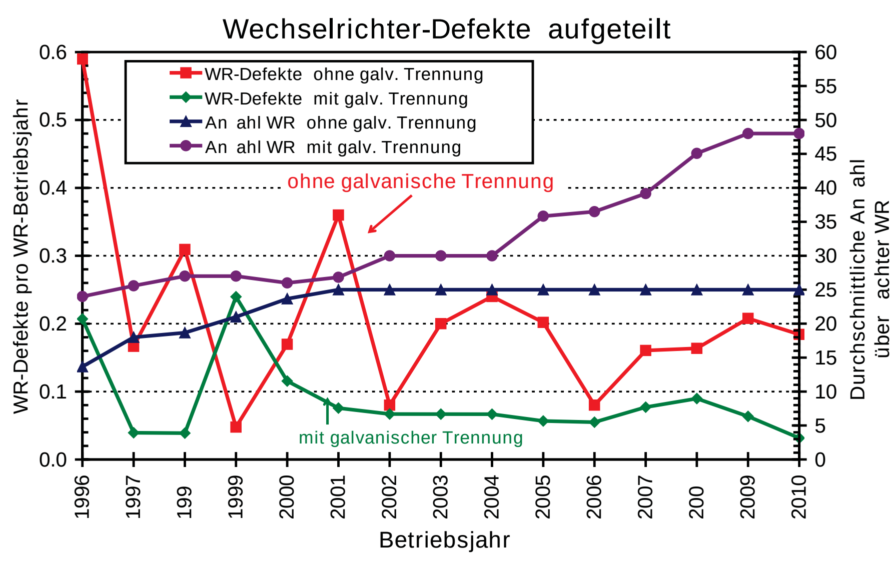

Fig. 2:
Wechselrichterdefekte nach T pen aufgeteilt (Daten bis August 2010)

Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr aufgeteilt nach Wechselrichtern mit und ohne galvanische Trennung von 1996 – 2010 (Stand Ende August 2010, hochgerechnet auf das ganze Jahr 2010).

Praktisch alle Wechselrichter ohne galvanische Trennung stammen vom gleichen Hersteller.

Auf Grund der gemessenen Daten scheint die Langzeit-Zuverlässigkeit von galvanisch getrennten Wechselrichtern etwas grösser zu sein. Allerdings ist die Grösse der Stichprobe relativ klein.

In der Regel verlaufen Wechselrichterdefekte relativ unspektakulär, das Gerät funktioniert einfach nicht mehr und speist nicht mehr ein. Ab und zu treten aber auch schwerwiegendere Ereignisse auf, die unter ungünstigen Umständen schlimmere Folgen haben könnten.

Am 22.6.2010 fiel um 20:00 im Alters- und Pflegeheim Burgdorf der Wechselrichter der Anlage APH7 aus. Der Ausfall hatte einen Brandalarm zur Folge. Die Kondensatoren explodierten und ein Teil des Gehäuses schmolz (siehe Fig. 3 und Fig. 4). Erstaunlich ist, dass der Vorfall nicht etwa um die Mittagszeit bei grosser Einstrahlung geschah, sondern am Abend. Es war Glück, dass nichts Schlimmeres geschah und kein grösserer Brand entstand, der möglicherweise sogar auf andere Wechselrichter übergegriffen hätte. Der betroffene Wechselrichter hatte ein Gehäuse mit einem Deckel aus Kunststoff, der teilweise durchschmolz. Ein Gehäuse aus Metall wäre bei gravierenden elektrischen Fehlfunktionen und Bränden innerhalb eines Wechselrichters wahrscheinlich besser. Das betroffene Gerät wurde kurz darauf durch einen SolarMax 4000CX ersetzt, der seither einwandfrei funktioniert.

Fig. 3:
Vom Brand betroffener Wechselrichter Convert 4000 mit explodierten Kondensatoren.

Fig. 4:
Durchgeschmolzenes Gehäuse des vom Brand betroffenen Wechselrichters Convert 4000.

Automatische Fehlerstrommessung nach DE126-1-1 auf der DC-Seite von trafolosen Wechselrichtern

Nach VDE126-1-1 müssen bei trafolosen Wechselrichtern relativ aufwändige Fehlerstromtests auf der Gleichstromseite durchgeführt werden. Neben relativ einfachen Tests mit plötzlich ansteigenden Fehlerströmen gemäss Tabelle 1 sind auch relativ komplizierte Tests mit kombinierten kapazitiven und ohmschen Fehlerströmen nötig, die bei manueller Ausführung nebst einer geeigneten Infrastruktur jeweils bis zu einigen Personentagen benötigen.

Effektiv ert des Fehlerstromes mA	Abschalt eit s
30	0.3
60	0.15
150	0.04

Tab. 1:

Maximal zulässige Abschaltzeiten bei verschiedenen plötzlich auftretenden Fehlerströmen.

Die für solche Messungen verwendete Prinzipschaltung wurde bereits im Schlussbericht zum BFE-Projekt "Photovoltaik-Systemtechnik 2003 – 2006 " eingehend dargestellt. Im Rahmen zweier Semester- und Bachelorarbeiten wurde in den Jahren 2009 und 2010 ein automatisches Fehlerstrom-Testgerät entwickelt, das zusammen mit einem PV-Generator-Simulator, der AC-Netzersatzquelle und einem Leistungsverstärker diese Tests unter Computersteuerung automatisch durchführt und die Messergebnisse dokumentiert. Das dabei entwickelte Gerät wurde im Rahmen dieses Projektes noch etwas verbessert und ist nun einsatzfähig. Fig. 5 zeigt das realisierte Gerät von aussen und Fig. 6 von innen.

Fig. 5:
Im Rahmen zweier Bachelorarbeiten in 2009 und 2010 entwickeltes Testgerät für automatische Fehlerstrommessungen nach VDE 126-1-1 auf der DC-Seite von trafolosen PV-Wechselrichtern. Oben auf dem Gerät ist der für die Erzeugung des variablen kapazitiven Ableitstromes notwendige Leistungsverstärker zu erkennen.

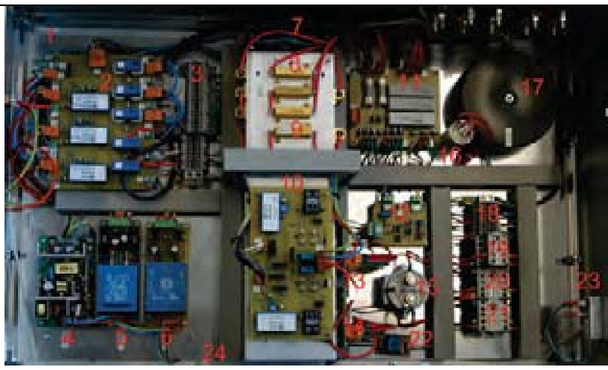

Fig. 6:
Innenansicht des im Rahmen zweier Bachelorarbeiten in 2009 und 2010 entwickelten Testgeräts für automatische Fehlerstrommessungen nach VDE 126-1-1 auf der DC-Seite von trafolosen PV-Wechselrichtern.

Neben diesem Testgerät sind noch diverse andere Geräte nötig, um solche automatischen Tests durchzuführen. Auf der DC-Seite wird der zu prüfende Wechselrichter von einem Solargenerator-Simulator gespeist, der von einem eigenen PC gesteuert wird. Für die Erzeugung der für gewisse Tests nötigen variablen kapazitiven Ableitströme benötigt das Fehlerstrom-Testgerät einen steuerbaren Kepco-Leistungsverstärker von 400 W. Zudem wird eine vom Computer steuerbare AC-Spannungsquelle von 3·5kW mit geringem Oberschwingungsgehalt benötigt. Mit Ausnahme des Solargenerator-Simulators wird die ganze Testanordnung von einem zweiten PC gesteuert (Details siehe [10]).

Gef hrdung der Feuer ehr durch P -Anlagen im atastrophenfall

In letzter Zeit wurde berichtet, dass die Feuerwehr Gebäude mit PV-Anlagen wegen möglicher Gefährdung der Feuerwehrleute nicht mehr lösche und dass bei solchen Anlagen bereits durch nächtliches Restlicht (z.B. bei Vollmond!) lebensgefährliche Spannungen aufträten. Dies ist übertrieben und basiert auf mangelnder Kenntnis der Eigenschaften von PV-Anlagen und der Gefährdung des Menschen durch die darin auftretenden Gleichströme. Durch Markierung der Gebäude mit PV-Anlagen und Ausbildung der Feuerwehrkader sollte im Brandfall vor Ort eine sinnvolle Beurteilung der Gefahr möglich sein, sodass ein Rettungs- und Löscheinsatz durchführbar ist.

Grunds t liche berlegungen ur effektiven elektrischen Gef hrdung

Bei Niederspannung (bei Wechselstrom (AC) $U \leq 1000$ V, bei Gleichstrom (DC) $U \leq 1500$ V) ist nicht die in der Anlage vorhandene Spannung, sondern der durch das Herz fliessende Strom die Ursache für tödliche Unfälle (Auslösung von Herzkammerflimmern beim Überschreiten bestimmter Grenzwerte) [9]. Zudem kann durch den Körper fliessender Strom schon bei etwas tieferen Werten unwillkürliche Muskelkontraktionen und bei AC auch einen Muskelkrampf bewirken, der das Loslassen verunmöglicht [9]. *ic st D ist a t a u in n a t ni ic a s c s st un i t in n us a , as s ass n in t* Je nach auftretender Stromstärke unterscheidet man verschiedene Bereiche (Tabelle 2, [9]):

	AC	DC
Bereich 1	< 0,5 mA	< 2 mA
Bereich 2	0,5 - 5 mA	2 - 25 mA
Bereich 3	5 - 35 mA	25 - 150 mA
Bereich 4	> 35 mA	> 150 mA

Tabelle 2: Bereich 1: Bemerkbarkeit bereits möglich, keine körperliche Reaktion
Bereich 2: Muskelkontraktionen möglich beim Berühren und Loslassen
Bereich 3: Starke unwillkürliche Muskelkontraktionen möglich
Bereich 4: Mit steigendem Strom Herzkammerflimmern möglich
i D - t ic tun n an u ss n t a t t u ssi

Gefahr durch Restlicht in der Nacht

Es wird behauptet, dass an Solargeneratoren bereits bei geringem Restlicht (z.B. bei Vollmond) lebensgefährliche Spannungen auftreten könnten. *Di s ist nsinn, nn P - n at n sin in annun s u n, s n n t u n* (Strom proportional zur Bestrahlungsstärke). Bei sehr geringer Beleuchtung reicht trotz einer allfällig vorhandenen Spannung der mögliche Strom meist nicht aus, um gefährliche Werte zu erreichen, und die Spannung fällt bei Belastung rasch zusammen. Experimente haben gezeigt, dass im Lichte des Vollmondes die Leerlaufspannungen < 2% der Leerlaufspannung U_{OC} bei STC (Standard-Testbedingungen) liegen und dass der Kurzschlussstrom weniger als etwa 0,0002% des Kurzschlussstromes I_{SC} bei STC beträgt.

Im Scheinwerferlicht oder im Licht eines Brandes in der Nacht sind höhere Bestrahlungsstärken möglich, aber weil diese immer noch viel geringer als bei Tageslicht und nicht gleichmässig über die ganze PV-Anlage verteilt sind, ist der mögliche Kurzschlussstrom aus dem PV-Generator selbst meist viel geringer als der Kurzschlussstrom bei STC. Bei Serieschaltung von Solarmodulen ist der Gesamtstrom bei höheren Spannungen vor allem durch den Strom der am schwächsten beleuchteten Module bestimmt.

Um das Problem an einer grösseren Anlage in der Praxis zu untersuchen, wurden am 27.10.2010 mit der Feuerwehr Burgdorf eingehende Beleuchtungsversuche mit Halogenscheinwerfern am PV-Generator der PV-Testanlage der BFH-TI in Burgdorf durchgeführt (Situation siehe Fig. 7, Resultate siehe Fig. 8, weitere Details siehe [10]).

Fig. 7:
Situation am Solargenerator bei Beleuchtung des PV-Generators der Teilanlage West der PV-Testanlage der BFH-TI durch zwei Scheinwerfer von je 1 kW am 27.10.2010 im Abstand von wenigen Metern durch die Feuerwehr Burgdorf. Die vorne liegenden Module werden relativ stark (teilweise mit Bestrahlungsstärken bis gegen 150 Lux) bestrahlt, die weiter entfernt liegenden Arrays in grösserem Abstand aber viel schwächer.

Die Fig. 8 zeigt einige bei diesen Beleuchtungsversuchen gemessene I-U-Kennlinien eines Teilgenerators von 5,28 kWp (4 Stränge zu 24 Modulen Siemens M55). Weitere Messungen sind in [10].

Aus den Messergebnissen von Fig. 8 (Versuche mit der Feuerwehr an einer für ein Einfamilienhaus typischen Anlagegrösse) kann geschlossen werden, dass bei nächtlicher Beleuchtung eines Schadenplatzes bei Einhaltung eines gewissen Minimalabstandes (z.B. 12 m bei einem Scheinwerfer von 1 kW, 17 m bei einem Scheinwerfer von 2 kW) bei einem PV-Generator die mögliche Leerlaufspannung höchstens etwa 60% von $U_{OC\text{-}STC}$ und der mögliche Kurzschlussstrom max. ca. etwa 0,1% von $I_{SC\text{-}STC}$ beträgt. Bei grösseren PV-Generatoren ist es zudem kaum möglich, eine genügend homogene Bestrahlungsstärke zustande zu bringen, so dass die Gefahr bei weitem nicht proportional zur Leistung ansteigt (siehe [10]). Von einem nächtlich durch Scheinwerfer beleuchteten PV-Generator allein (*n in un it in c s ic t*) geht somit nur eine sehr geringe Gefahr aus. Auch die möglichen Ströme sind so klein, dass eine Zündung und Aufrechterhaltung von allfälligen Lichtbögen kaum denkbar ist.

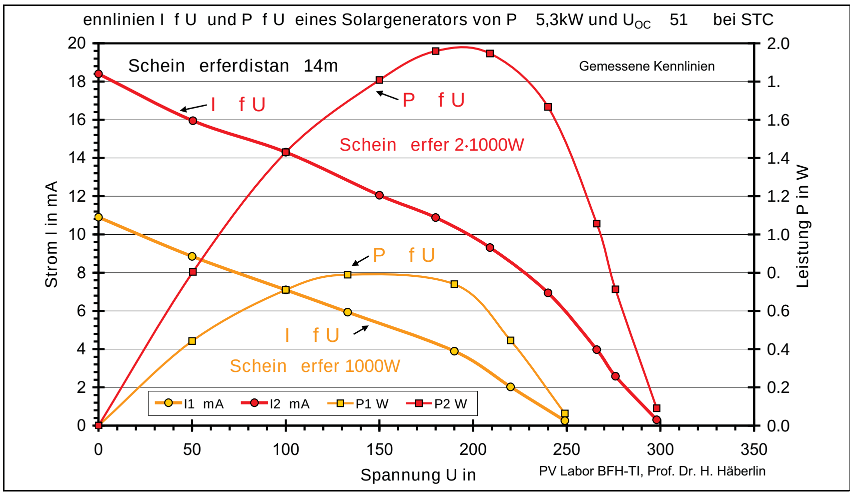

Fig. :
I-U- und P-U-Kennlinie eines PV-Generators von 5,3 kWp aus 96 Modulen Siemens M55 (4 Stränge zu 24 Modulen in Serie) bei Bestrahlung im Abstand von 14 m mit einem oder zwei Halogenscheinwerfern von 1 kW.

Technische glichkeiten ur Spannungsreduktion beim Feuer ehreinsat

In einer verschalteten PV-Anlage (mit durchgeschaltetem DC-Trennschalter beim Wechselrichter!) befindet sich im Wechselrichter meist ein Eingangskondensator C_E direkt an den Eingangsklemmen (bis einige 100 µF bei 3-phasigen, bis einige 1000 µF bei 1-phasigen Geräten), der sich auf die Betriebsspannung auflädt. An diesem C_E ist meist dauernd die DC-seitige Eingangsüberwachungsschaltung DC-ÜW des Wechselrichters angeschlossen. Fig. 9 zeigt ein Prinzipschema einer PV-Anlage mit verschiedenen Möglichkeiten zur DC-seitigen Spannungsreduktion bei Bränden, mit dem auch der Einfluss von C_E auf die Verhältnisse auf der DC-Leitung untersucht werden kann.

Das Öffnen des DC-Trennschalters S_{DC} unterbricht den Stromfluss zum Wechselrichter, löscht eventuelle Serielichtbögen im PV-Generator und trennt C_E von der DC-Leitung ab. Die DC-Leitung und der PV-Generator werden aber dadurch nicht spannungsfrei, sondern es ist auf der Leitung bis zur Trennstelle immer noch eine Spannung (und bei Belastung auch ein gewisser Strom) gemäss der sich auf Grund der aktuellen Bestrahlungsstärke ergebenden PV-Generatorkennlinie vorhanden. Wie bereits erwähnt, sind die möglichen Ströme bei Scheinwerferlicht in der Nacht sehr klein.

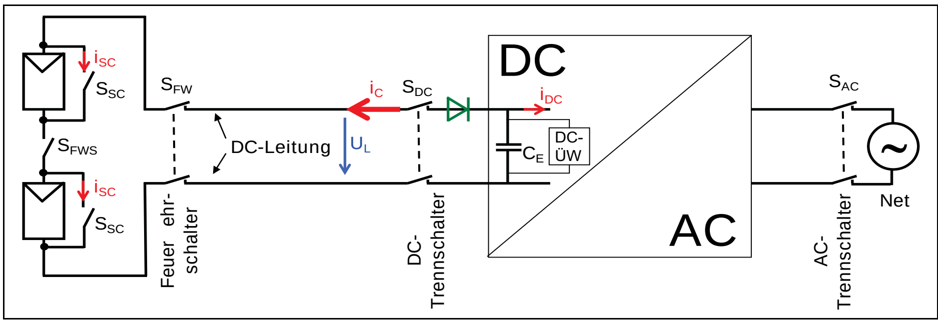

Fig. 9:
Prinzipschema einer PV-Anlage mit verschiedenen Möglichkeiten zur DC-seitigen Spannungsreduktion bei Bränden.

Wird die DC-Seite durch einen seriellen Feuerwehrschalter S_{FW} beim PV-Generator abgeschaltet, sind nur noch bis zur Trennstelle Spannung und Strom gemäss der PV-Generator-Kennlinie bei der aktuellen Bestrahlungsstärke vorhanden. Durch weitere Schalter S_{FWS} in den Strängen kann erreicht werden, dass nach dem Auslösen von S_{FW} alle Teile des PV-Generators Spannungen unter 120 V aufweisen.

Auf der Wechselrichterseite des Schalters S_{FW} (auf der Leitung!) ist bei geschlossenem S_{DC} und fehlender Diode (grün) die Spannung über dem Eingangskondensator C_E vorhanden. Nach dem Abtrennen des PV-Generators durch Öffnen der Feuerwehrschalter S_{FW} und/oder S_{FWS} oben beim PV-Generator entlädt die DC-seitige Eingangsüberwachungsschaltung DC-ÜW im Wechselrichter langsam den Eingangskondensator C_E. Dies dauert einige Sekunden bis Minuten. In dieser Zeit ist auf der Leitung immer noch eine langsam sinkende Spannung U_L vorhanden, die eine gewisse Gefahr darstellt. Durch eine Diode (grün) beim oder im Wechselrichter oder durch gleichzeitiges Öffnen von S_{DC} oder eines Eingangsrelais oder -schützes wird die DC-Leitung nach dem Öffnen der Feuerwehrschalter sofort spannungsfrei. Eine Diode hat aber zusätzliche Verluste und muss gekühlt werden.

Einige Hersteller wollen die einzelnen Module im Katastrophenfall (mit Schaltern S_{SCM}) *i t a - u u sc i ss n*. Diese Lösung kann an PV-Generatoren mit nur wenigen parallelen Strängen *n an sc ss n n c s ic t* durchaus funktionieren. Beim Kurzschliessen der Module in einer PV-Anlage mit angeschlossenem Wechselrichter werden diese Kurzschlussschalter S_{SCM} durch einen hohen Entlade-Kurzschlussstrom i_C aus dem Kondensator C_E beansprucht. Die dabei freigesetzte Energie ist beträchtlich (Bsp.: C_E = 2000 µF, U_C = 700 V ⇒ E =490 J!). Abhilfe ist durch eine Diode (grün) beim / im Wechselrichter, gleichzeitiges Öffnen von S_{DC}, ein gleichzeitig geöffnetes Eingangsrelais oder -schütz im Wechselrichter oder durch Strangdioden möglich. Weitere Details in [10].

Nationale / internationale usammenarbeit

- Wöchentliche Rapporte an die GMS (Diagramme der Anlagen Stade de Suisse und Mont Soleil).
- Vertrauliche (Teil-)Tests an Prototypen von Wechselrichtern verschiedener Hersteller.
- Durchführung von vertraulichen Untersuchungen an Prototypen von Bypassdioden oder Modulanschlussdosen für verschiedene Hersteller in Modulen mit und ohne Rahmen.
- Intensive Kontakte mit Vertretern des FhG/ISE im Zusammenhang mit der Feuerwehr-Sicherheit.
- Vortag über die Gefahr durch PV-Anlagen für die Feuerwehr bei der Berufsfeuerwehr Bern.
- Bau eines grossen 33kVar-Resonanzkreises für einen Wechselrichter-Hersteller in der Schweiz.
- Vortrag von U. Muntwyler bei Feuerwehr Gemeinde Wohlen nach Brandfall an Gebäude mit PV.

Referen en / Publikationen meist als PDFs auf .pvtest.ch herunterladbar

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Ausblick für 2011 m gliche Arbeiten im Rahmen eines Nachfolgeprojektes

- Definition und Eingabe eines Nachfolgeprojektes PV-Systemtechnik (2011 – 2013?) durch Urs Muntwyler, dem designierten Nachfolger von Heinrich Häberlin.
- Weiterführung der seit nun teilweise über 18 Jahren andauernden, ununterbrochenen Langzeitmessungen im bisherigen Rahmen (auch im Rahmen eines Nachfolgeprojektes).
- Verbreiterung der finanziellen Trägerschaft durch zusätzliche Akquisition von KTI-Projekten.
- Integration weiterer Anlagen mit neuen Technologien (z.B. Solyndra) in die Langzeitmessungen.
- Fertigstellung der Entwicklung einer neuen, frei programmierbaren Kennlinienerzeugung für die vorhandenen Simulatoren (mittelfristiger Trend in internationaler Normierung).
- Da sich die Anlage APH auch für Reinigungsversuche durch Putzroboter im EU-Projekt PV-Servitor eignet, ist geplant, die Anlage mit einer Feinmesseinrichtung mit wesentlich höherer Messgenauigkeit auszurüsten. Die Möglichkeit, 6 verschiedene Modultypen am gleichen Standort im Rahmen ganzer Anlagen genau zu vergleichen, ist für beide Projekte von Interesse.
- Da bei Netzverbund-Wechselrichtern ein Trend zu immer höheren DC-Spannungen besteht, Bau eines schnellen Solargenerator-Simulators für U_{OC} bis 1000 V und etwa 25 kW – 30 kW (eventuell mit bis zu drei unabhängigen Teilsimulatoren mit separaten MPP-Tracking-Messinterfaces).
- Weitere Stresstests an Solarmodulen von heute üblicher Grösse (Bypassdioden, Bypassdioden-Ersatzschaltungen und Solarzellen).
- Aufbau eines Angebots für zertifizierte Wechselrichtertests und die Durchführung derartiger Tests als Dienstleistung für interessierte Hersteller.

Ferner wird voraussichtlich im August im Wiley-Verlag unter dem Titel "Photovoltaic System Design and Practice" eine englische Übersetzung des Buches Photovoltaik [1] erscheinen.

BAC UP IN ERTER

PRAXISTEST EINES BACKUP-WECHSELRICHTERS IN DER SCHWEIZ

PRACTICAL TESTING OF BACKUP INVERTER IN SWITZERLAND

Annual Report 2010

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Project- / Contract Number	102421 / 153047
Duration of the Project (from – to)	October 2007 – October 2010
Date	21 of December 2010

ABSTRACT

Conventional power inverters for photovoltaic systems need to switch off during heavy grid disturbances or power outages due to safety reasons. Therefore, even if the solar panels can produce enough power to autonomously supply the load, no electricity is available in the building in the case of such events.

In this project, a backup-inverter is being tested. The backup-inverter separates the electrical grid inside a building ("backup grid") from the public electrical grid in case of power outage. The backup grid is designed to operate autonomously.

Backup-inverters have rarely been installed within Switzerland. Such a system is installed within a pilot plant and tested. In the first test in 2009, the backup-inverter ISA3000 (Conergy) is used. However due to malfunction and ceased technical support by Conergy, the inverter cannot be used.

In the second step, the "Sunny Backup Set S" (SMA) is tested, and this backup-inverter works properly. The quality of the voltage is high. The negative aspect is the high energy consumption of the device. Also, the PV power inverter tends to have difficulties synchronising with the emergency grid.

Einleitung / Projekt iele

Ende 2007 waren in der Schweiz über 44.1 MWp netzgekoppelte Photovoltaikanlagen installiert[1]. Aus Sicherheitsgründen sind diese Anlagen während Stromausfällen dazu verpflichtet, sich automatisch auszuschalten. Somit bietet eine Solaranlage gegenüber einem konventionellen Netzanschluss keine höhere Versorgungssicherheit, selbst wenn sie lokal genügend Strom produzieren könnte.

Nachdem Tests im Frühjahr 2009 gezeigt haben, dass der ISA 3000 nicht zuverlässig funktioniert, wurde der Backupwechselrichter im Rahmen einer Projekterweiterung im Herbst 2009 mit dem Sunny Backup Set S von SMA ersetzt. Die PV-Anlage sowie die Messgeräte wurden dem neuen System angepasst. Die Langzeitmessungen wurden vom Winter 2009 bis zum Sommer / Herbst 2010 durchgeführt. Die Messungen von transienten Vorgängen sowie die Spannungsqualitätsmessungen wurden im Sommer 2010 durchgeführt.

Ausgemessen und getestet wurden die folgenden Systeme:

- Sunn Backup Set S von S A: Pilot- und Demonstrationsanlage in Mönchaltorf, Langzeittests, Wirkungsgradmessungen sowie Messungen von transienten Vorgängen.
- Sunn Backup Set L von S A: In Privathaushalt installiertes System zur Notstromversorgung, Messungen von transienten Vorgängen.
- PC 2200 von Studer Innotec: In Privathaushalt installiertes System zur Notstromversorgung, Messungen von transienten Vorgängen.

Tests am neu installierten Sunny Backup-System sollen folgende Fragen beantworten:

1. Ist die Umschaltzeit von Normalbetrieb auf Notstrombetrieb genügend kurz und netz- und lastseitig störungsfrei, um anspruchsvolle Geräte (z.B. Computer) sicher betreiben zu können?
2. Sind die Lade- und Entladestrategien sowie die Massnahmen (Warnungen, Notausschalten) bei leerer und voller Batterie so implementiert, dass anspruchsvolle Geräte sicher betrieben werden können?
3. Wie verhält sich das Gerät bei Überlast?
4. Kann Batteriestrom ins Netz eingespeist werden? Kann die Batterie vom Netz geladen werden?
5. Sind die Wirkungsgrade (Einspeisung, Batteriebetrieb) dem Standard herkömmlicher Solar- und USV-Anlagen entsprechend?

Beschreibung des S stems Sunn Backup Set S

Im Gegensatz zum ISA3000 von Conergy sind die Sunny Backup Sets modular aufgebaut. PVWechselrichter, Backupwechselrichter und Umschalteinheit sind je einzelne Geräte, siehe Abbildung 1.

Die Philosophie des Backup Sets sieht zwei Betriebsarten vor:

- Normalbetrieb: Die PV-Anlage speist über die selbsttätige Schaltstelle für PV-Anlagen und über einen separaten PV-Einspeisezähler Strom ins Netz ein. Die PV-Anlage ist durch den PV-Koppelschütz von den Verbrauchern getrennt. Derweil lädt das Gerät Sunny Backup 2200 (SB 2200) die Batterien und ist im Bereitschaftsmodus (Parallelbetrieb zum Netz), um das Netz zu stützen.
- Notbetrieb: Bei Stromausfall wird die Selbsttätige Schaltstelle für PV-Anlage geöffnet und die PV-Anlage damit vom Netz getrennt. Verzögert wird der PV-Koppelschütz geschlossen und die PV-Anlage an das Notnetz angeschlossen. Gleichzeitig stellt der SB2200 vom Lade- auf den Entladebetrieb der Batterien um und versorgt die Verbraucher weiterhin mit elektrischem Strom.

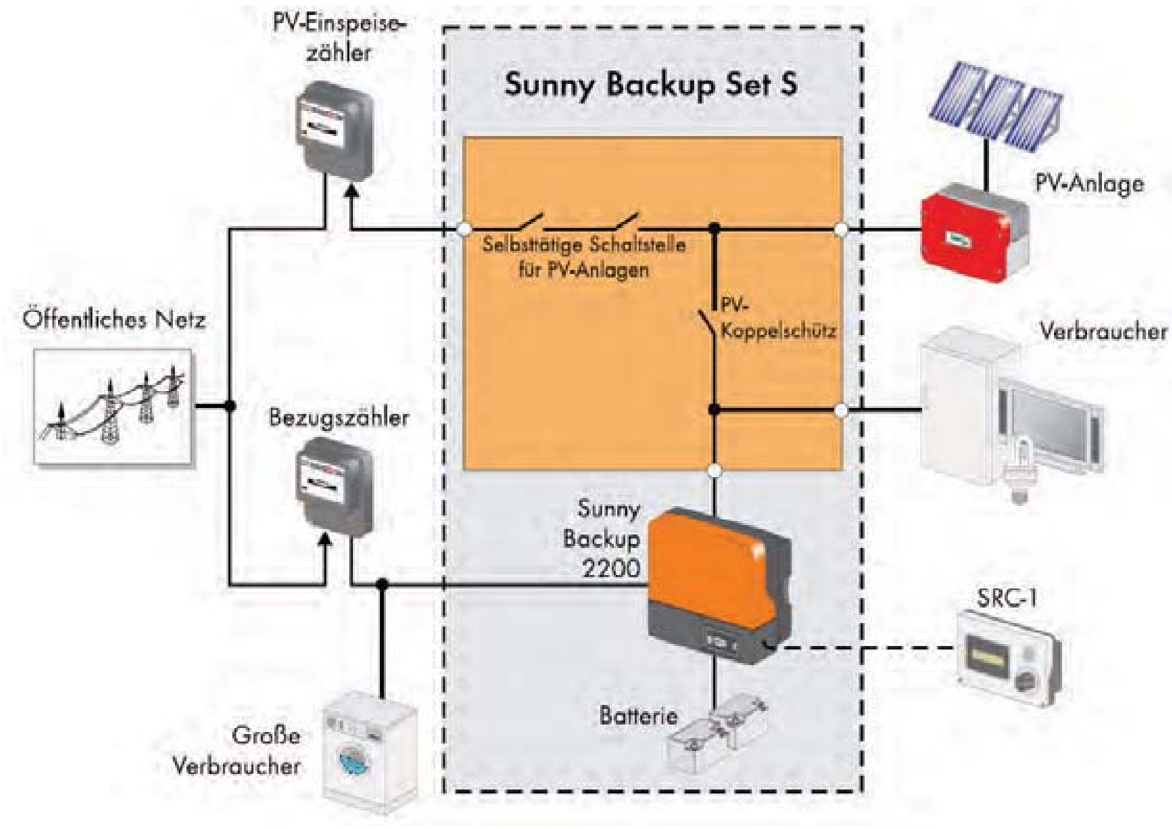

ABBILDUNG 1: PRINZIPSCHEMA DES SUNNY BACKUP SETS S[5].

Das Elektroschema mit den Messeinrichtungen für die Langzeittests ist im Jahresbericht 2009 abgebildet.

Die Beschreibung des Sunny Backup 2200 (SBU 2200) (inklusive der automatischen Switchbox, AS-Box) sowie des Sunny Boy 2500 (SB 2500) kann dem Schlussbericht entnommen werden.

Durchgeführte Arbeiten und erreichte Ergebnisse

Lang eittest

Während mehreren Monaten wird das Backupsystem im Lindhof betrieben und überwacht. Die Messwerte wurden im Minutentakt aufgezeichnet und gespeichert. Weil die Messperiode sowohl Winter- wie auch Sommermonate umfasst, lassen sich aus den Messungen Rückschlüsse auf den Ganzjahresbetrieb ziehen.

Neben den Messungen wird der zuverlässige Systembetrieb überwacht. Zu verschiedenen Zeitpunkten im Jahr und bei verschiedenen Einstrahlungen wird das System auf die Funktionalität überprüft.

Net ualit t

Über mehrere Minuten gemittelt werden zu verschiedenen Zeitpunkten die Oberschwingungen (OS) der Spannungen des Netzes gemessen. Zur Beurteilung der Sensitivität der Ergebnisse werden die Messungen jeweils mit und ohne zugeschaltetem Wechselrichter / Backupwechselrichter vorgenommen.

Mit den Netzqualitätsmessungen sollen drei Ziele verfolgt werden:

1. Die Spannungsqualität des Notnetzes soll bestimmt werden.
2. Rückwirkungen der PV-Backup-Anlage auf das öffentliche Stromnetz sollen ermittelt werden.
3. Es soll sichergestellt werden, dass ein allfälliges Fehlverhalten des Backupsystems (z. B. Einspeisung von OS) nicht auf die Netzqualität des öffentlichen Netzes zurückzuführen ist.

Die Netzqualitätsmessungen im Rahmen dieses Projekts werden nicht normenkonform (d.h. nach EN 50160 über mehrere Tage) durchgeführt und sind deshalb als Momentaufnahme zu verstehen. Sie sind nicht zur Überprüfung der Einhaltung von Grenzwerten geeignet.

essungen transienter org nge

Im Fokus dieser Messungen steht das Verhalten der Backup-Anlage zum Zeitpunkt des Netzunterbruchs sowie bei der Netzrückkehr. Gemessen werden jeweils die Momentwerte von Strom und Spannung am Verbraucher, welcher durch das Backup-System gestützt wird. Die entsprechenden Verbraucher sind nicht normiert, sondern durch die Nutzer der Backup-Anlagen vorgegeben.

Als weiterer Punkt wird das Zu- und Wegschalten von grossen Lasten am Notnetz analysiert. Strom- und Spannungsmessungen sollen zeigen, wie die Backup-Wechselrichter mit den entsprechenden Stresssituationen umgehen können.

Wirkungsgrade

Ein Ziel des Projekts ist, die Systemwirkungsgrade des Backupsystems zu ermitteln. Dazu werden – wo möglich – nicht Messungen eines kurzen Experiments herangezogen, sondern über einen längeren Zeitraum gemittelte Werte verwendet.

- Eigenverbrauch Backup echselrichter: Der Eigenverbrauch des Backupwechselrichters beträgt gemittelt über die Messperiode (ca. 6 Monate) 35.9 W. Dies entspricht einem Jahresverbrauch von 314.5 kWh resp. dem Energieertrag einer 330 Wp PV-Anlage in der Schweiz. Im Silent Mode reduziert sich der Energieverbrauch des Backupwechselrichters gemäss Datenblatt auf 4 W. Diese Energiewerte schliessen die Ladeerhaltung der Bleiakkumulatoren mit ein.
- Wirkungsgrad Net einspeisung P -Anlage: In den ausgewerteten Monaten hat der Wechselrichter SB 2500 860.5 kWh elektrische Energie ins Netz eingespeist, bei einer aus den PVModulen bezogenen Energie von 917 kWh. Dies entspricht einem Wirkungsgrad von

$$\eta_{PV} = \frac{860.5kWh}{917kWh} = 93.8\%$$

- S stem irkungsgrad Net einspeisung Backups stem: Hochgerechnet auf ein ganzes Jahr beträgt die eingespeiste Energie 2065 kWh, die von den PV-Modulen bezogene Energie 2201 kWh. Wird die vom Backupwechselrichter bezogene Bereitschaftsenergie (35.9 W während 8760 Stunden im Jahr) vom Energieertrag abgezogen, so resultiert ein Wirkungsgrad von:

$$\eta_{PV+SBU} = \frac{E_{Netzeinspeisung} - E_{VerbrauchBackup}}{E_{PV,DC}} = \frac{2065kWh - 35.9W \cdot 8760h}{2201kWh} = 79.5\%$$

  Würde der Backupwechselrichter durchschnittlich zehn Stunden pro Tag im Silent Mode betrieben, so entspräche dies einem Systemwirkungsgrad von

$$\eta_{PV+SBU,Silent\ Mode} = \frac{E_{Netzeinspeisung} - E_{VerbrauchBackup}}{E_{PV,DC}}$$
$$= \frac{2065kWh - 35.9W \cdot 5110h - 4W \cdot 3650h}{2201kWh} = 84.8\%$$

  Diese Wirkungsgrade sind stark abhängig von der Grösse der PV-Anlage. Die für dieses Backupsystem maximal zulässige PV-Anlage beträgt ca. 5 kWp (4.6 kW AC). Mit einer solchen Anlage liesse sich der Systemwirkungsgrad Netzeinspeisung Backupsystem nach obigen Annahmen auf maximal 87.7% steigern (89.9% mit Silent Mode). Wird ein Wechselrichter mit höherem Wirkungsgrad verwendet, steigt auch der Systemwirkungsgrad zusätzlich an.
- S stem irkungsgrad Backupbetrieb: Diesem Wirkungsgrad liegt die Frage zugrunde: Wie viel der Energie, welche der Backupwechselrichter zum Laden der Batterien aus dem Netz bezieht, kommt bei Netzausfall bei den Verbrauchern an? Die ermittelten Werte basieren auf mehreren Lade- und Entladezyklen, bei welchen das Backupsystem mit 0.5 bis 1 kW belastet wurde und die Batterien auf max. 50% des Ladestandes entladen wurden. Der durchschnittlich erreichte Wirkungsgrad beträgt dabei 65% - 70%.

Alle genauen Messresultate können dem Schlussbericht 2010 entnommen werden.

Fa it

Notstrom ja unterbrechungsfreie Stromversorgung nein

Alle untersuchten Systeme (bis auf den ausgewechselten ISA 3000 von Conergy) erfüllen die Erwartungen und Herstellerangaben weitgehend. Sie unterscheiden sich jedoch in einem wesentlichen Punkt von verwandten, nicht PV-assoziierten Systemen: Es sind reine Backup- oder Notstromsysteme, die keine unterbrechungsfreie Stromversorgung (USV oder englisch UPS) garantieren. Wer also Kühlschrank, Fernseher und Staubsauger auch zu Zeiten des Stromausfalls nutzen möchte, ist mit den getesteten Systemen bestens bedient. Wer hingegen seine anspruchsvollen Geräte wie den Computer vor einem Absturz sichern will, dem hilft ein Backupwechselrichter nur begrenzt[1].

Sunn Backup 2200, Backup Set S

Der "Sunny Backup 2200" von SMA erweist sich als zuverlässig und für den Alltag geeignet. Einige Punkte stechen dabei besonders positiv heraus:

- Die Umschaltvorgänge sind bei den gemessenen Szenarien sauber. Falls es zu einem Unterbuch kommt, nimmt dieser ein klares Zeitfenster ein. Vor und nach dem Unterbruch liegt eine saubere Netzspannung an.
- Es treten keine nennenswerten Netzverzerrungen auf, die Oberwellenbelastung des Notnetzes ist den Umständen entsprechend gering.
- Es treten zu keinem Zeitpunkt Spannungsüberhöhungen auf, auch nicht beim plötzlichen Lastabwurf.
- Weil der PV-Wechselrichter direkt ins Netz einspeist, ist sein Wirkungsgrad grundsätzlich unverändert.
- Das System ist modular und damit erweiterbar, der PV-Wechselrichter kann unter gewissen Bedingungen[2] durch ein beliebiges anderes Fabrikat ersetzt werden.

Als nachteilig sind hingegen folgende Punkte einzuordnen:

- Der Bereitschaftsverbrauch von 40 W (gemessen: 35.9 W) ist relativ hoch. Im Monat Dezember entspricht dies rund 35% der elektrischen Energie, welche eine 3 kWp PV-Anlage im Mittel erwirtschaftet, übers ganze Jahr gesehen sind es 10%.
- Der Backupwechselrichter ist kein USV-Gerät, er garantiert keine unterbrechungsfreie Stromversorgung. In den Messungen werden die angegebenen 50 ms Umschaltzeit in einem Fall sogar überschritten. Geschieht der Unterbruch jedoch hochohmig (z.B. aufgrund einer ausgelösten Sicherung am Hausanschluss), so wird meist ein echt unterbrechungsfreier Betrieb gemessen. Sensible Geräte wie z.B. Computer können deshalb mit dem Sunny Backup 2200 nicht zuverlässig geschützt werden.
- Die im BFE-Projekt SIMIBU[7] in Aussicht gestellten Synergien der Kombination von PVWechselrichter und Backupwechselrichter werden aufgrund der Modularität des Systems nicht wahrgenommen. Entsprechend hoch ist der Systempreis. • Bei Testläufen hat der Wechselrichter SB 2500 vermehrt Schwierigkeiten mit der Netzsynchronisation, insbesondere im Inselbetrieb. Weil der SB 2500 jedoch kein zwingender Bestandteil des Backupsystems ist und auch durch andere Geräte ersetzt werden kann, ist dieser Punkt kein Bewertungskriterium für das Backupsystem.
- Der Bereitschaftsverbrauch lässt sich zwar mit dem Silent Mode reduzieren, doch kann in diesem Fall weder die PV-Anlage Strom produzieren noch ein Netzausfall sofort abgefangen werden.

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[1] Dies geht aus den Herstellerangaben hervor.

[2] Insbesondere muss sich der Wechselrichter bei einer vorgegebenen Frequenz automatisch ausschalten.

Sunn Backup 5000, Backup Set L

Die leistungsfähigere Backup-Variante von SMA ist in Funktionalität und Eigenschaften dem kleineren System nicht unähnlich.

Vorteile:

- Leistungsfähiges, robustes und zuverlässiges Gerät
- Die mit 20 Millisekunden vom Hersteller angegebene maximale Unterbrechungszeit ist so gering, dass auch Geräte mit höheren Anforderungen an die Spannungsqualität unterbrechungsfrei arbeiten können sollten.

Nachteile:

- Mit 114 Watt (69 Watt im Silent Mode) ein grosser Stromfresser, der pro Jahr den Energieertra einer 1 kWp PV-Anlage zu Nichte macht.

PC 2200

Das Backup-System von Studer-Innotec XPC 2200 arbeitet zuverlässig und energiesparend, die Unterbrechungszeit bei Netzausfall ist jedoch nicht zu vernachlässigen. Im Folgenden werden die Vor- und Nachteile des Systems beschrieben.

Vorteile:

- Das Gerät arbeitet zuverlässig, die Spannungsqualität ist einwandfrei.
- Die Gerätegrösse ist mit 124 mm x 215 mm x 410 mm und 12.6 kg Gewicht deutlich geringer als die des vergleichbaren Geräts von SMA.
- Nach Herstellerangaben liegt der Bereitschaftsverbrauch bei nur 7 W und ist damit rund fünf Mal tiefer als der des Backupwechselrichters von SMA.

Nachteile:

- Wegen dem systembedingt nachgeschalteten Relais ist die Unterbrechungszeit an der Last deutlich grösser als die mit 20 ms veranschlagte Umschaltzeit des Backupwechselrichters. Diese Umschaltzeit ist auch bei einem hochohmigen Netzausfall (z. B. ausgelöste Sicherung) hinzunehmen

Nationale usammenarbeit

Nebst den zwei privaten Anlagebetreibern, welche ihre Anlagen freundlicherweise zu Testzwecken zur Verfügung stellten, wurde insbesondere mit dem Elektrizitätswerk der Stadt Zürich (ewz) zusammengearbeitet. Das ewz stellte die Messgeräte für die Messungen der transienten Vorgänge und wertete diese aus.

Internationale usammenarbeit

Es fand keine internationale Zusammenarbeit statt.

Be ertung 2010

Nach den Projektverzögerungen (verursacht durch den notwendigen Austausch des Backupwechselrichters ISA 3000 von Conergy) konnten im Jahr 2010 alle Fragestellungen an das Projekt bearbeitet und ausgewertet werden. Die detaillierten Ergebnisse können dem Schlussbericht 2010 entnommen werden.

Ausblick

Seit dem Projektstart im Jahr 2007 hat sich im Bereich Backupwechselrichter einiges getan. Nicht zuletzt wegen den Bemühungen Deutschlands (nach wie vor PV-Markt Nr. 1 weltweit), den Eigenverbrauch der PV-Anlagebesitzer zu fördern, hat die Kombination Photovoltaik und lokaler Speicher (bisher insbesondere Batteriespeicher) starken Aufwind erhalten. So soll z.B. aus einem Forschungsprojekt lanciert von namhaften deutschen und französischen Forschungsinstituten und Firmen[8] im Frühjahr 2011 ein neues Backup-System hervorgehen[3].

Weiterhin verfügbar sind die Produktepaletten an Backupwechselrichtern von Studer Innotec und SMA, welche die in SIMIBU gestellten Anforderungen erfüllen.

Nach Angaben von Conergy Schweiz soll auch Conergy wieder einen Wechselrichter mit Backupfunktion ins Auge gefasst haben, ein Produkt wird zurzeit jedoch nicht angeboten.

Die österreichische Firma Fronius bietet zurzeit mit der "Fronius Energiezelle" ein System an, welches in Zukunft Solarstrom in Wasserstoff zwischenspeichern können soll[9].

In diesem Projekt wurde die Praxistauglichkeit eines Backupwechselrichters eingehend geprüft, das Resultat ist positiv. Ein weiteres Folgeprojekt ist deshalb nicht vorgesehen.

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DISTRIBUTED P GENERATION

SIMULATION APPROACH TO INVESTIGATE THE IMPACT OF DISTRIBUTED POWER PRODUCTION WITH PHOTOVOLTAICS ON A POWER GRID

Annual Report 2010

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Duration of the Project (from – to)	September 2010 – December 2012
Date	3 December 2010

ABSTRACT

The project "distributed PV generation" investigates the technical impact of distributed PV power production on low- and medium voltage grids. The main questions to be answered in this task are the following:

- How much PV can be fed in the power grid at a certain point?
- What are the restrictions for feeding in PV power, and how can they be mitigated?
- How does a low- and medium voltage grid change its characteristics by feeding in PV power at certain points?

By modelling the grid with adequate algorithms for PV, these questions shall be answered, and in a second step, be adapted to the distribution grid of ewz Zürich.

Given the results of this project, a distribution system operator (DSO) should know the possibilities and limits of its grid concerning distributed feed-in of PV, and have a guideline / method where to place future investments in order to strengthen its grid for PV.

ETH Zürich offers a broad knowledge for grid simulations with direct contacts to the manufacturer of the grid simulation tool NEPLAN. With more than 20 years of international experience in PV planning and consulting, Basler & Hofmann delivers the practical experience with PV. The DSO ewz offers its power grid data and operating experience for calculations and simulations.

The power inverter design accounts greatly to the overall grid characteristics. The Austrian Institute of Technology, with its contacts to several inverter manufacturers, completes the team. Furthermore, the Austrian Institute of Technology is strongly involved in the IEA PVPS Task 14 and runs a team focused fully on smart grids. Oldenburg University completes the project team with a broad meteorological background, providing weather data and models.

Einleitung

Dieses Projekt wird im Rahmen des PV$^+$ Grid Calls des PV ERA NET mit den Projektpartnern *ust ian nstitut c n* und der *ni sit t n u* durchgeführt. Ein besonderes Gewicht hat deshalb der Wissenstransfer zwischen den beteiligten Institutionen: Dank der internationalen Kooperation wird ein Mehrwert für das Projekt angestrebt, der bei der rein nationalen Projektbearbeitung nicht erreicht werden könnte.

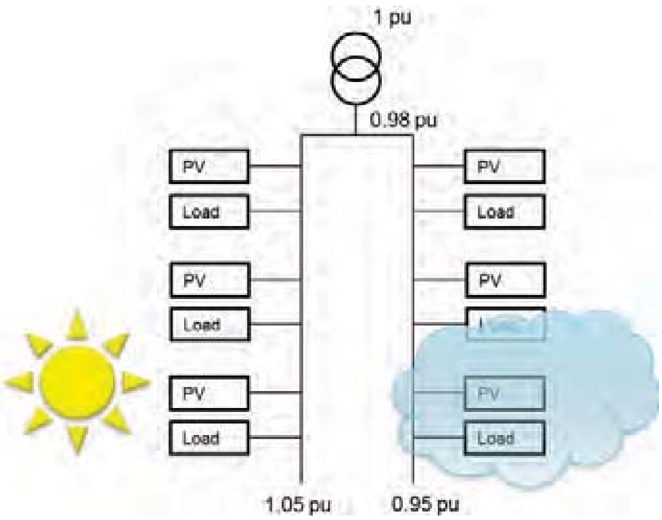
Das Projekt bildet zudem den Beginn und einen integralen Bestandteil der Dissertation des Projektleiters. Die enge Zusammenarbeit mit dem Institut für *t isc n i t a un un c s annun st c ni* der Abteilung für *n ati nst c n i un t t c ni D-* der ist somit ein weiterer Pfeiler für das Projekt.

Projekt iele

Die wesentlichen Ziele des Projekts sind die detaillierten und fundierten Antworten auf folgende Fragen:

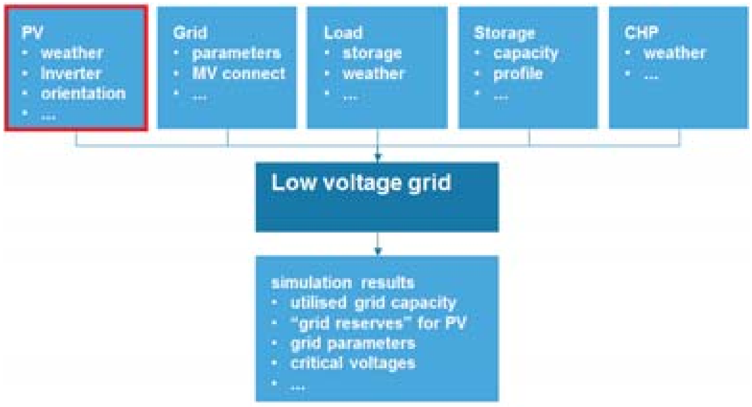
- Wie gross ist die PV-Leistung, die in ein bestimmtes Verteilnetz eingespeist werden kann?
- Welches sind die Limitierungen für die Einspeisung von PV in ein Verteilnetz, und wie können diese beeinflusst werden?

Zentral ist dabei die Untersuchung des Niederspannungsnetzes. Mit einem Simulationsmodell, welches räumlich wie zeitlich eine hohe Auflösung zulässt, sollen Spannungs- und Lastflusssimulationen gemacht werden. Innerhalb eines Niederspannungsnetzes soll damit der Einfluss von Wolkenzug und weiteren Wetterphänomenen auf das Netz nachvollzogen und beschrieben werden (vgl. Abbildung 1).



bbildung : Hypothetische Teilbeschattung eines Verteilnet es it Hilfe dieses Proje ts sollen die daraus resultierenden Effe te quantisiert erden nnen

Die Roadmap beschreibt das geplante weitere Vorgehen im Projekt.

Termin	Arbeitsschritt	erant- ortlich	Dokumen- tation
Dezember 2010	Kick-Off Meeting des Projekts	Basler & Hofmann	Protokoll
Dezember 2010	Literaturrecherche: Wichtige Literatur, welche an die Themen des Projekts anlehnt, wird studiert und zusammengefasst.	Basler & Hofmann	Kurzbericht
März 2011	Identifizieren und Bewerten relevanter Parameter für die Simulation	Basler & Hofmann	Kurzbericht
Mai 2011	Vorstellen eines Modells zur Berechnung / Simulation eines Verteilnetzes, welches obigen Anforderungen gerecht wird. Folgende Grafik zeigt eine mögliche Struktur des Modells auf:  Wobei der Fokus des Projekts auf dem Teil "PV" liegt.		
Oktober 2011	Vorstellen eines Wettermodells als Input für das Netzsimulationsmodell. Dieser Punkt ist stark mit dem Netzsimulationsmodell verknüpft und fällt möglicherweise mit diesem zusammen.	Universität Oldenburg	Kurzbericht
Oktober 2011	In einem Bericht werden die Forschungsaktivitäten des AIT im Bereich „intelligente Netze“ mit diesem PV ERA NET-Projekt verknüpft. Schwerpunkt soll „Smart Metering“ im Verteilnetz sein	AIT	Kurzbericht
November 2011	Zweite Plenumssitzung mit allen Projektbeteiligten	Basler & Hofmann	Protokoll
Dezember 2011	Vorstellen des Simulationsmodells inklusive Wettermodell. Erste Erkenntnisse aus Beispielsimulationen werden interpretiert und erläutert	Basler & Hofmann	Bericht
März 2012	Ein Index soll gefunden und definiert werden, der das Fassungsvermögen eines Verteilnetzes für PV beschreibt.	Basler & Hofmann	Kurzbericht
Mai 2010	Simulationsresultate eines existierenden Verteilnetzes (NS-Netz im Netzgebiet des ewz) werden vorgestellt und interpretiert	Basler & Hofmann	Kurzbericht
Herbst / Winter 2010	Schlussbericht	Basler & Hofmann	Bericht

Durchgeführte Arbeiten und erreichte Ergebnisse

Die bisher durchgeführten Arbeiten konzentrieren sich auf die Projektvorbereitungen. Die folgende Liste stellt die Meilensteine der durchgeführten Arbeiten vor:

- Herbst / Winter 2009: Bilden des Projektteams mit der ETH Zürich, dem ewz, der Universität Oldenburg und dem AIT.
- Dezember 2009 / März 2010: Einreichen von Preproposal und Proposal für den PV ERA NET PV+ Grid-Call.
- Frühjahr 2010: Schriftliche Vereinbarung mit der ETH Zürich über die Projektzusammenarbeit / das Doktorat, Erstellen des Forschungsplans in Anlehnung an das PV ERA NET Projekt.
- Sommer / Herbst 2010: Literaturstudium und Überarbeitung des Forschungsplans. Das Resultat ist im Kapitel „Projektziele" zusammengefasst.
- 2. Dezember 2010: Startsitzung mit allen Projektbeteiligten. In der dreistündigen Sitzung hat man sich auf das im Kapitel „Projektziele" beschriebene Vorgehen geeinigt.

Nationale usammenarbeit

Verschiedene Institutionen konnten für das Projekt gewonnen werden:

- ETH Zürich: Die ETH begleitet das Projekt im Rahmen der Doktoratsbetreuung von Ch. Bucher durch Prof. Dr. G. Andersson. Es findet zudem ein reger Austausch mit weiteren Doktoranden der ETH statt, welche in projektverwandten Themen tätig sind. Insbesondere fliessen so die Forschungsergebnisse der Arbeiten rund um Elektromobilität und dezentrale Speicher ins Projekt ein.
- ewz: Als weiterer Projektträger neben dem BFE konnte das Elektrizitätswerk der Stadt Zürich gewonnen werden. Das ewz ist bereits in verschiedenen Projekten rund um das Thema „intelligente Netze" tätig, so z.B. am Projekt „verteilte Einspeisung ins Niederspannungsnetz" (VEiN), in welchem die Thematik der verteilten Einspeisung von Solarstrom, Blockheizkraftwerken und Windenergie untersucht wird.

Internationale usammenarbeit

Das vorliegende Projekt wird gemeinsam mit zwei ausländischen Partnern abgewickelt:

- Die Universität Oldenburg untersucht meteorologische Modelle und Daten als Inputgrössen für das in diesem Projekt zu entwickelnde Netzsimulationsmodell.
- Das Austrian Institute of Technology (AIT) trägt mit seinen Erfahrungen im Bereich Smart Metering, Lastmanagement und aktive Regelung von Verteilnetzen wesentlich dazu bei, dass das Projekt auf dem neusten Stand der Forschung abgewickelt werden kann.

Be ertung 2010 und Ausblick 2011

Die Aufgleisung des Projekts im Jahr 2010 kann insgesamt als ein Erfolg gewertet werden. Die wesentlichen Ziele wie die Bildung des Projektteams und die Erstellung eines Forschungsplans, welchem alle Parteien zustimmen können, sind erreicht worden.

Für das Jahr 2011 ist nebst der Projektarbeit gemäss Kapitel „Projektziele" Folgendes zu erreichen:

- Definitive Bewilligung der Forschungsgelder für das AIT und die Universität Oldenburg
- Verpflichten eines Deutschen oder österreichischen Verteilnetzbetreibers zur Mitarbeit im Projekt. Diese Mitarbeit muss nicht aktiv sein, jedoch sollen die Erfahrungen und Fragestellungen eines weiteren Verteilnetzbetreibers neben dem ewz in das Projekt fliessen.

Die wichtigsten Arbeiten im Jahr 2011 sind gemäss Kapitel „Projektziele" das Entwickeln eines Simulationstools / einer Simulationsroutine, mit welcher stark lokale Effekte der verteilten Einspeisung von Solarstrom untersucht werden können.

Referen en

Die in diesem Kapitel aufgeführten Referenzen verweisen auf ausgewählte Publikationen, auf welchen das Projekt aufbauen wird.

[1] DG DE O NET : Technische und konomische Be ertung des Einsat es von innovativen Spannungsregelungs-kon epten in erteilnet en mit hoher Dichte an de entralen Stromer eugern, Austrian Institute of Technology, Technische Universität Wien, Helfried Brunner, Benoit Bletterie, Wolfgang Prüggler, Wien 2008.

[2] DG DE O NET : Strategien für die Spannungsregelung in erteilnet en mit einem hohen Anteil an de entralen Stromeinspeisern, Austrian Institute of Technology, University of Ljubljana, Helfried Brunner, Benoit Bletterie, Andreas Lugmaier, Tomaz Pfajfar, Wien.

[3] Erh hung der Aufnahmef higkeit von erteilnet en, Fraunhofer Institut, Degner, Strauss 2010

[4] oltage Limitation b Autonomous Reactive Po er Control of Grid Connected Photovoltaic Inverters, Technische Universität München, Georg Kerber, Rolf Witzmann, Hannes Sappl, München

SOLAR WINGS: MONITORING ZWEIACHSIGE NACHFÜHRUNG – FLUMROC

Annual Report 2010

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Project- / Contract Number	TPNr. 8100 -146-02; Proj. No. SI/500466 / SI/500466-01
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Date	30.11.2010

ABSTRACT

The two axis PV Solar Wings tracking system was measured to evaluate the energy yield of the first two axis prototype installation at the Flumroc AG in Flums, Switzerland. The DC power of a PV string, tracked by the Solar Wings system, was compared to the DC output of a fixed flat-roof mounted PV string consists of the same PV mono-crystalline silicon standard modules and the same 10kW inverter.

During the first period, March till Oct 2010, a specific AC yield of the whole system of 1047 Wh/Wp was measured (78.96 kWp nominal power including the 3.76 kWp of the fixed reference system). Thus an AC yield of about 1200 Wh/Wp for the full first year of operation is expected. This represents about 20% higher yield relative to the longtime average PV yield of new large scale installation in Switzerland.

On a clear sky day in June 2010 a detailed performance analysis shows 26% higher measured DC performance of the traced modules. Due to higher wiring losses and elevated temperatures in the DC cables of the tracked system in average 33V lower string voltage was measured in the traced system. Assuming the same amount of DC losses in both systems, tracked versus fixed installed, the increase in energy yield is about 34% for the tracking system for that particular day. The about 4°C lower measured average module temperature increase the PV power by about 2% for that sunny day.

A detailed analysis of the shading effect of the nearby pylon in September shows additional losses of the tracked system of 4% of the daily DC production on a clear sky day in August.

During the analyzed period, May to Sept 2010 an increase of about 18% of the DC yield of the tracked system was found relative to the fix mounted modules.

Einleitung / Projektziele

Dieses Projekt hat die Performanceanalyse des zweiachsig, seilbasierten Solarnachführsystem Solar Wings zu Ziel, welches bei der Flumroc AG, Flums von der Firma Bartholet AG, Flums installiert wurde. Dieser Bericht ist ein Zwischenbericht für die ersten Monate seit Inbetriebnahme im Jahr 2010 und soll erweitert werden, um ein vollständiges Erfassungsjahr dokumentieren zu können.

Anlagenkonzept

Der Auftraggeber, Flumroc AG hat die Realisierung des ersten Prototypen einer zweiachsigen Solar Wings Nachführung auf dem Aussenlagergelände der Flumroc am Standort Flums in Auftrag gegeben. Sie wurde Anfang 2010 gebaut und die Netzeinspeisung erfolgt seit März 2010.[1] Es bestand der Wunsch des Auftragsgebers mit dem Bau der Anlage auch den Doppelnutzen, der Solarstromerzeugung und des ungestörten Betriebs des Warenverkehrs mit LKW unterhalb der Solaranlage, ansprechend zu demonstrieren. Daher wurde die Platzierung der Anlage an den südseitigen Rand des Freilagers und aus ästhetischen Gründen, parallel zur Anfahrtstrasse, die eine Azimuth-Abweichung von 45° aus der Südrichtung aufweist, in Auftrag gegeben.

Das PV Systemdesign ist auf 7 dreiphasige Wechselrichter mit einer Nennleistung von je 10kW (Sunways NT 10000) aufgeteilt. Die verteilten Wechselrichter wurden anstatt eines Zentralwechselrichters ausgewählt, um die Abschattungseffekte des angrenzenden Hochspannungsmasten, möglichst auf den betroffen Modulträger/String zu lokalisieren. Zwei Modulträger mit je 8 Stk. monokristalliner Solarmodule mit einer Modulnennleistung von 235W (Sharp NU-E235, Vmp=30V STC, Aussenmasse 1.65m x 0.99m) bilden in Serie einen der drei unabhängigen Stringeingänge. (DC Eingangsnennleistung 3x2x8x235Wp=11280Wp) Es werden 40 Modulträger also gesamthaft 75.2 kW Nennleistung zweiachsig nachgeführt.

Die Modulausrichtung erfolgt im zehnminütigen Intervall als Funktion der Tages/ Jahreszeit.

Abbildung 1 Blick auf die zweiachsige Solar Wings Nachführung der Flumroc AG, die über dem Aussenlager der Flumroc in Flums Anfang 2010 realisiert wurde. Die Zwischenstützen haben einen Abstand von 35m und je 10 Modulträger sind im Abstand von 3.2m auf den Tragseilen zwischen zwei solcher Zwischenstützen montiert.

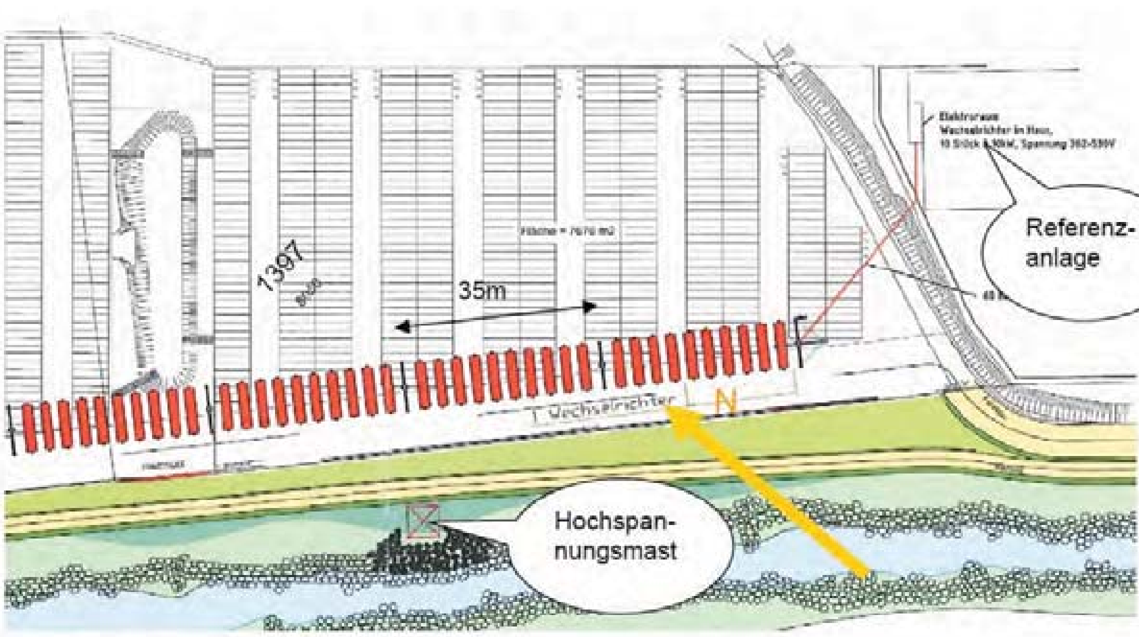

Abbildung 2 Konzept der beiden PV Systeme, Messobjekt: zweiachsige Solar Wings Nachführung und das Referenzsystem: baugleiche Module mit 30° Neigung exakt nach Süd orientiert auf dem Betriebsgebäudes im oberen rechten Bildbereich.(Zeichnung, Pamag Engineering, Flums, Nr. 091240) Sechs Modulträger werden mit einem 10kW Wechselrichter zusammengefasst. Der Nordpfeil zeigt die Abweichung mit 45° aus der Südrichtung der Tragseile.

Das Messsystem

Die DC Grössen Strom und Spannung werden an einem Strang der Sonne nachgeführten Module gemessen und verglichen mit den DC Messgrössen des nicht nachgeführten Referenzstrangs, welcher fix auf dem Dach installiert, 30° geneigten nach Süd orientiert ist. Die Messung des Gleichstroms von 7A erfolgt mit dem eingesetzten Hallstromwandler (LEM CT-10) mit einer GUM Unsicherheit von 0.08% (k=1) inklusive der Weiterverarbeitung der Ausgangsspannung des Stromsensors über den analogen DC Spannungsmess-Einschub AI110 (16bit Auflösung) des DAQ Systems CFP 2200 von National Instruments. Die Spannungsmessung UDC, erfolgt mit dem Messwandler Sineax 829 (0.1% Garantie Unsicherheit) von GMC mit einer resultierenden GUM Unsicherheit von 0.1% (k=1). Somit kann für die Messung der DC Leistung aus dem Produkt der obigen Messgrössen Strom und Spannung über die eingesetzten Messwandler eine resultierende Unsicherheit von 0.13% erzielt werden, ohne den Einflüssen der GUM Typ A Unsicherheitsbeiträge (individuelle Schwankung der Messwerte). Die Temperaturmessung erfolgt mittels PT1000 (Klasse B) und dem Messwandler RTD122 des DAQ Systems CFP 2200 mit einer Unsicherheit von 0.5°C auf der Rückseite der Module.

Durch unvorhergesehene Lieferschwierigkeiten der ausgewählten ISE Einstrahlungssensoren, durch das Fraunhofer Institut für Solare Energiesysteme ISE in Freiburg, war es nötig als Alternative die Einstrahlungswandler Spektron 310 mit 20mA Stromausgang einzusetzen. Am 9. Aug 2010 wurde zum Sonnenhöchststand ab 13 Uhr eine Referenzmessung innerhalb von 15 Minuten, zum Sonnenhöchststand mit 60 Teilmessungen ausgeführt. Der Mittelwert des ISE Präzisionssensors (Bezeichnung HOQ 009-2010, einkristalline Zellen; 2% Unsicherheit bei k=2 bzw. 95% Vertrauensbereich) betrug 1026 W/m2 an diesem klaren Sonnentag. Die Sonnenhöhe betrug dabei 59° und die Ausrichtung war Süd, wodurch für diesen Zeitabschnitt, die Sonne senkrecht auch auf die fest aufgeständerten Solarmodule eingestrahlt hat in der auch der Referenzsensor positioniert war. Die Solarmodule waren zu diesem Zeitpunkt ebenfalls in gleicher Position (Abweichung kleiner 2°) zur Sonnen positioniert. Die Standardabweichung aller in diesem Zeitraum mit einem Abtastintervall von 15 Sekunden aufgezeichneten Werte betrug 0.2%, was für einen wolkenlosen Himmel spricht. Die resultierende Unsicherheit für die Kalibrierung dieser Spektron 310 Sensoren war damit deutlich kleiner als 2.1% (k=2) dominiert durch den ISE Referenzsensor. Nach der durchgeführten Kalibrierung über die Addition der Offsetkorrektion von 2.69% zum ursprünglichen Sensorsignal lag auch der Mitternachtswert des Einstrahlungssensors um 0.2% um den Nullwert. Die Tagessumme dieses klaren Sonnentages lag bei 8.96 kWh/m2 für den fix 30° geneigten nach Süd montieren Referenzsensor. Die Kalibrierung konnte mit einer resultierenden Unsicherheit von 1.1% (k=1) ausgeführt. Auf Basis dieser Kalibrierung wird die resultierende Messunsicherheit der Einstrahlungsmessung mit dem Spektron 310 Sensor konservativ mit 2% bei (k=1) für das nächste Halbjahr angegeben und damit neben dem Drift auch mögliche spektrale Mismatchfaktoren einbezogen.

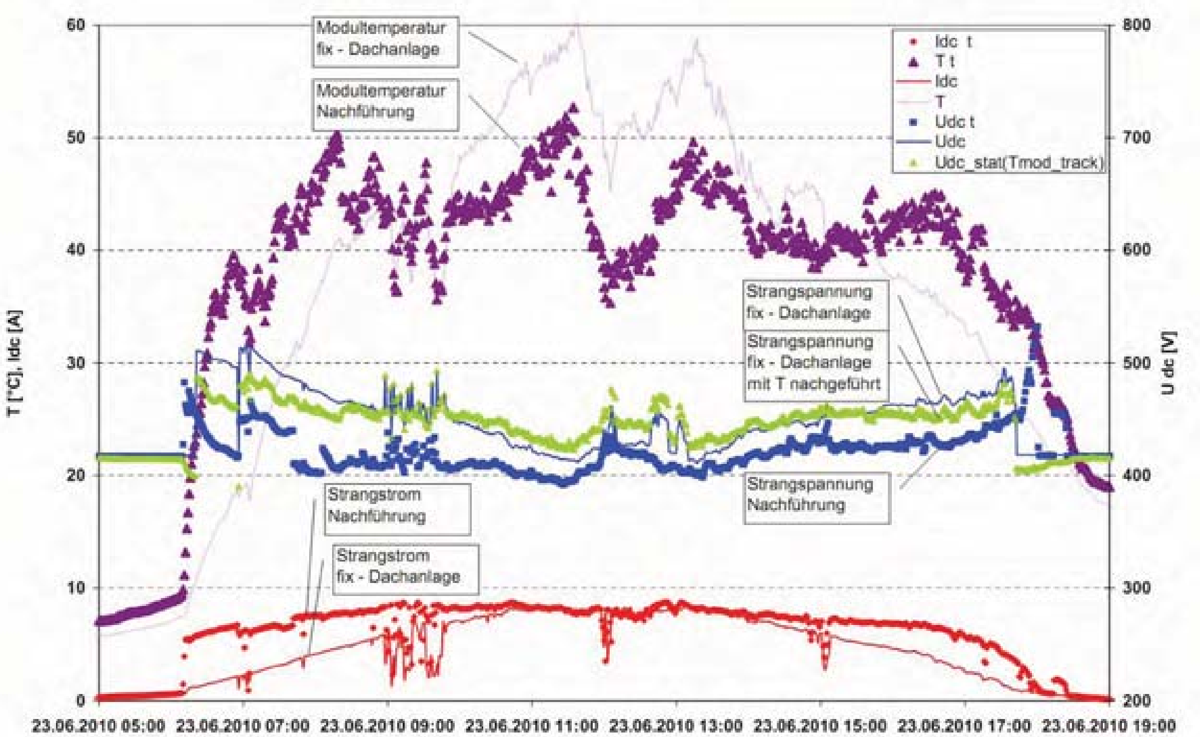

Abbildung 3 Tagesverlauf der DC Leistung der nachgeführten Modulen (Index Idc t Gleichstrom, T t Modultemperatur in °C, Udc t Stringgleichspannung), sowie der baugleichen Referenzmodule die fix auf dem benachbarten Industriedach, unter dem Winkel von 30° geneigt und exakt nach Süd orientiert sind Module (Index Idc Strangsstrom, Udc Strangspannung, T Modultemperatur). Mehrertrag an diesem Sonnentag durch Tracking 26% relativ zu fest aufgeständert.

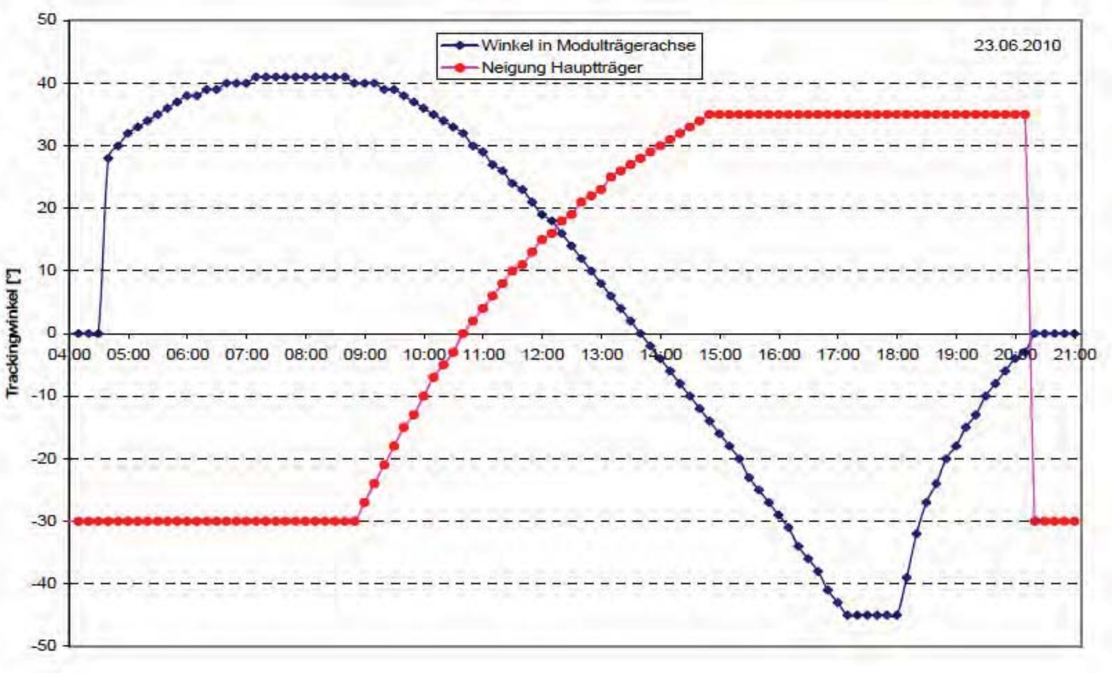

Abbildung 4 Verlauf der Winkelvorgaben für den Tracker auf der Basis der Ortszeit (MEZ keine Sommerzeit) am 23. Juni 2010. (Winkelbereiche -42° bis 45° und -30° bis 35°) Ertrag siehe Abb. 3.

Messergebnisse

Aus den mit dem Standardstromzähler des EW ermittelten eingespeisten Wechselstromerträgen von 1047 Wh/Wp in den Monaten März bis Oktober 2010 wird auf einen AC-Ertrag der Nachführanlage von über 1200 Nennbetriebsstunden im ersten vollständigen Betriebsjahr geschlossen. Damit liegt dieser Wert um ca. 20% über dem spezifischen Schweizer Durchschnittsertrag für grössere neue PV Anlagen in der Schweiz und ca. 40% über dem langjährigen landesweiten Durchschnittertrag von 820 Wh/Wp für fast ausschliesslich nicht nachgeführte PV-Anlagen.[3] Der erste 650kW Solar Wings Prototypen, der an der Nordgrenze der Schweiz, in Waldshut als einachsiges seilbasiertes Nachführssystem installiert ist, erreichte in den ersten beiden Betriebsjahren spezifische Jahreserträge von ca. 1300 Wh/Wp an einer ideal nach Süden orientierten 22° geneigten, völlig unbeschatteten Betriebsstandort. [1, 2].

Die Ursachen für den in der Messperiode ermittelten niedrigeren Ertrag, verglichen mit dem Erwartungswert, wird nachfolgend diskutiert.

TABELLE 1 Ertragswerte des zweiachsigen Solarnachführsystems der Flumroc AG bezogen auf die gesamte PV Nennleistung von 78.96kW wovon 3.76kW als Referenzsystem fix auf dem Dach des benachbarten Betriebsgebäudes installiert sind. Die AC Erträge wurden als Messwerte der Standardstromzählers aus der Stromabrechung des EW übernommen (Landis &Gyr 1%, Industriezähler). In der rechten Spalte ist der Mehrertrag ohne die zusätzlichen Leitungsverluste von 8% angegeben. Zusätzlich ist noch die Ertragsminderung durch Abschattung zu berücksichtigen.

	AC Ertrag	spezifischer AC Ertrag	Tages Einstrahlung	Tracking Mehrertrag	Performance zu Pin fix	Tracking Mehrertrag gleiche Leitungsverl.
2010	kWh_AC	Wh_AC/ Wp	kWh/m2/d	Pdc track/fix	PR_t_to_fix	Pdc track/fix
März	9355	118				
April	12219	155				
Mai	9250	117	4.769	3.3%	0.836	11.3%
Juni	11647	148	5.308	13.4%	0.986	21.4%
Juli	13767	174	7.233	15.0%	0.826	23.0%
August	9435	119	4.139	7.7%	0.969	15.7%
September	9494	120	4.819	13.3%	0.853	21.3%
Oktober	7481	95				
Zwischensumme	82648	1047				18.6%

- Der Grund für die niedrigen Erträge im Mai 2010 lagen in den fallweise aufgetretenen Empfangsfehlern des DCF 77 Funksignale im Schatten der nahen Berge. Durch die resultierenden Synchronisationsfehler wurde der SPS Steuerrechner ein falsches Datums- und Zeitsignal übermittelt, was unmittelbar zu einer nicht optimalen Modulausrichtung führte, da sie Zeit gesteuert erfolgt. Gleich nach erkennen des Fehlfunktion wurde Mitte Mai dieser Fehler durch eine zusätzliche SPS Software Kontrollroutine vollständig behoben.
- In Abbildung 3 sind für einen klaren Sonnentag, 23. Juni 10 die Mehrerträge durch die zweiachsige Nachführung am frühen Vormittag und am späten Nachmittag sehr gut ersichtlich, durch die Analyse der Strangsströme im unteren Bildbereich. Der gemessene Gleichspannungstagesertrag des nachgeführten Stranges war an diesem Tag um **26%** höher als der fix auf dem Dach installierten (34.9kWh zu 27.8kWh)
- Weiters ist aus dem Verlauf der Temperatur zur Mittagszeit in Abb. 3 (oberer Bildbereich) eine um ca. 10 Grad geringer Temperatur der auf den Tragseilen nachgeführten Solarmodule verglichen mit den Modultemperaturen auf dem Flachdach ersichtlich. Wird die Temperaturdifferenz mit der produzierten DC Leistung gewichtet und so die mittlere energierelevante Modultemperatur bestimmt, so ergibt sich an diesem Tag eine um 4°C geringere Modultemperatur. Bezogen auf den Unterschied von Einstrahlungsmessungen fix bzw. nachgeführt ist als die Solar Wings Nachführung mit der optimalen Hinterlüftung der Module, mit einer DC Leistungssteigerung von **ca. 2%** verbunden verglichen mit einer Dachanlage.

- Die Strangspannung der nachgeführten Module ist im Mittel um 28V kleiner als jene des fix auf dem Dach montierten Referenzstranges im Zeitraum 6:00 bis 19:00 (16V zwischen 13:00 bis 14:00 und 63V zwischen 8:00 und 9:00). Um 14 Uhr, wenn die Ströme im nachgeführten und im Referenzstrang etwa gleich gross sind beträgt die Spannungsreduktion im nachgeführten Strang 21V oder 5% der Strangspannung. Um die Spannungsabweichung durch unterschiedliche Temperaturen der beiden zu vergleichenden Stränge auszuschliessen, wurde die Spannung des Referenzstrings auf das Temperaturniveau der nachgeführten Module zurückgerechnet und dieser Verlauf in Abb. 3 eingetragen (TC der Modulspannung nach Datenblatt -0.35%/°C). Im Tagesmittel verbleibt eine Spannungsdifferenz nach der Temperaturkorrektion von 33V (oder 8% bezogen auf die Strangspannung). Dies wird zurückgeführt, auf deutlich höhere Kabellängen der nachgeführten Anlage, die Referenzanlage ist direkt bei den Wechselrichtern installiert, wo die Spannungsmessung erfolgt. Zusätzlich sind die 4mm2 DC Leitungen ausgesprochen eng in einem Kabelkanal geführt, was zu hohen Leitertemperaturen und damit erhöhtem Leitungswiderstand führt, da alle Wechselrichter im benachbarten Betriebsgebäude installiert sind (siehe Abb1). Ein zielführender Vergleich der Leistungsgewinn der Nachführung muss also auf der Basis von gleichen Spannungsabfällen, sprich gleichen Leitungslängen und Kühlungsbedingungen der Kabelführung erfolgen. Dazu müssen also die im Messaufbau ermittelten Leistungsgewinn um 8% zugunsten der Nachführung aufgewertet werden, was in der Tabelle 1 in der äussert rechten Spalte erfolgt ist.
- Weitere eher geringfügige Ertragseinbussen erfolgen, wenn die Anlage zu Demonstrationszwecke bei Werksführungen für die Besucher bewusst aus der optimalen Orientierung gefahren wurde.
- Ein gleichwertiger Vergleich von nachgeführtem und fix installierter Dachanlage muss auch die Abschattungsverluste der auf eine Flachdach installierten hintereinander liegenden Modulreihen zu Sonnenaufgang und Sonnenuntergang, der ca. 3% beträgt (für einen typischen Reihenabstand bzw. Abschattungswinkel von 20%.

Ertragsminderung durch Abschattung

Nachfolgend wird der Sachverhalt und die ermittelten Messergebnisse für die Ermittlung der Abschattungsverluste durch den südseitigen Hochspannungsmasten, wie in Abb. 6 gezeigt, exemplarisch für den 9. August beschrieben. Aus Tabelle 2 ist für diesen klaren Sonnentag aufgrund der einsetzenden Abschattung ab ca. 13 Uhr ersichtlich, dass eine Leistungsminderung von ca. 8% für den Nachmittag, verglichen mit der Situation ohne Hochspannungsmasten, zu verzeichnen ist. Bei sinkender Sonnenhöhe im Rest des Jahrs sind besonders die Wechselrichter 5 bis 7 betroffen.


Abbildung 5
Rechts Abschattungssituation am 4. April 2010 um 17:03 durch den südostseitigen Hochspannungsmasten (Im Hintergrund ist der Südwesthang der Kurfirsten zu sehen.)

TABELLE 2 Leistungsminderung pro individuellem DC Strang am Nachmittag des 9. Aug 2010 durch die Schattenwirkung des zwanzig Meter entfernten Hochspannungsmasten. Zur Veranschaulichung der Abschattungsverluste wurde die Farbe grün für Leistungen grösser 2kW, orange für den Leistungsbereich 1 bis 2kW (Teilabschattung) und orange für unter 1kW (Abschattung gewählt). Die rechte Spalte zeigt die Verluste. Ein Strang umfasst zwei nachgeführte Modulträger mit in Summe 2 x 8 Module je 230Wp, Nummer der Wings in Zeile 2 mit 1 beginnend von Süd bis 41; reale Abschattungssituation Abb. 5. (Leistungen wurden dem Wechselrichtermonitoring entnommen)

09-08-10	WR1	WR1	WR1	WR2	WR2	WR2	WR3	WR3	WR3	WR4	WR4	WR4	WR5	WR5	WR5	WR6	WR6	WR6	WR7	WR7	WR7	
P_AC [kW]	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	Verlust
17:30	2.7	2.6	2.7	2.5	2.7	1.4	0.8	0.5	2.1	2.7	2.6	2.6	2.7	2.6	2.5	2.6	2.7	2.6	2.6	2.6	1.9	-12.2%
17:10	2.5	2.5	2.4	2.3	2.5	2.4	0.9	0.5	0.7	2.6	2.6	2.6	2.6	2.6	2.6	2.7	2.7	2.7	2.7	2.7	2.1	-12.7%
16:50	2.7	2.7	2.7	2.7	2.8	2.7	2.6	0.5	0.5	2.3	2.7	2.7	2.7	2.7	2.6	2.7	2.7	2.7	2.7	2.7	2.4	-10.0%
16:30	2.7	2.8	2.8	2.8	2.8	2.8	2.7	2.1	0.4	2.1	2.8	2.7	2.8	2.8	2.6	2.8	2.7	2.8	2.8	2.7	2.5	-7.1%
16:10	2.8	2.8	2.9	2.9	2.9	2.9	2.9	2.8	0.5	0.5	2.8	2.7	2.8	2.9	2.7	2.9	2.9	2.8	2.9	2.8	2.7	-9.0%
15:50	2.9	2.9	2.9	3	2.9	2.9	2.9	2.9	2.3	0.3	2.7	2.8	2.9	2.9	2.8	2.9	2.8	2.8	2.9	2.9	2.8	-5.8%
15:15	2.9	2.9	2.9	3	2.9	2.9	2.9	2.9	2.9	0.9	2.3	2.9	2.8	2.9	2.8	3.0	2.9	2.9	2.9	2.9	3.0	-3.6%
14:45	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9	2.5	0.4	2.5	2.9	3.0	2.9	3.0	3.0	2.9	2.9	2.9	3.0	-6%
14:15	3.1	3.1	3.1	3.1	3.0	3.0	3.0	3.0	3.0	3.0	0.7	0.5	2.9	3.0	2.9	3.0	3.0	3.0	2.9	2.9	3.1	-8.7%
13:45	3.1	3.1	3.2	3.2	3.2	3.1	3.1	3.0	3.0	3.0	2.5	0.9	0.8	3.0	2.9	3.0	3.0	3.0	3.0	3.0	3.1	-8.8%
13:15	3.0	3.1	3.1	3.2	3.2	3.2	3.2	3.1	3.	.1	3.0	2.5	3	2.6	2.9	3.1	3.1	3.1	3.1	3.1	3.1	-3.2%

Abschattung

Idc = 2.56A
Udc = 413V
Pac= 952W

Keine Abschattung
Idc = 7.2A
Udc = 430V
Pac= 2924 W

mittlere Abschattungsverluste Nachmittag	-8.2%


Abbildung 6 Schattenwurf des Hochspannungsmasten am 9. Aug 2010. Im linken Teilbild ist die Beschattung um 15:20 zu sehen, die links vom Zwischenträger den Modulträger Nr. 20 der Länge nach beschattet (Modulträger 20 und 19 bilden den Strang 1 des Wechselrichter 4, siehe Eintrag der geminderten Leistung von 0.9kW in Tabelle 2 zum Zeitpunkt 15:15). Im rechten Teilbild ist der Schatten um 17:30 ersichtlich, den ein Strassenbeleuchtungsmast auf Modulträger Nummer 8 im Vordergrund wirft, wodurch dessen erstes Modul an der rechten unteren Ecke im Umfang von ca. zwei Solarzellen beschattet wird. Die Leistung sinkt durch die Wirkung der Bypassdioden in diesem Modul nur minimal auf 2.5kW ab (siehe Tabelle 2 in der ersten Zeile beim Eintrag Modulträger 7 bis 8)

Zusammenfassung - erster Zwischenbericht

Das zweiachsige Solar Wings Nachführsystem erzielt am Standort Flums einen jährlichen spezifischen EW-Stromzählerertrag von 1047 kWh/kWp in den Monaten März bis Oktober 2010, was einen Jahresertrag im ersten vollständigen Betriebsjahr von über 1200 kWh/kWp erwarten lässt. Dies ist um 20% höher als der in der Schweiz mit Photovoltaikanlagen im Durchschnitt mit fest installierten neuen Grossanlagen im Langjahresmittel erzielt wird.

An einem Sonnentag im Juni konnten 26% Mehrertrag durch die nachgeführten Module gemessen werden, verglichen mit der fix auf dem Flachdach des benachbarten Betriebgebäudes installierten 30° Grad geneigt, exakt nach Süd orientiert, Referenzanlage. Würden beide PV Systeme mit exakt den gleichen Zuleitungen ausgestattet sein, so wäre beim nachgeführten System nicht im Mittel eine um 33V geringern Strangspannung (ca. 8%) zu verzeichnen. Dann wäre der ermittelte Mehrertrag an diesem Sonnentag mit ca. 34% zu ermitteln. Im Mittel würde diese Anrechung der gleichen Leitungsverluste den in den Monaten Mai bis Sept. gemessenen Mehrertrag durch Tracking auf ca. 18% erhöhen.

Aufgrund der exzellenten Hinterlüftung der Solarmodule die in eine Höhe von 8 Metern über Boden montiert sind, wurden an Sommertagen um ca. 10° Grad geringere Temperaturen um die Mittagszeit gemessen und im Mittel auf die Stromproduktion gewichtet 4°C, was einen Leistungsgewinn von ca. 2% bezogen auf aufgeständerte Nennleistung der Dachanlagen bedeutet.

Das zweiachsige Solar Wings Nachführsystem könnte allerdings noch deutlich mehr erwirtschaften wäre es nicht durch äussere Einflüsse, der Einbettung in die bestehende Bausituation bzw. Bergschatten begrenzt. Diese Verluste sind im Einzelnen:

- Die Abschattung durch den Hochspannungsmasten führt, jeweils am Nachmittag zu Verlusten, dann wenn die Nachführung an klaren Sonnentagen den Mehrertrag gegenüber fix montierten Solarsystemen erzielt. Beispielsweise wurde im August an klaren Sonnentagen eine Minderung des Mehrertrags von ca. 8% am Nachmittag gemessen (siehe Tabelle 2). Daraus wird eine Minderung des zusätzlichen Trackergewinnes von täglich 4% abgeschätzt. Ohne Abschattung durch den Hochspannungsmaster wäre ein Tracking-Mehrertrag von ca. 22% möglich.
- Würden die Tragseile nicht wegen der Zufahrtstrasse nach Süd-Ost orientiert sein, könnte ebenfalls ein höherer Mehrertrag erzielt werden, da dann der Back-Tracking Modus reduziert werden könnte, was zu Mehrerträgen von bis zu ca. 3% führen könnte
- Abschattung durch die nahe Bergkette im Nordosten und im Südwesten ca. 6%
- Unsicherheit der Einstrahlungsmessung 3%, Unsicherheit der Nennleistung +/-3%
- All die hier ermittelten Messwerte basieren auf einem unbeschatteten fix installierten Referenzsystems auf dem Industrieflachdach. Für einen gleichwertigen Vergleich müsste für grössere Referenzanlagen eine typische Reihenverschattung von ca. 3% abgezogen werden.

Fazit: Soll bei zukünftigen Installationen maximaler Ertrag erzielt werden, muss strikt auf einen abschattungsfreien Standort geachtet werden und auch die Ausrichtung der Tragseile optimal nach Ost-West orientiert sein. Nach dem Vorliegen einer vollständigen Jahresmessreihe können die angegeben Kennwerte weiter präzisiert werden.

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Autonomous cleaning robot for large scale photovoltaic po er plants in Europe resulting in 5 cost reduction of electricit

(PV-SERVITOR)

Annual Report 2010

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Date	20. January 2011

ABSTRACT

Purpose and goals of the P laborator of BFH-TI in this project during 2010

- Supplying basic information about PV systems and possible operational problems of such plants especially due to pollution to the other project partner which are not familiar with PV systems technology. Coaching of the project partners in PV systems technology.
- Neutral assessment and documentation of the results and effectiveness of cleaning by the PV-Servitor robots developed by the project partners MRU, DTI and Profactor doing the research part in this project. Assessment and quantitative measurements of cleaning effectiveness of robot prototypes B and C cleaning polluted PV modules as soon as they are operational.
- Inclusion of monitoring data of some PV plants in Germany, where cleaning tests with PV-Servitor robots are planned, into established long-term monitoring project of the PV laboratory in order to assess cleaning effectiveness and re-pollution speed at PV plants cleaned by robots.

ost important results in 2010

- Coaching of and consulting for project partners in PV systems technology
- First steps for connecting some PV plants in Germany, at which cleaning tests are planned, to the established PV monitoring system operated in long-term monitoring projects of the PV laboratory of BFH-TI. Due to delays in robot development and production this was not completed in order to save project time for tests with operational robots.
- In order to assess the present state of pollution of the PV test plant of BFH-TI measurement of I-V-curves of PV arrays before and after cleaning at PV-sub-plant West (about 21kW).
- Preparatory measurements of I-V-curves of 12 other arrays of 650 Wp to 1300 Wp (not cleaned for 4 years) in order to be prepared for cleaning tests and subsequent I-V-curve measurements in the winter months where sufficient irradiance for exact measurements is quite rare.
- Measurement of I-V-curves of 2 arrays of 650 Wp (not cleaned for 17 years) in order to compare the pollution after 4 years of no cleaning with 17 years of no cleaning (since commissioning of the plant) in order to get an idea of appropriate cleaning intervals. Results showed that the pollution after 4 years seems to be comparable with the pollution after 17 years, therefore a more frequent cleaning would make sense at the PV plant concerned.
- Unfortunately the main objective of the project, the development of robots that are capable of cleaning modules, is delayed several months and besides these preparatory measurements no tests before and after cleaning by PV-Servitor robots could be performed yet.

1 Introduction

Besides supplying basic information about PV systems and possible operational problems of such plants especially due to pollution, the main task of the PV laboratory of BFH-TI in this project is a neutral assessment and documentation of the results and effectiveness of cleaning by the PV-Servitor robots developed by the project partners MRU, DTI and Profactor.

In order to quantify cleaning efficiency, in principle two different measurement methods are possible. In order to assess long-term behaviour and energy loss, the evolution of the generator correction factor $k_G = Y_a / Y_T$ over a prolonged period of time makes sense [1], [2]. This method requires a detailed long-term monitoring of the plant to be examined (see chapter 2). A much faster method is to compare I-V-curves (converted to STC = standard test conditions) measured immediately before and after cleaning (see chapter 3). However, for such measurements a certain minimum irradiance is necessary in order to ensure a sufficient accuracy.

2 onitoring k_G over some time for assessment of long-term behaviour

For an assessment of the energy yield of a PV array over a prolonged period of time (e.g. years) it makes sense to examine the generator correction factor $k_G = Y_a / Y_T$ in the months April to September that are not affected by snow covering, unless unusual events (e.g. inverter defects, cleanings) occurred in these months. As the influence of temperature is already contained in Y_T, k_G should be close to 1 in an ideal case. Fig. 1 shows k_G from 1994 to 2009 for the part of BFH-TI's PV plant that has been monitored for the longest time.

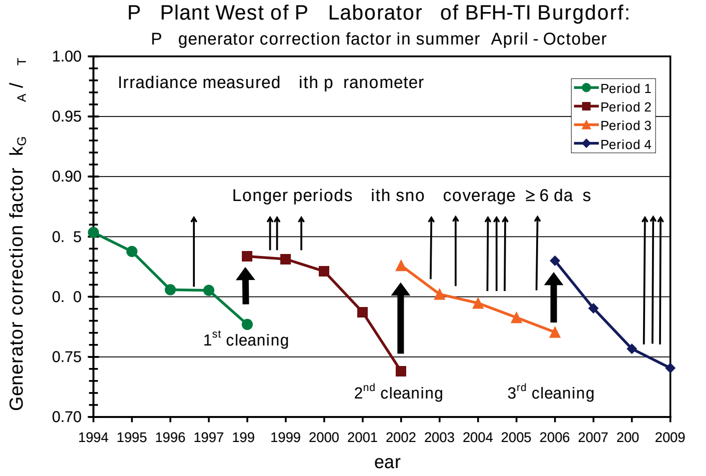

Fig.1:
Measured generator correction factor k_G (in the summer months) from 1994 to 2009 of sub-plant West of the PV test plant of BFH-TI Burgdorf with modules Siemens M55 with frames (long sides horizontal) and tilt angle $\beta = 30°$.
k_G-values for cleaning in 2010 are not available yet [3].

Fig. 1 shows that the generator correction factor $k_G = Y_a/Y_T$ (relevant for energy yield of the PV generator) at first drops slowly, but after a few years always faster. From 1994 until the first cleaning in 1998 it dropped about 9%, from 1998 till the second cleaning in summer 2002 about 11% and between 2002 and 2006 about 7% (slower decrease due to several winters with a significant amount of snow). *st t is n ss as si c anin* (and replacement of a defective module in 2002) [2], [3].

3 easurements of I- -curves before and after manual cleaning

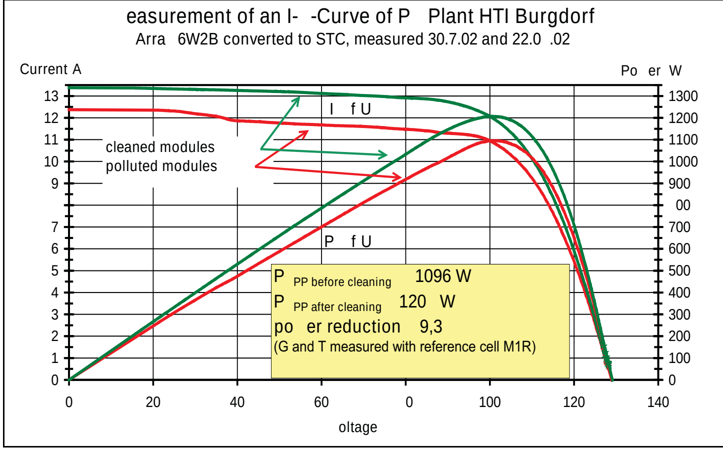

Fig. 2:
Measured I-V and P-V curves (converted to STC) of an array of BFH-TI's PV plant with a rated power of 1310W (24 modules M55 with 55W (±10%) minus about 10W diode losses) before and after *anua* cleaning in August 2002 [3].

The reduction of measured STC power matches quite well with the reduction of k_G according to fig. 1 observed between 1998 and 2002. Similar reductions of STC power were also measured at PV arrays with modules without frames and low tilt angle (β < 5°).

The same array was also measured during the most recent cleaning campaign in the beginning of July 2010 (see fig. 3). The effect of cleaning 8 years later is comparable to the result obtained in 2002. Compared to the value obtained in 2002, measured P_{MPP} power in cleaned condition in 2010 is about 3% lower.

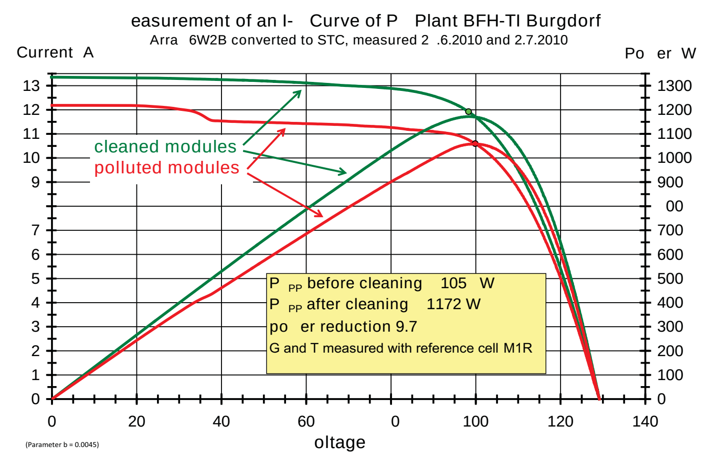

Fig. 3:
Measured I-V and P-V curves (converted to STC) of an array of BFH-TI's PV plant with a rated power of 1310W (24 modules M55 (±10%) with 55W minus about 10W diode losses) before and after *anua* cleaning in the beginning of July 2010 [3].

4 Preparations for measurements of cleaning efficienc

4.1 Preparations for measurements of generator correction factor k_G

As it was shown in chapter 2, the quantity $k_G = Y_A/Y_T$ measured over a long period is an excellent tool to assess re-pollution speed and the effect of natural cleaning by rain and snow (see fig. 1). In order to be prepared for this task, attempts have been made to connect data from some PV plants of the end-users to the established PV monitoring evaluation programs that have been used successfully by BFH-TI for more than 15 years. An evaluation of such monitoring data would be especially interesting in order to assess - *uti n s a t c anin* by a robot. Therefore first steps were taken to connect data from IBC's PV plant Hafenpreppach to the established and proven PV monitoring data evaluation system.

However, as it became obvious that the development of robots capable of cleaning would take more time than originally foreseen, the efforts in that direction were stopped in order to save time for measurements of cleaning effectiveness immediately before and after cleaning by a PV-Servitor robot like in fig. 2 and 3. The time for re-pollution would be quite low in the remaining project time, because the official project duration is only 2 years.

4.2 Preparative I- -curve measurements for future cleaning tests in inter

As shown in the previous chapter, for a quantitative assessment of cleaning efficiency it is necessary to measure I-V-curves before and after cleaning and convert them to STC (standard test conditions). For such measurements, a sufficient solar irradiance (e.g. > 700 W/m^2) is necessary. As such days are rare in the winter months, with consent of the project-co-ordinator it was decided to measure in advance 14 polluted arrays (cleaned last time 4 years ago) in order to be prepared for possible cleaning experiments with prototype B an C at our PV plant in the coming winter months 2010/2011 with low probability of sufficient sunshine. Thus only one sunny day after cleaning (instead of two before and after cleaning) will be necessary.

Further steps and Conclusion

As soon as an operational prototype B of the PV servitor robot with cleaning capabilities will be available and weather conditions permit, intense cleaning tests will be performed at BFH-TI's PV plant in Burgdorf. The effect of cleaning will be documented by photographs and by comparing measurements of I-V-curves before and after cleaning like those shown in chapter 3.

t u a t t n t n t ct t nt s in t t st t u t t t s an in su an autu n t a s n s ns t c u it a t t in a u it ut a ca u a uati n t t st su ts it t t an a isati n t n c ssa i nts

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ESS A PAGNE PHOTO OLTAI SCHALLSCHUT ANLGE NSINGEN

Annual Report 2010

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Date	23.12.2010

ABSTRACT

On the important North-South railway line Bern-Lötschberg in Switzerland the worlds first bifacial Photovoltaic plant integrated in a noise barrier along the railway has been realized in December 2008. For this project the originally planned transparent glass noise barrier elements have been substituted by bifacial PV modules based on a special glass-glass-structure to fulfill the noise protection requirements. Economical considerations such as the substitution of conventional glass noise barrier elements by PV modules fulfilling the noise protection requirements can be studied with this pilot project as well as technical questions concerning the use of bifacial PV modules in a noise barrier along a railway line. The most interesting of these technical issues concerning the further use of bifacial PV noise barriers are the influence of partial shading due to typical railway infrastructure such as power lines or bypassing trains on the overall yield and the behaviour of the MPP tracking of the inverters in respect to the above mentioned shading and the fact that for a east-west-oriented bifacial PV plant the irradiation has two maxima per day. One further question is the influence of dirt deposits on the surface of the PV modules, caused by iron dust from the trains while reducing their speed in the area of the train station, on the overall yield of the plant.

The estimated yield in the process of planning of this bifacial PV noise barrier plant of 7'560kWh/a has not been reached. The measured yield of the plant is at 5'076kWh after one year of full operation.

Introduction and aims

With the construction of the first bifacial PV noise barrier on the motorway flyover in Aubrugg, Zürich, the concept for bifacial PV noise barriers has been proofed. An intensive measurement campaign has been carried out at the PV plant Aubrugg, which showes that the concept of gathering energy on two vertical planes facing east and west equals energy yield of a south oriented and tilted plane PV system. Different PV specific parameters such as shading, dirt deposits, inverter behaviour and sizing have been examined and optimized. All of these experiences have been taken into the account during the planning of the bifacial PV noise barrier plant along the railway in Münsingen.

The bifacial PV noise barrier in Münsingen is the first bifacial PV noise barrier along a railway line. There are several railway specific issues such as shading by railway infrastructure or passing trains, reduction of the yield through deposits of iron dust from the brakes of the trains, general maintenance issues and of course the analysis of the economics of a bifacial PV noise barrier on a railway.

1 Shading b t pical rail a infrastructures

Shading for bifacial PV noise barriers is even more delicate than for on-roof PV systems. The vertically arranged PV modules are more suspect to shading at low elevation of the sun. On the other hand, shading will never occur on both sides at the same time, allowing the non-shadowed side of the bifacial PV module to absorb at least the indirect irradiation. The influence on the yield of typical railway infrastructure, such as shading from transmission lines shall be explored. Due to the close geographical location of the noise barrier to the railway line the influence of a short passing shadow caused by passing trains shall also be investigated.

2 aintenance and influence of rail a parameters

The maintenance requirements of the bifacial PV noise barrier on the motorway in Aubrugg has proofed to be minimal. Rain and snow are sufficient for a cleaning of the modules, even on the side facing the road. The amount of maintenance, especially in regard to the iron dust from the brakes of the trains, shall be evaluated in Münsingen. The arrangement of several equal arrays of modules allows the side-by-side comparison of cleaned versus non maintained modules.

3 Economics

a Substitution of transparent noise barriers through P modules

The transparent noise barrier elements consist basically of a glass-glass element with a frame for mounting in the noise barrier. These elements can be substituted with glass PV modules without influencing the noise reflection properties of the actual noise barrier. It is therefore a real substitution and the investor of the noise barrier will benefit in lower investment costs. This benefit should be passed on to the PV plant owner. The frame of the noise barrier element has to be adapted for a PV module in order to connect the modules electrically and make the connections to the inverters. For all the components there are high aesthetic requirements, specially since the PV noise barrier is located near The transparent noise barrier elements consist basically of a glass-glass element with a frame for mounting in the noise barrier. These elements can be substituted with glass PV modules without influencing the noise reflection properties of the actual noise barrier. It is therefore a real substitution and the investor of the noise barrier will benefit in lower investment costs. This benefit should be passed on to the PV plant owner. The frame of the noise barrier element has to be adapted for a PV module in order to connect the modules electrically and make the connections to the inverters. For all the components there are high aesthetic requirements, specially since the PV noise barrier is located near the railway station in the middle of the town with a lot of passengers passing by the PV plant and the PV noise-barrier being exposed to general view.

b Prefabrication of P modules and integration into noise barrier construction logistics

Since there are no standard PV products for the bifacial PV noise barrier construction, the components like solar cells, modules, frames and inverters have to be brought together by different manufacturers. The additional interface to the noise barrier construction needs an integration of the PV related products and processes to the conventional noise barrier construction. This should lead to a reduction of steps needed for the construction of a bifacial PV noise barrier and therefore to a cost optimisation.

The realisation of the bifacial PV noise barrier along a railway line allows a detailed analysis of the cost structure. With this the potential of the bifacial PV noise barriers on railway lines can be estimated under economic aspects.

The transparent noise barrier elements consist basically of a glass-glass element with a frame for mounting in the noise barrier. These elements can be substituted with glass PV modules without influencing the noise reflection properties of the actual noise barrier. It is therefore a real substitution and the investor of the noise barrier will benefit in lower investment costs. This benefit should be passed on to the PV plant owner. The frame of the noise barrier element has to be adapted for a PV module in order to connect the modules electrically and make the connections to the inverters. For all the components there are high aesthetic requirements, specially since the PV noise barrier is located near the railway station in the middle of the town with a lot of passengers passing by the PV plant and the PV noise-barrier being exposed to general view.

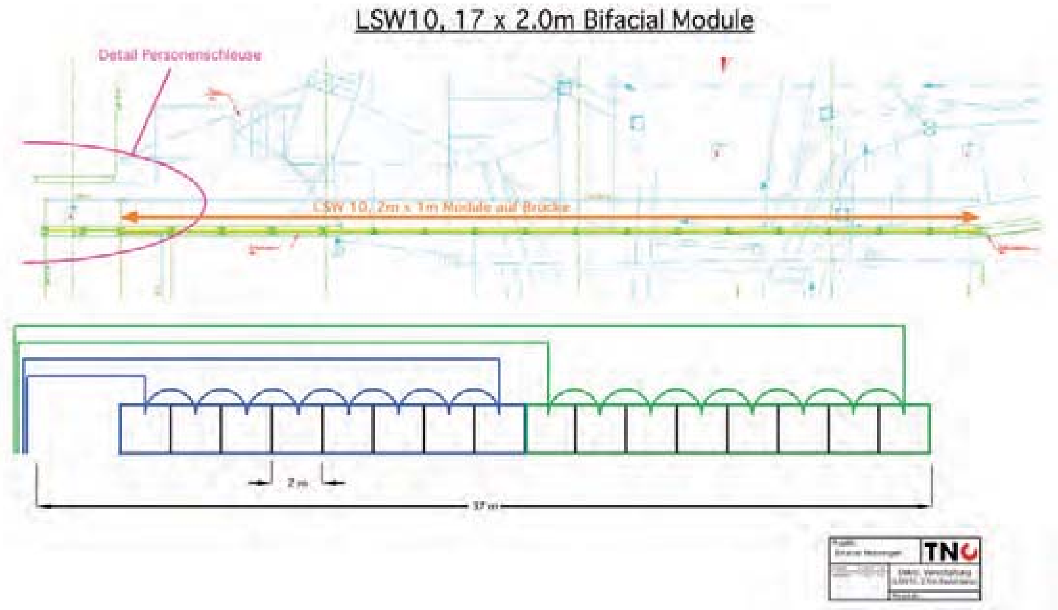
4 Description of the bifacial P noise barrier on a rail a line in ünsingen

On the important North-South railway line Bern-Lötschberg in Switzerland, the world's first bifacial Photovoltaic plant integrated in a noise barrier along the railway has been realised in December 2008. For this project, the originally planned reflective transparent glass noise barrier elements have been substituted by bifacial PV modules based on a special glass-glass-structure to fulfil the noise protection requirements. Economical considerations such as the substitution of conventional glass noise barrier elements by PV modules fulfilling the noise protection requirements can be studied with this pilot project as well as technical questions concerning the use of bifacial PV modules in a noise barrier along a railway line. The most interesting of these technical issues concerning the further use of bifacial PV noise barriers are the influence of partial shading due to typical railway infrastructure such as power lines or bypassing trains on the overall yield and the behaviour of the MPP tracking of the inverters in respect to the shading and the fact that for a east-west-oriented bifacial PV plant the irradiation has two maxima per day. One further question is the influence of dirt deposits on the surface of the PV modules, caused by iron dust from the trains while reducing speed in the area of the train station, on the overall yield of the plant.

i u P ant c nsists asica t a inin n is a i s cti ns, a an a it is a i t s cti n ic sta ts i ct at t n t n t t ain stati n an t s cti n is a i , ic sta ts at t n t n t is su ts in a t ta a a ai a t P n is a i nts a i n i t

5 P plant design

The 115m2 noise barrier section results electrically to a total nominal power of about 7.25kWp for the front side of the bifacial modules (higher cell efficiency), or a nominal power of a little more than 5.6kWp for the backside of the bifacial modules (lower cell efficiency). Electrically, the plant is split up in 3x2 groups, each group with 7 or 8 modules. Two identical groups are combined to one inverter. This allows the side-by-side comparison of two groups of modules under real operating conditions in order to answer some of the questions concerning the influence of partial shading by the rail infrastructure, the temporary shading of passing trains or the influence of dirt deposits on the overall yield of the plant. By using three small one-phase inverters instead of one larger three-phase inverter, the possibility of making side-by-side comparisons of the inverters under real operating conditions has been preserved.



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6 easurement b TNC

The measurement equipment was installed in May 2009 by TNC.

In the middle of section LSW 7 three temperature compensated reference cells were installed. One reference cell each is installed parallel to the modules, facing east and west. The third reference cell is oriented south with an inclination of 35°. This allows the comparison of the solar irradiation of the two sides to the east and the west in comparison to a south oriented plane. In addition there is a temperature sensor that is located with the three reference cells for the measurement of the ambient temperature.

To measure the electrical parameters of the PV plant, 3 DC voltage measuring units have been installed, one before each inverter for the 3 arrays. Every inverter is fed by two groups of modules in parallel, consisting of the same amount of modules of the same type. Each of these groups of modules has a Hall sensor to measure the current on the DC side. This results in 6 DC current values. In addition one single phase AC energy meter is installed per inverter on the output side of the inverter.

All sensors are connected to a data logger, which stores the input values. First calculations are done by the data logger, based on a customized logger program developed and written by TNC for the bifacial PV plant in Münsingen. The data on the data logger is collected regularly by TNC using a GSM modem connected to the data logger for remote access.

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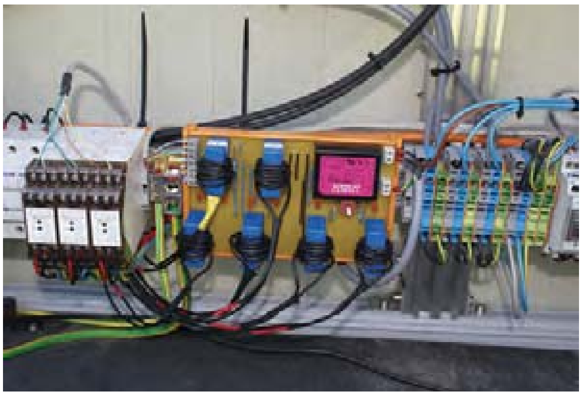

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Data ac uisition

The first month with a complete set of data was therefore June 2009. In order to get a full year of measurement data for average year values, thefirst half of the data 2010 was combined with the se c-ond half of 2009 data besides the evaluation of the partially recorded years.

7 Overvie of the first full ear of operation

The estimated yield in the process of planning of this bifacial PV noise barrier plant '756kW h/a has not been reached. The measured yield of the plant is at 5076kW h after one year of full operation. Several reasons for this lower yield have been located:

• The inverters have been slightly oversized, leading to a reduction of the efficiency due to operation with partial loads.

• Shading of some parts of the modules lead to losses, which are calculated comparing different groups of modules of the plant.

Taking these facts into account, the plant has been close to expectations concerning the yield (about 90% of expected yield reached).

The first year of operation has also shown some challenges with maintenance and operation of a PV noise barrier plant in public space with easy accessibility. The modules have been affected by grafitties. Influence of these grafitties on the yield has been analysed. There has also been an incident with a PV module being destroyed on purpose.

Economical, in the realized form the bifacial PV plant is not able to produce power to a competitive price compared to conventional PV plants. Different aspects of cost structure, pilot plant size leading to untypical cost shares of components, substitution effects with economic benefits and exploring synergy effects in planning and installing PV noise barrier plants are shown. The results lead to the assumption that for future bifacial PV noise barrier plants substantial cost savings should be possible.

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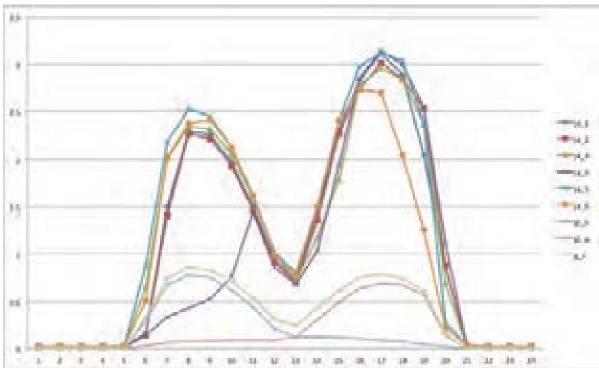

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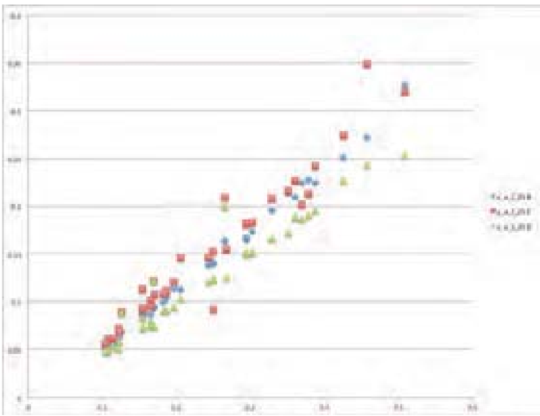

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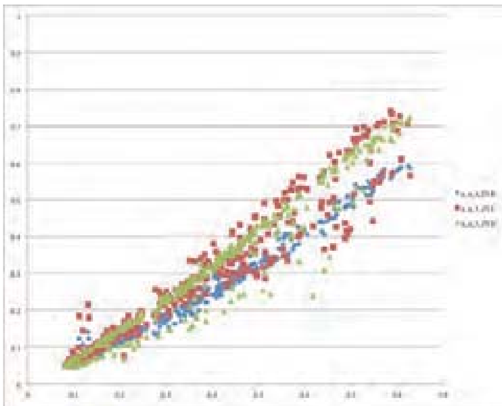

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Anal sis of ield

Based on the experience from the bifacial PV noise barrier plant in Aubrugg and several other PV plants, a calculation of the expected yield was done by TNC basing on a simulation of the solar irradiation and the technical specifications of the components used in the bifacial PV noise barrier plant. The expected yield was calculated at 6'750kWh/a. In one year of operation, 5'076kWh have been measured on the AC output side of the inverters. This corresponds only to 75.2% of the expected yield.

International collaborations

During planning and construction, several international companies were involved for the bifacial PV noise barrier plant in Münsingen. The bifacial solar cells have been provided by Hitachi from Japan. Hitachi has also provided the technical specifications for the bifacial cells. For module construction several European companies have been contacted. Scheuten Solar processed the bifacial solar cells to glas-glas modules fulfilling the requirements of transparent noise barriers on railways. Installation of the modules and electrical installations have been provided by local companies. Installation of the modules and the construction of the frames of the modules for integration into the noise barrier has been carried out by Walo Bertschinger. Electrical installations have been carried out by a team consisting of BaumannElektro and SunTechnics Engineering, product development and project lead has been done by TNC Consulting.

9 Outlook 2011

In the second part of the measurement campaign further data shall be acquired. Especially the influence of shading by bypassing trains and passengers shall be tried to evaluate using a higher time resolution of the sensors. For this the logger program has to be adapted and recompiled. This shall be done in spring 2011. The data measurement with the high time resolution can only be carried out over a limited part of time because of the available storage space in the data logger. Afterwards the original logger program shall be installed again.

Referen en / Publications

[1] Th. ontobel, Th. Nordmann, L.Clavadetscher: Erstmalige Realisierung einer in eine Schallschutz-Konstruktion voll integrierten bifacialen Photovoltaik Anlage entlang einer Eisenbahnschiene in der Schweiz, 24. Symposium Photovoltaische Solarenergie, 4. - 6. März 2009, Staffelstein

Internationale Koordination

NOR IERUNG F R P -S STE E
IEC-TC82 UND
NATIONALES TK82 FÜR PV-SYSTEME

Annual Report 2010

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Project- / Contract Number	17967
Duration of the Project (from – to)	2008 - …..
Date	January 2011

ABSTRACT

The TC 82 of the International Electrotechnical Commission (IEC) (www.iec.ch) is in charge of the preparation and maintenance of standards for PV Power Systems. As per end of 2010, five working groups are active und two joint committee working groups:

WG 1 - Glossary
WG 2 - Modules, non-concentrating
WG 3 - Systems
WG 6 - Balance-of-system components
WG 7 - Concentrator modules

The delegates from Switzerland focused on activities in WG3 and WG6. In several national and international meetings new and revised standards were discussed and implemented. Hot topics in 2010 among others were certainly the fire safety issues. This will have consequences in several existing and new standards. Another major topic is the revision of the part 712 in IEC 60364-7-712 about PV installations in buildings. A TC 82 delegation is supporting the work of the TC64-MT9 groupe. Due to the large number of comments the revision process is delayed. The 712 part is an important document because it is widely used by installers and suppliers of electrical equipment.

A stronger collaboration between CENELEC and IEC has been launched for the preparation of a standard for BIPV applications. In autumn 2010 Cenelec accepted a new work item about BIPV. Within IEC a similar document has been accepted by working group 3 and is ready for the voting process.

On national level there were a few activities in order the launch a joint activity between ISO and IEC. At an afternoon workshop the formation of an ISO task group about definitions in the renewable energy standardisation process was discussed. From the view point of IEC-TC82 there was no strong exigence visible.

Einleitung / Projekt iele

Aufgrund des stetig, sowohl in Menge wie auch geografisch, wachsenden PV-Marktes, ist der Normenbedarf gleichermassen zunehmend. In gewissen Bereichen hinkt die Erarbeitung der Normen dem Markt hinterher. Weil das starke Marktwachstum neben Japan und Deutschland auch andere Länder erfasst hat, beteiligen sich heute mehr Länder aktiv an der Normierung. Das ist grundsätzlich erfreulich, hat aber auch zur Folge, dass einige Arbeitsschritte länger dauern und die Neuausgabe verzögern. Das wiederum steht dann im Zielkonflikt mit dem Wunsch, dass neue Normen jeweils baldmöglichst verfügbar sein sollten.

Die Projektziele waren zum Teil ähnlich wie im Jahr zuvor, weil etliche Projekte eine mehrjährige Bearbeitungszeit aufweisen. Im Bericht werden die jeweiligen Aktivitäten kurz beleuchtet.

Nachfolgend die Übersicht über einige Schwerpunkte:

- PV und Feuerwehr: Risiken minimieren, Verhaltensvorschläge erarbeiten
- Zusammenarbeit mit Versicherungen bezüglich Brandschutz, Hagelschlag und Hochwasser
- Überarbeitung des Abschnitts 712 in den NIN 2010 (TC-64 Dokument)
- BIPV (Building Integrated PV)
- Bedürfnisse in den Entwicklungsländern berücksichtigen

ur beschrieb des Projekts

Der Zweck des vorliegenden Projektes ist die Betreuung der Normenarbeit für den PV-Bereich nach fest gelegten Prioritäten. Das Projekt wird in enger Zusammenarbeit mit Vertretern von Swissolar, der Electrosuisse und den internationalen Normengremien durchgeführt. Der Schwerpunkt liegt in der Betreuung und Leitung des nationalen IEC-TK 82 und der Schweizerischen Vertretung im IEC-TC 82, welche zuständig sind für die PV-Normen. Die IEC-Normen fokussieren sich auf die Elektrotechnik und zugehörige Themen wie Sicherheit, Brandschutz und generelle Aspekte zur Qualität. Die Normen gelten für Produkte wie auch die Systemtechnik, Installations- und Unterhaltsarbeiten.

Durchgeführte Arbeiten und erreichte Ergebnisse

Im üblichen Rahmen sind auch im Jahr 2010 neue Normen entworfen, revidiert oder in Kraft gesetzt worden. Die neu in Kraft gesetzten IEC-PV-Normen und diejenigen in Arbeit sind im Anhang 1 aufgeführt.

Die üblichen zwei internationalen WG3 & WG6-Meetings fanden in Sevilla und Newcastle statt. Ergänzend gab es wie üblich zwei nationale TK82-Sitzungen und weitere internationale Meetings mit Schweizer Beteiligung, insbesondere zum Thema BIPV. Nachstehend ist der Stand zu den wichtigsten Themen zusammen gefasst.

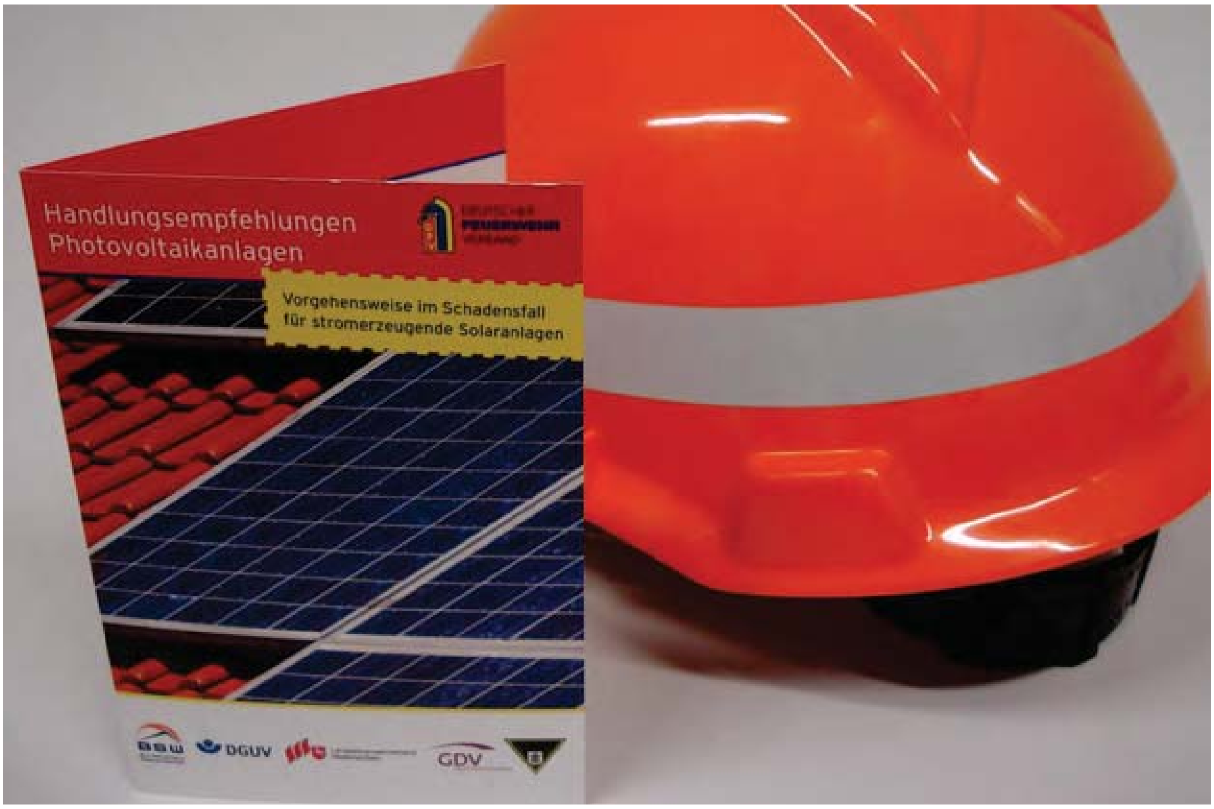
Brandschut , Feuer ehren und ersicherungen

Nachdem vor einem Jahr das Thema "Feuer & PV-Anlagen" verschiedentlich als kurze Mitteilung dargestellt wurde, so sind mittlerweile die Brandereignisse bei Gebäuden mit PV-Anlagen durch verschiedene Medienberichte in die Schlagzeilen geraten. Dadurch musste das Thema nicht nur in Bezug auf die Technik behandelt werden, sondern zusätzlich auch mit der korrekten und verständlichen Kommunikation. Als Folge der Ereignisse bilden die Feuerwehren eine neue Zielgruppe mit Informationsbedarf über PV-Anlagen. In Deutschland hat der Bundesverband Solarwirtschaft (BSW) das Thema aufgriffen und in Zusammenarbeit mit dem Deutschen Feuerwehrverband Handlungsempfehlungen erarbeitet. Es wurde erkannt, dass die sachgerechte Information von entscheidender Bedeutung ist. Ein erstes Ergebnis ist eine Taschenbroschüre für Feuerwehrleute gemäss Abbildung 1 entstanden. Sie ist unter http://www.solarwirtschaft.de/fileadmin/content_files/feuerwehr_pv_bswsolar.pdf verfügbar. In der Schweiz arbeitet die Feuerwehrkoordination Schweiz (FKS) an einem neuen Basisreglement erarbeitet, das 2012 in Kraft treten soll. Swissolar begleitet diese Arbeiten mit der Kommission Bildung & QS.

In der Schweiz wurde nach mehrmaligen Gesprächen vom Schweizerischen Verband der kantonalen Feuerversicherungen (VKF) eine Arbeitsgruppe ins Leben gerufen, welche Empfehlungen für PV-Anlagen in der Schweiz erarbeiten soll. Thomas Hostettler vertritt Swissolar in dieser Arbeitsgruppe.

Der Europäische PV-Industrieverband (EPIA) hat dieses Thema, ebenfalls als Folge der Medienpräsenz, aufgegriffen und am 16. September 2010 in Brüssel den Workshop PV Fire Safety organisiert. Unter anderem wurde die Situation in verschiedenen Ländern vorgestellt und weitere Vorgehensoptionen skizziert. Ein Kurzbericht dazu kann bei Peter Toggweiler bestellt werden.

Abbildung 1: Taschenbroschüre für Feuerwehrleute in Deutschland



Neben dem Schutz bei einem Feuerwehreinsatz soll beim Bau der Anlage die potentielle Gefährdung bei Löscheinsätzen berücksichtigt werden. In erster Priorität soll das Risiko einer Brandauslösung durch die PV-Anlage selbst möglichst minimiert werden. Zum letzteren gehört die Gewähr, dass die Solaranlage in einem guten Qualitätsstandard bezüglich Arbeit und Komponenten erstellt wird. Als zusätzlicher Schutz kommt der Arcdetector in Frage. Die FHB (Berner Fachhochschule) in Burgdorf hat dazu unter der Leitung von Prof. H. Häberlin schon vor einigen Jahren wesentliche Entwicklungsarbeit geleistet. Die IEC will den Arc Detector zu Pflicht machen, sobald Produkte in zuverlässiger Qualität und genügender Menge verfügbar sind.

Um mögliche Gefährdungen bei einen Brand gering zu halten kann einer oder mehrere der folgenden Massnahmen umgesetzt werden:

- Die DC Leitungen zwischen dem Solarfeld und dem Wechselrichter sollen einen erhöhten Schutz gegen Berührung auch im Störungsfall aufweisen.
- DC-Hauptleitungen ausserhalb des Gebäudes verlegen
- DC-Leitungen im Gebäude in Metallrohren verlegen
- Verlegeplan der DC-Leitungen gut sichtbar beim Hausanschlusskasten anbringen
- DC-Leitungen kurz halten, indem der Wechselrichter möglichst nahe beim Solarfeld montiert wird.
- DC-Leitungen nicht im Bereich von Fluchtwegen oder Zugangswegen für Rettungskräfte verlegen.

- Fernsteuerbarer Trennschalter beim Gebäudeeintritt mit hoher Zuverlässigkeit im Brandfall (Feuerwehrschalter).

P -Norm als Bestandteil der Hausinstallationsnorm

Eines der Kernthemen war das Dokument 60364-7 7.12. Das TC-64 für elektrische Hausinstallationen hat einen Revisionsentwurf für Photovoltaik vorgelegt. Es gibt zahlreiche Überschneidungen mit dem PV-Generator Dokument vom TC 82 (IEC 62548 Ed. 1.0, Installation and safety requirements for photovoltaic (PV) generators). Darum ist es notwendig, dass die Überarbeitung des Kapitel 7.12 in der NIN mit Unterstützung des TC 82 statt findet. Weil Peter Toggweiler schon beim ersten Entwurf mitgearbeitet hat, ist er zusammen mit zwei weiteren Delegierten mit der Koordination beauftragt. Im Herbst fand dazu ein Meeting statt, ein weiteres folgt im Februar 2011 in Bonn. Zum aktuellen IEC-Entwurf sind mehr als 300 Kommentare eingegangen, was einen grossen Bearbeitungsaufwand zur Folge hat und die Neuausgabe leider verzögert.

P in Buildings

Noch vor einem Jahr war es unklar, nun sind im 2010 die Würfel gefallen. Es werden zwei Dokumente zu BIPV (Building Integrated PV) verfasst, das eine innerhalb CENELEC und das zweite unter der Leitung von Ryan Gaston für die IEC. Nach wie vor stellt sich die Frage, ob wirklich eine Norm herausgegeben werden soll, oder lediglich eine "technical specification" (technische Beschreibung). Cenelec hat den Vorschlag schon angenommen, bei der IEC wird gegenwärtig das Abstimmungsverfahren vorbereitet. Bei der Erarbeitung der CENELEC-BIPV-Norm arbeiten erfreulicherweise vier Delegierte aus der Schweiz mit: Dr. Thomas Friesen (SUPSI), Thomas Hostettler (Ingenieurbüro Hostettler), Juergen Sutterlueti (Oerlikon Solar AG), Tamas Szacsvay (3S).

Normen und Guidelines für Ent icklungsl nder

Im 2010 konnte mit Sivaganthan Jayasingam aus Malaysia ein neuer Leiter der Joint Committee Working Group (JCWG) für die dezentrale Stromversorgung im ländlichen Raum (Decentralized Rural Electrification (DRE)) gewonnen werden. Die Gruppe setzt sich aus Vertretern vom TC 82, TC 88, TC 21 und SC 21A zusammen. Die Revision und Komplettierung der technischen Standards sollte, wie sie vor 10 Jahren begonnen wurde, dringend bearbeitet werden. Dennoch sind bisher leider keine Aktivitäten gestartet worden. Gemäss IEC-Zentrale in Genf ist die Nachfrage gross und das Bedürfnis ausgewiesen. Trotzdem stehen zurzeit für diese Arbeit kaum Ressourcen zur Verfügung. Daher soll als erste Massnahme versucht werden, finanzielle Mittel für diese Tätigkeit zu finden.

usammenarbeit mit anderen Normengruppen

Die Liste der TCs mit regelmässiger Zusammenarbeit zeigt Anhang 2. Nachstehend einige Hinweise zu aktuellen Aktivitäten:

- ta s itc a an c nt a

Im Zusammenhang mit der Personensicherheit der Feuerwehrleute im Brandfall hat das Thema Trennschalter eine neue Dimension erreicht. Unter anderem darum eine Arbeitsgruppe im TC 17 aktiv geworden, um die Anforderungen an einen DC-Lastschalter für PV zu definieren. Gegenwärtig wird intensiv darüber diskutiert, wo der DC-Trennschalter platziert sein soll/muss und ob er weiterhin im Wechselrichtergehäuse untergebracht sein darf.

us s

Sicherungen für den Überstromschutz sind weiterhin von zentraler Bedeutung. Japan setzt anstelle der Sicherungen Blockingdioden (Seriedioden im String) ein und möchte dies auch in der Norm verankert haben.

P s st s ana nt an ass ciat in ati n c an

Da wird unter anderem die Kommunikation innerhalb der Verteilnetze reguliert. Das hat eine zunehmende Bedeutung aufgrund der Entwicklungen in Richtung der "Smart Grids".

i tnin t cti n

Die geplante Zusammenarbeit zwischen dem TC 81 & 82 konnte noch nicht lanciert werden. Blitzschutz und PV-Anlagen sind naturgemäss oft eng miteinander verknüpft, weshalb das Ziel der Zusammenarbeit weiterhin als hohe Priorität bestehen bleibt.

Be ertung 2010 und Ausblick 2011

Das Jahr 2010 war ein arbeitsreiches und intensives Jahr in Sachen Normen und Qualitätssicherung bei der Photovoltaik. Die geplanten Prozesse und Ziele konnten weitgehend erledigt werden. Neben der eigentlichen Normenarbeit verursachten vor allem die Themen Erdung, Blitzschutz, Hagelfestigkeit, Brandschutz und Anweisungen für das Verhalten bei Brandereignissen einen grossen Zusatzaufwand. Die neuen und bestehenden Normen und die zahlreichen individuellen Beratungen bilden einen wichtigen Beitrag an die Sicherheit von PV-Anlagen. Gleichzeitig ist für alle Akteure in der PV-Wertschöpfungskette wichtig, dass unnötige Vorschriften vermieden werden, damit keine Hindernissen und Marktbarrieren in Kraft gesetzt werden. Die starke Präsenz von einigen Industrievertretern und Prüflabors birgt das Risiko, dass Eigeninteressen zu stark einfliessen. Bisher konnte das weitgehend vermieden werden.

Die Liste im Anhang 1 zu den Dokumenten per Anfangs 2011 in Arbeit ist lang, d.h. es wartet viel Arbeit.

Geplante Meetings mit Teilnehmern aus der Schweiz:

IEC:

- Bonn, Februar 2011, Arbeitssitzung zur Revision des NIN-Teils 712
- Shanghai, Mai 2011, TC-82 Meeting, zusammen mit WG3 & WG 6 Meetings
- Herbst 2011: WG3&WG6 Meetings, Ort noch nicht bekannt

Cenelec:

- Im 2011 sind diverse Meetings zur Erarbeitung der BIPV-Norm geplant.

Referen en

[1] www.iec.ch

[2] www.electrosuisse.ch

[3] www.swissolar.ch

Beilage 1: Aus ug von neu publi ierten Normen und Dokumenten in Arbeit

Im Jahr 2010 neu publi ierte IEC-Normen u P :

International:

IEC 62109-1 (2010-04) Ed. 1.0 English
Safety of power converters for use in photovoltaic power systems - Part 1: General requirements

IEC/TS 62257-7-1 (2010-09) Ed. 2.0 English
Recommendations for small renewable energy and hybrid systems for rural electrification - Part 7-1: Generators - Photovoltaic generators

IEC 62509 (2010-12) Ed. 1.0 Bilingual
Battery charge controllers for photovoltaic systems - Performance and functioning

In der Sch ei :

ESTI 233.0710 d
Solar-Photovoltaik (PV) Stromversorgungssysteme

Dokumente per Anfang 2011 in Arbeit vom TC 2

(IEC-Dokument Nr., mit Bearbeitungsstand und Titel des Dokumentes)

IEC 60904-5 Ed. 2.0; Draft at Editing Check
Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method

IEC 60904-8 Ed. 3.0; Approved Maintenance Work
Photovoltaic devices - Part 8: Measurement of spectral response of a photovoltaic (PV) device

IEC 61215 Ed. 3.0; Approved Maintenance Work
Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval

IEC 61683 Ed. 2.0; Approved Maintenance Work
Photovoltaic systems - Power conditioners - Procedure for measuring efficiency

IEC 61701 Ed. 2.0; Draft circulated as Committee Draft with Vote
Salt mist corrosion testing of photovoltaic (PV) modules

IEC 61730-1am.1 Ed. 1.0; Approved for FDIS circulation
Amendment 1 - IEC 61730-1: Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction

IEC 61730-2am.1 Ed. 1.0; Approved for FDIS circulation
Amendment 1 to IEC 61730-2: Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing

IEC 61829 Ed. 2.0; Approved Maintenance Work
Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics

IEC 61836 TS Ed. 3.0; Approved Maintenance Work
Solar photovoltaic energy systems - Terms, definitions and symbols

IEC 61853-1 Ed. 1.0; Publication being printed
Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating

IEC 61853-2 Ed. 1.0; Draft circulated as Committee Draft with Vote
Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral response, incidence angle and module operating temperature measurements

IEC 62109-2 Ed. 1.0; Text for FDIS received and registered
Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters

IEC 62109-3 Ed. 1.0; Potential new work item
Safety of power converters for use in photovoltaic power systems - Part 3: Controllers

IEC 62109-4 Ed. 1.0; Approved Maintenance Work
Safety of power converters for use in photovoltaic power systems - Part 4: Particular requirements for combiner box

IEC 62253 Ed. 1.0; Draft circulated as Committee Draft with Vote
Photovoltaic pumping systems - Design qualification and performance measurements

IEC 62548 Ed. 1.0; 2nd Committee Draft
Installation and safety requirements for photovoltaic (PV) generators

IEC 62670 Ed. 1.0; 1st Committee Draft
Concentrator photovoltaic(CPV) module and assembly performance testing and energy rating - Part 1: Performance measurements and power rating - Irradiance and temperature

IEC 62688 Ed. 1.0; 1st Committee Draft
Concentrator photovoltaic (CPV) module and assembly safety qualification

IEC 62716 Ed. 1.0; Approved Maintenance Work
Ammonia corrosion testing of photovoltaic (PV) modules

PNW 82-609 Ed. 1.0; Proposed New Work
Concentrator Photovoltaic (CPV) Module, array and assembly: Energy rating by measurement

PNW 82-618 TS Ed. 1.0; Proposed New Work
Specification for solar trackers used for photovoltaic systems

Beilage 2: Other IEC-Committees ith at least some collaboration ith TC 2

TC 4	Small hydro
TC 8	Systems aspects for electrical energy supply
SC 17B	Low-voltage switchgear and control gear
TC 21	Battery Storage
TC 22	Power electronic systems and equipment
SC 23B	Plugs, socket-outlets and switches
SC 23E	Circuit-breakers and similar equipment for household use
SC 32B	Low-voltage fuses
TC 47	Semiconductor devices
TC 57 WG17	PV-Communications
TC 64	Electrical installations and protection against electric shock
TC 77 / SC77A	EMC Low frequency phenomena
TC 81	Lightning Protection
TC 88	Wind turbines
TC 105	Fuel Cells

Three publications with relevance to TC 82:

TC 8/1275/NP: Guidelines on dispersed generation - Impact of renewable energy sources on grid planning and operation
To provide guidelines for planning, design and operation of MV/LV grids with substantial dispersed generation.

TC8/1285/NP:	Standard calculation methods of performance indexes for energy supply. Today, reliability performance indexes are defined, but there are many ways to process the data. In order to calculate those indexes in a useful and comparable way, the TS will provide a catalogue of methods that can be used optionally by energy suppliers.
TC 77/IEC/TR 61000-3-15:	Electromagnetic compatibility (EMC) - Part 3-15: Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network. It forms part 3-15 of IEC 61000.

Beilage 3: H ufig ver endete Abkür ungen in IEC-Dokumenten und eitere Abkür ungen

RVD:	Report of Voting on FDIS
AC:	Administrative Circular
RVN:	Report of Voting on NP
CC:	Compilation of Comments
CD:	Committee Draft
CDV:	Committee Draft for Vote
DA:	Draft Agenda
DC:	Document for Comments
DTR:	Draft Technical Report
DTS	Draft Technical Specification
EN:	European Standard
FDIS:	Final Draft International Standard
FprEN:	Draft European Standard for Formal Vote
HD:	Harmonization Document
MTG:	Meeting Documents
NCP:	National Committee Proposal
NP:	New Work Item Proposal
prEN:	Draft European Standard
RM:	Report of Meeting
RR:	Review Report
RVC:	Report of Voting on CDV

Weitere im Dokument verwendete Abkürzungen:

IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
CENELEC	Europäisches Komitee für elektrotechnische Normung
NIN	Niederspannungs-Installationsnorm, gültig für die Schweiz, aktuell gilt die Ausgabe NIN 2010

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Umwelt, Verkehr, Energie und Kommunikation UVEK
Bundesamt für Energie BFE

SCHWEI ER BEITRAG U IEA P PS PROGRA , TAS 1

Annual Report 2010

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Project- / Contract Number	SI/500547 / SI500547-01
Duration of the Project (from – to)	1.1.2010 – 31.12. 2010
Date	20.01.2011

ABSTRACT

The Swiss contribution to the PVPS Programme includes:

- National Survey Report, a summary of developments in the market and political areas. The report's data is integrated into the IEA's Trends in Photovoltaic Application Report
- Acquisition of Swiss contributions to PV Power, collecting subscribers for the new Email-Newsletter
- Targeted search for new contacts in the PV area, maintain a network of contacts.
- Contributions/organizations to/of national and international workshops
- PR-work in Switzerland. Reference to the programme‘s international publications

The results of these activities include:

- National Survey Report (NSR) based on the statistics provided by the Swiss Association of Solar Professionals and the Swiss Association of Utilities (grid-coupled installations)
- 1 Task 1 meeting in Sevilla, Spain
- 1 Workshop in Valencia, Spain
- Webmastering support for www.iea-pvps.org

Ongoing work:

- Contribution to the PVPS Workshop in Istanbul, Turkey (Feb. 2011)
- Workshop organization at the PV conference in Hamburg (Sept. 2011) & Yokohama (Dec. 2011)
- Participation at Task 1 Meetings in Istanbul (February) and Amsterdam (September)
- Migration and Support for CMS-Website for the PVPS-programme
- National survey report 2011.

ur beschrieb des Projekts

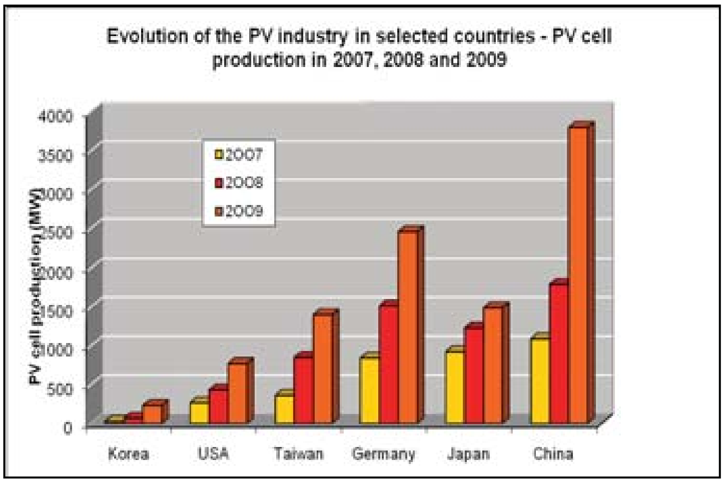
Task 1 unterstützt die generelle Strategie des PVPS Programmes (Kostenreduktion, Potenzial erfassen, Barrieren beseitigen, Kooperation mit Nicht-IEA-Ländern) mit folgenden Produkten.

- PV POWER, seit April 2009 erscheinender E-Newsletter. 2 Ausgaben in 2010
- Trends Report (Trends in Photovoltaic Applications, Survey report of selected IEA countris Between 1992 and 2009), ein Jahresbericht zur Markt- und Technologie-Entwicklung der dem Programm angeschlossenen Länder
- Reports und Workshops zu spezifischen Themen der Photovoltaik
- Eigene Programm-Homepage unter www.iea-pvps.org

Ziel ist es, die identifizierten Zielgruppen (Regierungen, EW's, Industrie, Forschung usw.) mittels qualitativ hochstehenden Produkten zu informieren.

Der Schweizer Beitrag innerhalb des PVPS Programms (Task 1) konzentriert sich auf folgende Schwerpunkte:

- National Survey Report [1], eine Zusammenstellung der Marktentwicklung und des politischen Umfeldes in der Schweiz. Diese Daten werden im Trends Report [2] zusammengefasst und publiziert
- Organisieren von Schweizer Beiträgen in PV Power sowie Mitarbeit im Editorial Board.
- Bewerbung der Anmeldemöglichkeit für den E-Newsletter (als Ersatz für die gedruckte Version)
- Gezielte Suche nach weiteren Kontakten innerhalb der Zielgruppe
- Beiträge an Workshops und Konferenzen auf nationaler und internationaler Ebene
- Organisation von Workshops
- Medienarbeit in der Schweiz: Hinweise auf internationale Publikationen des Programms, Publizieren von Marktstatistiken
- Unterstützung des ExCo beim Internetauftritt



Durchgeführte Arbeiten und erreichte Ergebnisse

National Surve Report NSR

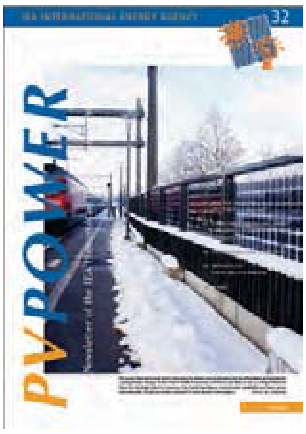
Der NSR bildet die Grundlage für den jedes Jahr erscheinenden "Trends Report". Als Basis für die Statistiken dienen die jährlichen Erhebungen des Sonnenenergie Fachverbandes Swissolar, ergänzt mit Daten der VSE-Statistik zu den netzgekoppelten PV-Anlagen. Die nachfolgende Tabelle gibt einen Überblick über die erhobenen Marktzahlen.

Aus ug aus dem National Surve report: The cumulative installed P po er in 4 sub-markets

	Cumulative installed capacity as of 31 December 2009																	
Sub-market	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Stand-alone domes-tic	1 540	1 675	1 780	1 940	2 030	2 140	2 210	2 300*	2 390*	2 480*	2 570*	2 740*	2 810*	2 930*	3 050*	3 200*	3 800	4 000
Stand-alone non-domestic	70	100	112	143	162	184	190	200*	210*	220*	230*	260*	290*	320*	350*	400*		
Grid-connected distributed	2200	2900	3 600	4 050	4 850	5 950	7 630	9 420	11 220	13 340	15 140	16 440	18 440	21 240	23 740	30 040	41 540	67 040
Grid-connected centralised	900	1 100	1 200	1 350	1 350	1 450	1 470	1 480	1 480	1 560	1 560	1 560	1 560	2 560	2 560	2 560	2 560	2 560
TOTAL (kW)	4 710	5 775	6 692	7 483	8 392	9 724	11 500	13 400	15 300	17 600	19 500	21 000	23 100	27 050	29 700	36 200	47 900	73 600

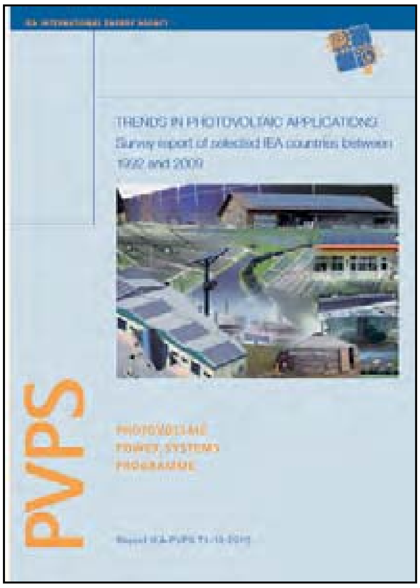
ischen den beiden Daten uellen ergeben sich Ab eichungen aufgrund der unterschiedlichen Art der Erhebung. Einerseits werden von Importeuren, Distributoren und Installateuren Verkaufszahlen erhoben (in MWp der DC-Leistung der odule .

P Po er



PV Power wurde im Berichtsjahr 2 mal als elektronische Version versandt. Zusätzlich wurden 200 exemplare für die EUPVSEC-Konferenz gedruckt und in Valencia verteilt.
Die Schweiz hat beim Wechsel zur neuen Editorin aktiv sowohl bei der Suche wie auch beim „Handling" des Email-Versandes mitgeholfen.

Trends Report

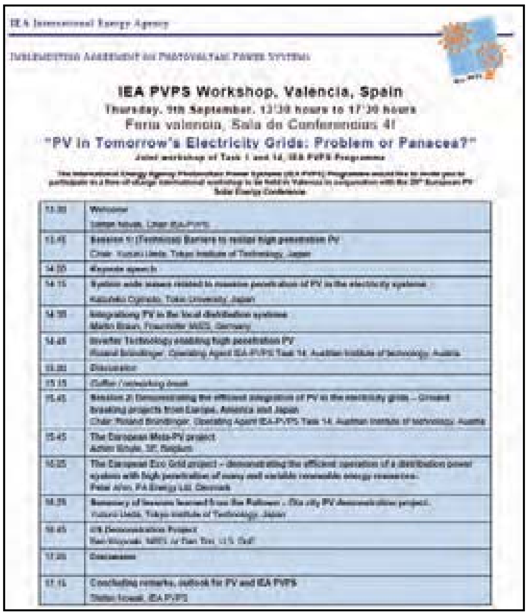


Basierend auf den Daten des "National Survey Reports" wurde Ende September der Trends Report publiziert. Zeitgerecht konnten die wesentlichen Tabellen zu Beginn der Europäischen PV-Konferenz in Hamburg auf dem Internet aufgeschalten werden. Die gedruckte Ausgabe wurde Anfang Oktober ausgeliefert.

Die wichtigsten Daten aus dem Report sind im Internet unter www.iea-pvps.org [3] einsehbar. Der ganze Report wie auch einzelne Tabellen können als PDF-Dokumente heruntergeladen werden.

Workshops

P in s ct icit i s P Panac a
IEA P PS Workshop, 9. Sept. 2010, alencia


IEA International Energy Agency

IEA PVPS Workshop, Valencia, Spain

Thursday, 9th September, 13'30 hours to 17'30 hours

"PV in Tomorrow's Electricity Grids: Problem or Panacea?"

Das Thema Netzbelastung von vielen PV-Anlagen wurde vertieft behandelt. Interessante Lösungsansätze wurden aufgezeigt.

onferen en

EUPVSEC Valencia: Posterpräsentation der Resulate des Trends Reports 2009.
Zusätzlich wurden für den PVPS-Stand (innerhalb des EPIA-Standes) Flyer mit den neusten Resultaten des Trends Reports aufgelegt. Der PVPS-Newsletter wurde in einer gedruckten Version (200 Exemplare) ebenfalls abgegeben.

Neue Webseite P PS Sonderauftrag P PS

Betreuung/Koordination der Webseiten-Entwicklung (Struktur CMS) sowie Migration der Inhalte aus der bestehenden Webseite.

PR und Net orking

Referat anlässlich der Schweiz. Photovoltaik-Tagung 2010 in Winterthur zur internationalen und nationalen Marktentwicklung.

Leitung der Kommission Photovoltaik des Branchenverbandes Swissolar.

Der direkte Draht zu den Swissolarmitgliedern ermöglicht auch das direkte Abrufen von spezifischen Informationen zum PV-Markt in der Schweiz.

Be ertung 2010 und Ausblick 2011

Auch dieses Jahr verzögerte sich die die Auslieferung des Trends Reports aufgrund von spät eintreffenden Daten insbesondere aus England.

Der Workshop in Valencia war sehr gut besucht und wurde sowohl wegen den organisatorischen wie auch inhaltlichen Qualitäten gelobt.

In Planung sind im Moment die Workshops in Istanbul, Hamburg und Yokohama.

Die Nachfrage nach qualifizierten Informationen steigt mit dem rasch wachsenden Markt in Europa. Dies ist sehr gut spürbar in der Schweiz wo auf der einen Seite das Installationsvolumen massiv gestiegen ist, die Exporte (Maschinen etc.) aber ebenfalls auf hohem Niveau geblieben sind.

Referen en

[1] P. Hüsser National Surve Report on P Po er Applications in S it erland 2009, Mai/Aug. 2010

[2] *Trends in Photovoltaic pplications in selected IE countries bet een and* , IEA, PVPS, Task I – 19:2010

[3] *Internet site iea-pvps org*

[4] I. Kaizuka, G. Watt, P. Hüsser, R. Bründlinger, Trends in Photovoltaic Applications - The Latest Surve Results on P arket, Industr and Policies from the IEA P PS Programme *P st P s ntati n an u P - n n , t , a ncia*

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Bundesamt für Energie BFE

SWISS INTERDEPART ENTAL PLATFOR FOR RENEWABLE ENERG AND ENERG EFFICIENC PRO OTION IN INTERNA-TIONAL COOPERATION REPIC

Annual Report 2010

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Project- / Contract Number	SECO UR-00123.02.01
Duration of the Project (from – to)	January 2008 – December 2010
Date	January 2011

ABSTRACT

The Swiss State Secretariat for Economic Affairs (SECO), the Swiss Agency for Development and Cooperation (SDC), the Swiss Federal Office for the Environment (FOEN) and the Swiss Federal Office of Energy (SFOE) have been operating the interdepartmental platform for the promotion of renewable energy in international cooperation since 2004. In 2008, phase II of the REPIC Platform started and promotes now also energy efficiency in international cooperation. The REPIC-Platform contributes to the implementation of global climate protection agreements and to a sustainable energy supply in developing and transition countries, as well as in Switzerland, and represents an important part in the implementation of the Swiss policy for sustainable development on the international level. The REPIC-Platform thereby represents an important contribution to the creation of a coherent policy and strategy in Switzerland, for the promotion of renewable energy in international cooperation.

The specific goals of the REPIC-Platform in relationship with renewable energy in international cooperation are:

1. Information and awareness of the stakeholders
2. Project promotion and project realisation
3. Contribution to international networks
4. Coordination and quality control

The measures of the REPIC-Platform are subsidiary to national and international promotion instruments which already exist. The measures are meant to support these instruments, especially in the area of finance (project lines of the governmental agencies involved, mixed credits, WB, IFC, GEF, and similar) and climate policy instruments (Kyoto-mechanisms). Furthermore, the measures of the REPIC-Platform should provide for synergies between activities from the private sector and the civil society.

Einleitung

Die seit 2004 bestehende REPIC-Plattform ist eine gemeinsame Initiative des Staatssekretariates für Wirtschaft (SECO), der Direktion für Entwicklung und Zusammenarbeit (DEZA), des Bundesamtes für Umwelt (BAFU) sowie des Bundesamtes für Energie (BFE) zur Förderung der erneuerbaren Energien und der Energieeffizienz in der Entwicklungszusammenarbeit – Renewable Energy and Energy Efficiency Promotion in International Cooperation.

Die REPIC-Plattform stellt seit ihrem Bestehen eine neue Form der interdepartementalen Zusammenarbeit dar. Während früher die einzelnen an der REPIC-Plattform beteiligten Ämter in der Regel individuell und punktuell Projekte mit erneuerbaren Energien und Energieeffizienz in der internationalen Zusammenarbeit gefördert haben, erfolgt heute dank dieser Initiative ein koordinierter Ansatz zur Förderung solcher Projekte. Damit werden eine bessere Koordination zwischen den beteiligten Ämtern und ein einheitlicheres Vorgehen angestrebt. Die REPIC-Plattform wirkt subsidiär zu bestehenden Instrumenten der beteiligten Ämter und soll insbesondere dort Wirkung entfalten, wo früher keine oder wenig Aktivitäten stattgefunden haben.

Die REPIC-Plattform leistet einen wichtigen Beitrag zur Umsetzung einer kohärenten Politik und Strategie der Schweiz zur Förderung der erneuerbaren Energien und der Energieeffizienz in der internationalen Zusammenarbeit. Sie trägt zur Umsetzung der globalen Klimaschutzvereinbarungen und zur Förderung einer nachhaltigen Energieversorgung in Entwicklungs- und Transitionsländern ebenso wie in der Schweiz bei und ist damit ein wertvoller Bestandteil der Umsetzung der schweizerischen Politik der nachhaltigen Entwicklung auf internationaler Ebene. Der vorliegende siebte Jahresbericht beschreibt die Aktivitäten, Resultate und Erfahrungen im siebten Jahr der Plattform.

REPIC versteht sich als marktorientiertes Dienstleistungszentrum zur Förderung der erneuerbaren Energien und der Energieeffizienz in der internationalen Zusammenarbeit. Unter Berücksichtigung der vorhandenen Erfahrungen soll diese Plattform neue konkrete Projekte mit erneuerbaren Energien und Energieeffizienz unter vermehrter Mitwirkung von Schweizer Unternehmen und Organisationen ermöglichen. Sie baut dazu ein Netzwerk zur Information und Sensibilisierung interessierter Kreise auf, pflegt den Erfahrungsaustausch zwischen verschiedenen Akteuren und fördert die Kenntnis von lokalen Rahmenbedingungen und Projektmöglichkeiten. Zur Realisierung erfolgversprechender Projekte kann die REPIC-Plattform Beiträge zu einer Anschubfinanzierung leisten. Darüber hinaus erfolgt über die REPIC-Plattform die Mitwirkung in internationalen Netzwerken.

Die REPIC-Plattform umfasst die folgenden Arbeitsebenen:

1. Strategische Leitung, gebildet durch die Direktoren der beteiligten Bundesämter
2. REPIC-Steuergruppe, gebildet durch Vertreter der beteiligten Bundesämter
3. REPIC-Sekretariat, bei NET Nowak Energie & Technologie angesiedelt

Die einzelnen Ansprechpartner sind im REPIC-Leitfaden [1] aufgeführt.

Im Jahr 2010 wurde die Phase II von REPIC abgeschlossen. Bereits Anfang 2010 zeichnete sich eine frühzeitige Vollverpflichtung der vorhandenen Mittel aus Phase II für die Förderung von Projekten ab. Das Jahr 2010 stand im Zeichen der Evaluation der bisherigen Aktivitäten und Resultate der REPIC-Plattform sowie darauf basierend der Strategieentwicklung für ihre Verlängerung um eine weitere Phase von 3 Jahren. Neue Projektskizzen und -gesuche mussten bis zum Entscheid zurückgestellt werden. Die projektbezogenen Aktivitäten und operativen Abläufe für die laufenden Projekte aus der REPIC Phase II wurden fortgesetzt.

iele 2010

Die schwerpunktmässigen Ziele der REPIC-Plattform lauteten für 2010 wie folgt:

- Evaluation und Strategiediskussion
- Kommunikationsaktivitäten, insbesondere Veranstaltungen
- Projektbezogene Aktivitäten
- Koordination innerhalb der Trägerschaft und mit internationalen Netzwerken

Durchgeführte Arbeiten und erreichte Ergebnisse

Die REPIC Tätigkeiten im Jahr 2010 werden entsprechend der Schwerpunkte unter den folgenden vier Aspekten dargestellt:

1) Evaluation und Strategie
2) Information und Kommunikation
3) Projektbezogene Aktivitäten
4) Koordination

Evaluation und Strategie

Eine Wirkungsevaluation der ersten und zweiten Phase im Jahr 2010 [2] hatte zum Ziel, die bisherigen Aktivitäten und Resultate der REPIC-Plattform kritisch zu durchleuchten und Erkenntnisse für eine mögliche Weiterführung der Plattform in einer Phase III zu gewinnen.

Die Beurteilung von REPIC ergab im Allgemeinen ein positives Bild. Konkret beurteilt wurden die folgenden 4 Bereiche: REPIC-Projekte, Zusammenarbeit zwischen den Bundesämtern, Akteursnetzwerk Schweiz und internationale Netzwerke. Die Zufriedenheit mit REPIC wurde als hoch eingestuft. Bezüglich Projektunterstützung wurde REPIC eine professionelle Arbeit attestiert. Die Hauptkritikpunkte lagen beim planmässigen Vollzug der Projekte in den Entwicklungsländern, was in diversen technischen, örtlichen, wirtschaftlichen oder politischen Schwierigkeiten und Gegebenheiten in den Projektländern begründet liegt. Zudem wurde festgestellt, dass konkrete Folgeprojekte bis anhin erst vereinzelt entstanden waren, was zum Teil durch die langen Vorlaufzeiten solcher Projekte begründet ist. Die Netzwerkqualität innerhalb der Schweiz und international wurde wiederum positiv beurteilt. Es konnte festgestellt werden, dass die Akteure bereits gut informiert sind und die Koordination mit den Bundesämtern gut funktioniert. Die Evaluation kam zur klaren Empfehlung, dass die Aktivitäten von REPIC weitergeführt werden sollten.

Aufgrund dieser positiven Einschätzung und der allgemein hohen und wachsenden Bedeutung von erneuerbaren Energien und Energieeffizienz beschloss die strategische Leitung der REPIC-Plattform auf Basis eines Konzeptes [3] und eines Logical Framework Approach (LFA) [4] im Herbst 2010, die REPIC-Plattform für eine weitere Phase von 3 Jahren zu verlängern. Die finanziellen Mittel bleiben im gleichen Rahmen wie für die REPIC-Phase II. Basierend auf den bereits gemachten Erfahrungen der Phasen I und II wird in der dritten Phase verstärktes Gewicht auf die Umsetzung und die Multiplikation bei Projektförderung und -realisierung gelegt.

Für die dritte Phase wurden in Absprache mit dem Programm RUMBA zudem erste Abklärungen durchgeführt, ob und wie REPIC eine aktive Rolle bei der zentralen Beschaffung von Zertifikaten für die CO_2 Kompensationsmassnahmen des Bundes übernehmen könnte.

Information und ommunikation

Der bereits im 2009 verstärkte Fokus auf Veranstaltungen und Workshops konnte im 2010 weitergeführt werden. Insbesondere standen thematische Informationsanlässe im Vordergrund, die nach Möglichkeit im Kontext grösserer Veranstaltungen erfolgten.

Als erster thematischer Anlass des Jahres konnte am 15. April 2010 ein Workshop zum Thema Biomasse [5] durchgeführt werden. Dieser fand anlässlich der Messe Energissima 2010 in Freiburg statt. Er zog gut 45 Teilnehmer an und war sehr geeignet für die Kontaktpflege.

Ein zweiter themenspezifischer Anlass konnte in der zweiten Hälfte des Jahres durchgeführt werden. Am 11. November 2010 fand anlässlich der Hausbau- und Energiemesse in Bern ein Workshop zum Thema Energieeffizienz [6] statt, an dem wiederum gut 45 Personen anwesend waren. Der Workshop konnte als Erfolg gewertet werden.

An der Hausbau- und Energiemesse vom 11.-14. November 2010 war REPIC gleichzeitig auch während der gesamten Messedauer mit einem Stand an der Sonderschau „Nachhaltige Projekte in Entwicklungs- und Schwellenländern“ präsent. Dadurch konnte REPIC einem breiteren Publikum vorgestellt und die Kontakte zu Organisationen und Teilnehmern der Sonderschau konnten gepflegt und ausgebaut werden.

Die üblichen REPIC Kommunikationsaktivitäten wurden weitergeführt. Die REPIC Website (www.repic.ch) wurde laufend aktualisiert, der Projektleitfaden [1] und der REPIC Flyer [7] standen und stehen weiterhin zur Verfügung. Der Projektleitfaden [1] wird zudem Anfang 2011 aufgrund der Änderungen der REPIC-Phase III aktualisiert werden. Die Projektberichte von abgeschlossenen Projekten sind auf der REPIC-Website aufgeschaltet.

Abgerundet wurden die Kommunikationsaktivitäten mit einer REPIC-Präsentation durch das BFE beim Africa Energy Forum vom 29. Juni bis 1. Juli 2010.

Projektbe ogene Aktivit ten

Nachdem 2009 eine markante Steigerung der Projekttätigkeit und -förderung stattfand, zeichnete sich bereits Anfang 2010 im Rahmen der bestehenden Mittel der REPIC Phase II eine frühzeitige Vollverpflichtung der Mittel ab. Ab Frühjahr 2010 mussten neue Projektskizzen und -gesuche bis zum Entscheid über eine Weiterführung von REPIC zurückgestellt werden.

Für die laufenden Projekte wurde ein reibungsloser Vollzug sichergestellt.

oordination

Die REPIC Plattform wurde auch 2010 wieder genutzt, um Aktivitäten der beteiligten Bundesämter in diesem Bereich auszutauschen und allenfalls abzusprechen. Dabei wurde auch auf die Koordination mit neuen Aktivitäten und Strukturen von DEZA und SECO (Infrastrukturfinanzierung SECO, Globales Programm Klimawandel der DEZA) Wert gelegt. Die Koordination mit weiteren relevanten Organisationen innerhalb des Bundes, insbesondere mit der Fachgruppe „Zentrale Beschaffung von CO2-Kompensationen“ von RUMBA, wurde verstärkt.

Im Hinblick auf eine verstärkte Umsetzungsorientierung und Multiplikationswirkung von Projekten gemäss der beschlossenen REPIC Phase III wurden zudem vermehrt Kontakte mit anderen Programmen und Initiativen aufgebaut und erweitert.

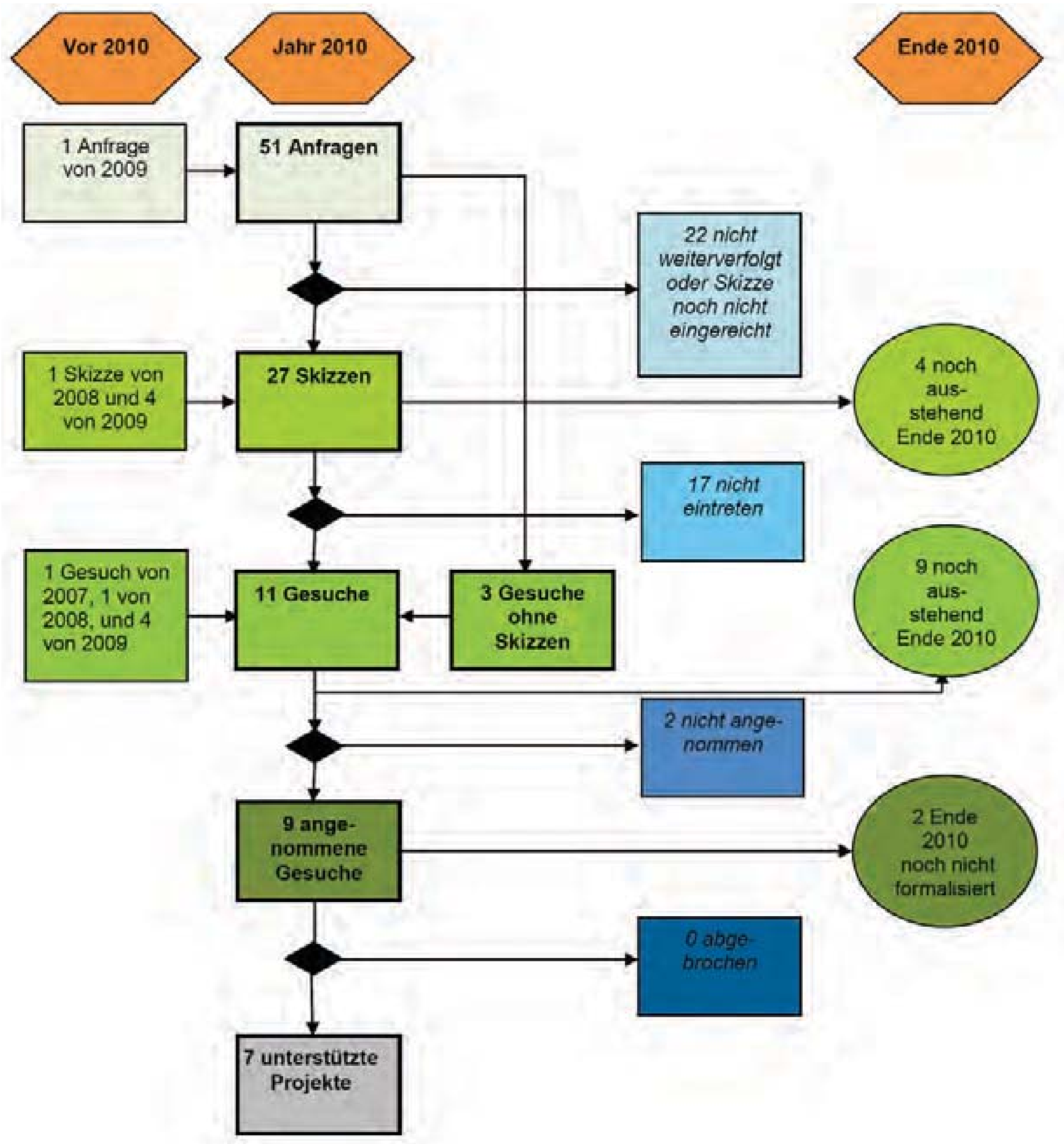
Projektantr ge 2010

Die Gesuche und Projekte konnten auch 2010 effizient und gemäss den bereits eingespielten Verfahren abgewickelt werden.

Im Verlauf von 2010 sind 51 neue Anfragen beim REPIC-Sekretariat eingegangen. Dies entspricht einer erneuten Erhöhung der Projektanfragen, 2009 waren 44 Projektanfragen eingegangen, 2008 38 und 2007 deren 27. Insgesamt 1 Anfrage, 5 Skizzen und 6 Gesuche von früheren Jahren wurden zudem im 2010 behandelt.

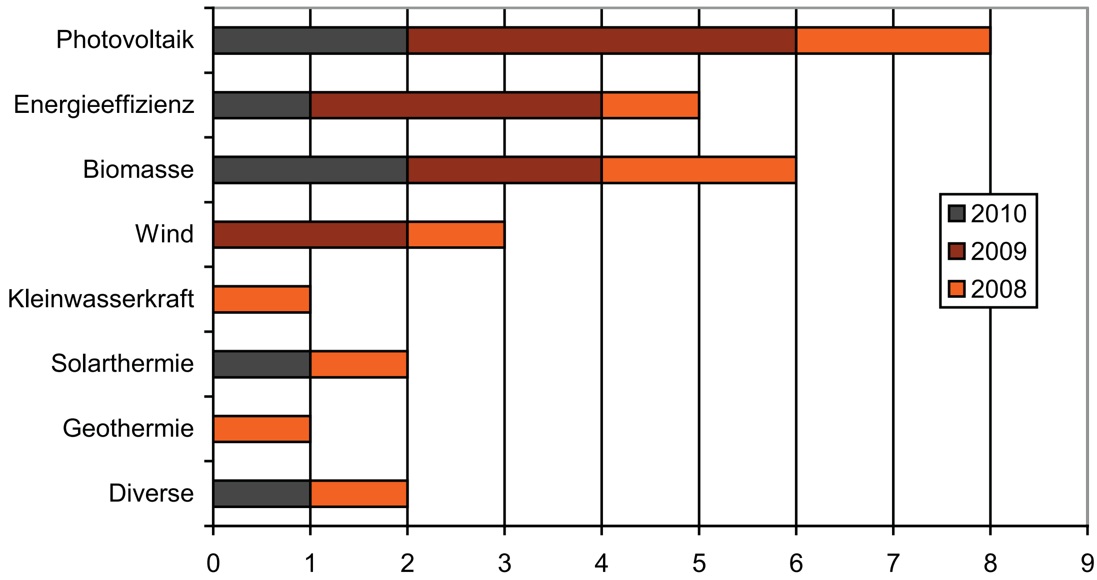
Bei den 51 Projektanfragen im 2010 handelt es sich um 46 technische Projekte, 3 Veranstaltungen, 1 Studie und 1 Diverses. Die erneute Erhöhung der Projektanfragen zeigt die erweiterte Bekanntheit von REPIC, insbesondere da bereits ab Frühjahr 2010 neue Projektskizzen und -gesuche auf Eis gelegt werden mussten und dies entsprechend kommuniziert wurde.

Figur 1 zeigt eine schematische Darstellung der im Jahr 2010 behandelten Anfragen.

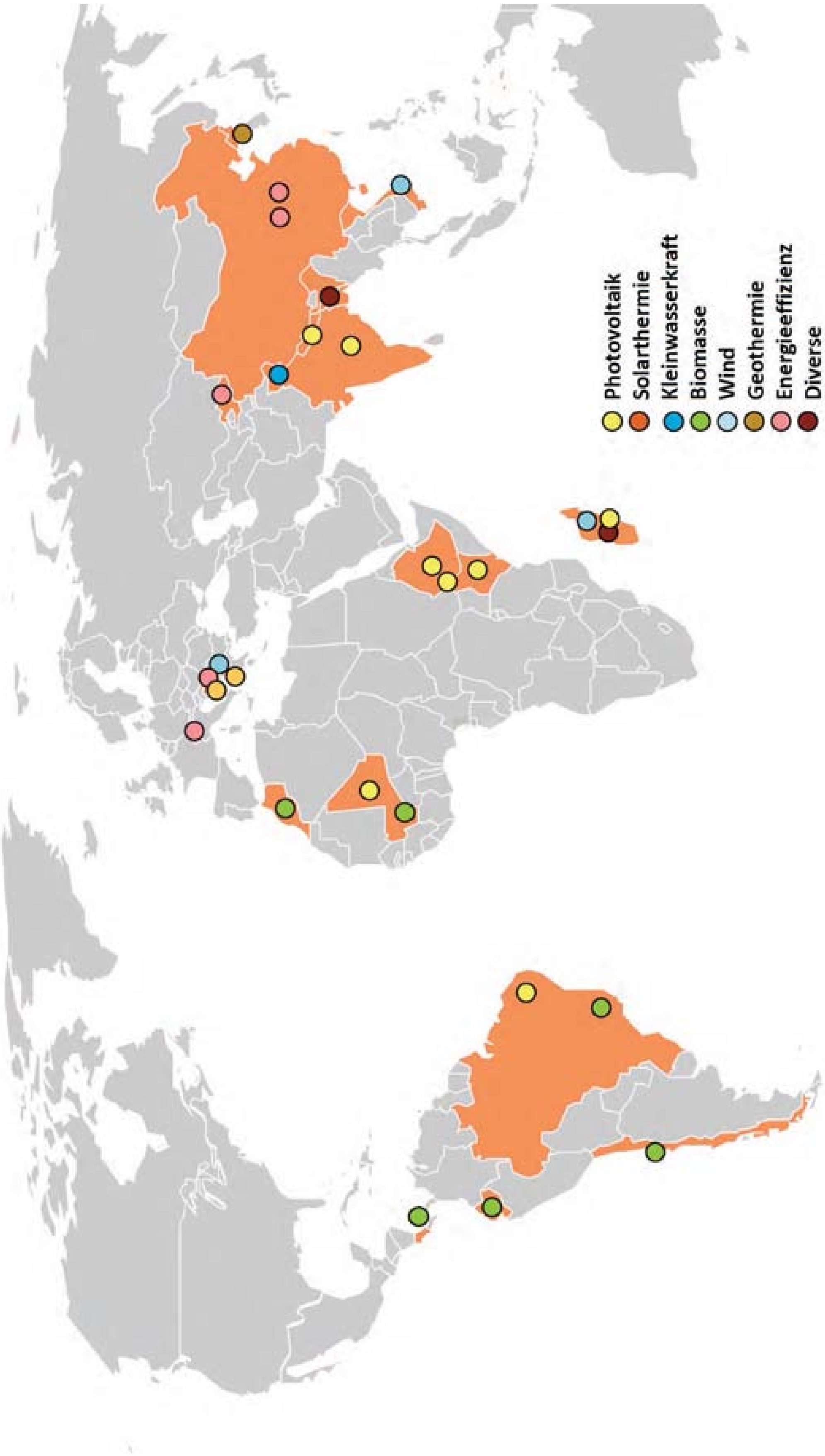


Figur : c a n a ni a

Seit dem Beginn der REPIC Phase II im Jahr 2008 erfolgten bis Ende 2010 total 134 Anfragen. Insgesamt erfolgte bei 28 Projekten ein finanzieller Beitrag durch die REPIC-Plattform. Figur 2 gibt einen Überblick über die Verteilung der unterstützten Projekte.



Figur : t iun in R P P as unt st t t n P t nac c n i ic n



Figur : t iun a in R P P as unt st t t n P t nac R i n un c n i - ic P t

Stand der be illigten REPIC Projekte

Stand der be illigten Projekte der REPIC Phase I

Die REPIC Phase I wurde zwar hinsichtlich Projektverpflichtungen per Ende 2007 abgeschlossen und entsprechend keine neuen Projekte mehr unterstützt, verschiedene Projekte sind aber noch in der Abschlussphase oder wurden im Laufe des Jahres 2010 abgeschlossen. Deshalb wird hier noch eine Projektübersicht der REPIC Phase I aufgeführt.

Im Jahr 2010 konnte folgendes Projekt mit Bezug zur Photovoltaik abgeschlossen werden:

- Helvetas, Laos: Einkommensgenerierung durch nachhaltige Energie-Projekte im ländlichen Raum (RISE)

Das IEA PVPS Projekt „Photovoltaic Services for Developing Countries", welches bereits unter REPIC I bewilligt und gestartet wurde, wird formell in der REPIC Phase II weitergeführt und wird entsprechend unter den Projekten der Phase II genauer beschrieben.

Auf der folgenden Seite wird das aktuelle technische Projekt mit Bezug auf Photovoltaik beschrieben.

Communit Based Rural Income through Sustainable Energ Project RISE in Laos	
Projektart	Infrastrukturorientiertes Projekt
Sch ei er Partner	Helvetas, Zürich, www.helvetas.org, Marcus Büzberger
Technologie	Kleinwasserkraft, Photovoltaik
Beschreibung	Laos gehört zu den ärmsten Ländern Südostasiens. Die Bevölkerung in abgelegenen Gebieten wünscht sich Zugang zu Elektrizität. Bis jedoch das nationale Stromnetz diese Gebiete erreicht, könnte es 20 Jahre oder noch länger dauern. In rund 40 Dörfern gibt es Kleinwasserkraftwerke, deren Turbinen aber nicht mehr in Betrieb sind. Dies vor allem auf Grund von Mängeln bei Design, Material und Wartung. Helvetas geht mit der laotischen Firma Sunlabob eine innovative private-public partnership ein, um im Rahmen eines Pilotprojekts die hybriden Stromnetze in drei ausgewählten Dörfern wieder voll funktionsfähig zu machen. Diese Stromnetze sollen Haushalte und Kleinunternehmen entlang der landwirtschaftlichen Wertschöpfungskette mit erneuerbarer Energie versorgen. Ein besonderes Augenmerk gilt der Ausbildung auf kommunaler Ebene, um eine gute Bewirtschaftung und Wartung der dörflichen Stromnetze zu gewährleisten.
Land	Laos
Sch ei er Beitrag	Der Schweizer Beitrag unterstützt den nachhaltigen Ansatz des Projekts. Konkret sollen innovative Finanzierungsmodelle und Vernetzungsstrukturen insbesondere zwischen dem privaten Stromverkäufer und dem öffentlichen Sektor (hier die Gemeinden) entwickelt und umgesetzt werden. Bewährte Modelle für solche nachhaltige institutionelle Strukturen gelten als Vorbedingung für eine allfällige Fortsetzung des Projektes nach der Pilotphase.
Projektstatus	Abgeschlossen – Nach dem bereits im 2007 elektrifizierten Pilotdorf Ban Nam Kha konnten im 2010 weitere Pilotdörfer elektrifiziert werden. Dabei wurden Diskussionen mit dem nationalen Stromnetzbetreiber geführt. Weiter fokussierten sich die Aktivitäten auf die Entwicklung von lokalen Wertschöpfungsketten, unter Einbezug der neu vorhandenen Elektrizität. Neben Viehwirtschaft und biologischer Gemüseproduktion stehen vor allem die Bereiche Tourismus, Kunsthandwerk und Fischzucht im Vordergrund. Es wurden entsprechend Marktanalysen durchgeführt und Schulungen für die Bevölkerung angeboten. www.riselaos.org  © Helvetas
Wirkungen	Das Projekt RISE wird in einer 2. Phase weitergeführt, dabei wird einerseits vor allem die Entwicklung der identifizierten lokalen Wertschöpfungsketten weitergeführt und das Projekt andererseits auf neue Gebiete ausgeweitet.
Dokumentation	Schlussbericht „Rural Income through Sustainable Energy (RISE)“ [8] zu beziehen bei NET AG, Helvetas oder www.repic.ch.

Stand der be illigten Projekte der REPIC Phase II

Die Projektübersicht nach Status für die Phase II für 2010 ergibt folgende Übersicht. Zudem wird das IEA PVPS Projekt „Photovoltaic Services for Developing Countries“, welches bereits unter REPIC I bewilligt und gestartet wurde, formell in der REPIC Phase II weitergeführt. Von diesen Projekten haben 8 einen Bezug zur Photovoltaik.

Im Jahr 2010 konnten die folgenden REPIC II – Projekte mit Bezug auf Photovoltaik erfolgreich abgeschlossen werden:

- Stiftung Solarenergie, Äthiopien: Licht für Bildung und Entwicklung – Anschubfinanzierung für fünf lokale Solar-Center
- Solafrica.ch, Kenia: Solarenergie in Afrika – Start in Kenya mit LED-Lampen
- SUPSI-ISAAC, Nepal: Ausbau der netzgekoppelten Photovoltaik
- Wirz Solar, Mali: Pilotprojekt zur Einführung von solarbetriebenen Wasserpumpen zur Bewässerung von Flächen zur Nahrungsmittelproduktion durch Kleinbauern/-bäuerinnen

In der Abschlussphase befinden sich Ende 2010 keine Projekte mit Bezug zur Photovoltaik.

Folgende REPIC II - Projekte mit Bezug zur Photovoltaik waren 2010 in der Ausführungsphase:

- entec, International: Schweizer Beitrag im IEA PVPS-Projekt Task 9 Photovoltaic Services for Developing Countries (PVSDC)
- Muntwyler Engineering, Indien: Demonstrationsprojekt Solare Elektrofahrzeuge im öffentlichen Verkehr in Clean Air Island
- Ecogeo, Brasilien: Solare Trinkwasserversorgung

Für folgende Projektgesuche mit Bezug zur Photovoltaik wurde 2010 die Unterstützung durch REPIC beschlossen:

- Sahay Solar Solutions, Äthiopien: Aufbau eines Solar Kompetenz-Zentrums, Arbaminch Universität
- Nouvelle Planète, Madagaskar: Bau einer Photovoltaikanlage und eines dörflichen Stromnetzes zur Speisung neuer Batterie- und Akkuladestationen in der ländlichen Gemeinde Ankaranana

Folgendes Projekt mit Bezug zur Photovoltaik muss noch formalisiert werden:

- Tritec, Madagaskar: Elektrifizierung der letzten Meile – Stromversorgung mittels Solarenergie in abgelegenen Gebieten in Madagaskar

Auf den folgenden Seiten werden die aktuellen technischen Projekte mit Bezug auf Photovoltaik im Einzelnen beschrieben. (Die weiteren Projekte können im REPIC-Jahresbericht [13] nachgelesen werden)

Sch ei er Beitrag im IEA P PS-Projekt Task 9 Photovoltaic Services for Developing Countries P SDC	
Projektart	Internationales Projekt im Rahmen der IEA-Zusammenarbeit
Sch ei er Partner	entec AG, St. Gallen; www.entec.ch, Alex Arter
Technologie	Photovoltaik
Beschreibung	Gestützt auf die umfangreichen weltweiten Erfahrungen mit Photovoltaik Anlagen in Entwicklungsländern, strebt dieses Projekt die Erhöhung von erfolgreich und nachhaltig betriebenen Anlagen dieser Art für unterschiedliche Zwecke an. Die internationale Expertengruppe umfasst auf diesem Gebiet eine breite Projekterfahrung und konzentriert ihre Arbeit insbesondere auf die nichttechnischen Aspekte dieser Anwendungen. Durch den Status eines internationalen Netzwerkprojektes ist die Expertengruppe in permanentem Kontakt mit zahlreichen internationalen Entwicklungsorganisationen.
Land	Internationales Projekt
Sch ei er Beitrag	Die Schweizer Erfahrung in der internationalen Zusammenarbeit und das bei entec verfügbare Know-how aus einem verwandten Gebiet (Kleinwasserkraft) stellen wesentliche Beiträge zu diesem Projekt dar, insbesondere auch in Bezug auf die Übertragbarkeit der Resultate auf andere Technologien.
Projektstatus	Laufend – Die PVSDC Expertengruppe hat sich im Jahr 2010 weiterhin auf die Themen Photovoltaik und Wasserversorgung sowie Photovoltaik Hybridanlagen fokussiert und an entsprechenden Veranstaltungen teilgenommen. Angesichts der zunehmenden Bedeutung rund um das Thema Wasserversorgung (Trinkwasser und Bewässerung) setzt PVSDC hier die grösste Priorität der laufenden und künftigen Aktivitäten. Im 2010 wurden Kooperationsgespräche mit SKAT (Swiss Resource Center and Consultancies for Development) geführt. Die PVSDC Expertengruppe nahm im Juni 2010 an der Intersolar in München teil. Ein Entwurf des Positionspapieres zu Wasserversorgungsprojekten in Entwicklungsländern lag Ende 2010 vor.  © gtz
Dokumentation	Publikationen IEA PVPS Task 9, siehe http://www.iea-pvps.org/tasks/task9.htm

Licht für Bildung und Ent icklung Anschubfinan ierung für 5 lokale Solar-Center in thiopien	
Projektart	Aufbau von Marktstrukturen
Sch ei er Partner	Stiftung Solarenergie, Zürich, www.stiftung-solarenergie.ch, Harald Schützeichel
Technologie	Photovoltaik
Beschreibung	Die wenigsten Bauernhütten (Tukuls) in Äthiopien befinden sich im Versorgungsbereich des öffentlichen Stromnetzes. In der Regel geschieht die Beleuchtung durch Petroleumlampen. Dies produziert eine Menge CO_2 und zudem sind das schwache Licht und die Russemissionen gesundheitsschädigend. Die Stiftung Solarenergie hat seit 2005 erfolgreich Modellprojekte für solarbetriebene Beleuchtung durchgeführt und eine professionellen Ausbildungsstätte für Solartechniker aufgebaut. Nun soll mit dem Aufbau eines landesweiten Netzwerks von kleinen Solar-Handwerksbetrieben, genannt Solar-Center, begonnen werden, die in einer Art Franchisesystem mit der äthiopischen Stiftung Solarenergie verbunden sind. In den Solar-Centern werden Solarsysteme teils gegen Barzahlung, teils auf Ratenzahlung vertrieben. Alle Solar-Center sollen in den ersten sechs Monaten nach Gründung eine Anschubfinanzierung als Starthilfe erhalten, anschliessend jedoch selbsttragend funktionieren. Das von REPIC unterstützte Projekt umfasst fünf solche neue Solar-Center.
Land	Äthiopien
Sch ei er Beitrag	Der Schweizer Partner besitzt langjährige Erfahrung mit der Planung und Umsetzung von solaren Elektrifizierungsprojekten in Äthiopien und ein entsprechendes Netzwerk von lokalen Partnern.
Projektstatus	Abgeschlossen – Bis April 2010 konnten vier Solar-Center eröffnet werden. Zudem konnten in der "International Solar Energy School" in Rema im April 2009 und im April 2010 insgesamt 39 Techniker in einem je 6-monatigen Kurs ausgebildet werden. Die speziell für die Stiftung Solarenergie entwickelten Solar Home Systems werden in unterschiedlicher Grösse angeboten. Für die grösseren Solar-Home-Systems gibt es ein spezielles Finanzierungsangebot mit Kleinkrediten, den "Revolving Fund". Sämtliche verkauften Solar-Home-Systems werden in einem GPS - System erfasst und können so jederzeit einfach wiedergefunden werden.  © Stiftung Solarenergie
Wirkung	Der Ausbau des Netzwerkes der Solar-Center wurde und wird weitergeführt.
Dokumentation	Schlussbericht „Licht für Bildung und Entwicklung“ [9] zu beziehen bei NET AG, Stiftung Solarenergie oder www.repic.ch.

Solarenergie in Afrika Start in en a mit LED-Lampen	
Projektart	Pilotprojekt
Sch ei er Partner	Solafrica.ch
Technologie	Photovoltaik
Beschreibung	In Kenia sind über 70% der Bevölkerung nicht ans Stromnetz angeschlossen und sind deshalb für die Lichterzeugung oft auf Biomasse, Kerosin oder Einweg-Batterien angewiesen. Einzelne Solarlampen sind bereits erhältlich, diese sind jedoch oft zu teuer, von schlechter Qualität oder nicht auf die kenianischen Bedürfnisse abgestimmt. Die Projektpartner haben deshalb eine Solarlampe designt, welche sowohl als Taschenlampe (für Toilettengänge, Wächter) oder aufgehängt auch zur Raumbeleuchtung verwendet werden kann. Die Lampe mit LED-Leuchtkörpern, integrierter Solarzelle und aufladbaren Batterien ist einfach aufgebaut und leicht reparierbar. In einer ersten Phase des Projekts soll die bereits in verschiedenen Ländern getestete Lampe einen vertieften Markttest in Kenia durchlaufen, wobei technische, soziale und wirtschaftliche Aspekte betrachtet werden. Die Lampe wird lokal vom kenianischen Projektpartner, dem Kibera Community Youth Programm, produziert und vorerst hauptsächlich in Kibera, einem der grössten Slums Afrikas, vertrieben. Ein Teil der Produktion soll jedoch auch in der Schweiz, insbesondere im Bildungsmarkt, verkauft werden.
Land	Kenia
Sch ei er Beitrag	Die Schweizer Projektpartnerschaft besteht aus Greenpeace und dem Solarunternehmen Megasol, welche beide grosse Erfahrung im Solarbereich mitbringen. Die gemeinsam zu gründende „Social Solar Enterprise“ wird das Projekt mit Expertise unterstützen und gleichzeitig den Schweizer Markt für die kenianischen Solarprodukte aufbauen.
Projektstatus	Abgeschlossen – 28 Jugendliche des Kibera Community Youth Programme wurden als Solartechniker ausgebildet. 4 davon wurden fest für das Projekt eingestellt. Die Ergebnisse des Markttestes sind im Allgemeinen positiv im technischen, sozialen sowie wirtschaftlichen Bereich. Insgesamt 300 LED Solarlampen wurden in Kenia produziert und vor Ort sowie in der Schweiz verkauft. Weiter wurden zwei neue Produkte entwickelt; ein aus der modifizierten Solarlampe entstandenes solares mobiles Telefon und eine Solarbox-Heimbeleuchtung. Der im Rahmen des Pilotprojekts erstellte Businessplan muss nun an die zukünftigen Aktivitäten des Vereins anpasst werden.  © Solafrica.ch
Wirkungen	Das Projekt hat in der Schweiz den „Prix Nature“ Award 2010 in der Kategorie „Generation Zukunft“ gewonnen. Die Auszeichnung erweckte grosses Medien-Interesse.
Dokumentation	Schlussbericht „Production of Solar LED Lamps in Kenya [10], zu beziehen bei NET AG, Solafrica.ch oder www.repic.ch.

Ausbau der net gekoppelten Photovoltaik P in Nepal: achbarkeitsstudie und Ausbildungsprogramm	
Projektart	Machbarkeitsstudie, Ausbildung
Sch ei er Partner	SUPSI – ISAAC, Canobbio, www.supsi.ch, Daniel Pittet
Technologie	Photovoltaik
Beschreibung	Die klimatischen Bedingungen in Nepal sind ideal für die Nutzung der Sonnenenergie. Entsprechend werden in abgelegenen Regionen immer mehr Photovoltaik Inselanlagen installiert. Netzgekoppelte PV-Anlagen jedoch werden noch nicht als wirkliche Alternative angesehen, dies obwohl die nepalesische Stromversorgung unter Produktionsengpässen leidet. Die Ausnutzung des Potenzials für netzgekoppelte PV-Anlagen würde die Stromversorgung diversifizieren und unabhängiger, ökologischer und wirtschaftlicher machen. Im Rahmen dieses Projekts soll deshalb eine Machbarkeitsstudie durchgeführt werden, welche das tatsächliche Entwicklungspotenzial von netzgekoppelten PV-Systemen beziffert. Die Studie wird in enger Zusammenarbeit mit lokalen Partnern ausgeführt, sodass gleichzeitig institutionelle und technische Barrieren beseitigt und die lokalen Partner durch Know-How Transfer und gezielte Ausbildung gestärkt werden können.
Land	Nepal
Sch ei er Beitrag	Der Schweizer Partner bringt grosse Erfahrung im Bereich netzgekoppelte PV-Systeme und Ausbildung mit.
Projektstatus	Abgeschlossen – Die sehr günstigen Klimabedingungen für Photovoltaik in Nepal wurden bestätigt. Der Markt für PV-Module ist zurzeit immer noch sehr marginal. Fachkenntnisse für netzkoppelte PV fehlen im Land. Meinungen zur Technologie von Stakeholdern, potentiellen Verbrauchern und des Industriesektors wurden mittels Interviews und Workshops erforscht. Die Ergebnisse zeigten eine positive Haltung gegenüber der Technologie, vor allem als Alternative gegen Lastabschaltung. Die Anfangskosten für PV-Systeme sind relativ teuer im Vergleich z. B zu den „inverter-Batterie“-Systemen, die Kosten für die Energiezufuhr sind jedoch billiger. Um den Ausbau der netzgekoppelten Photovoltaik zu ermöglichen, müssen nationale Gesetze angepasst werden. Die Standards und Normen von Komponenten müssen ebenfalls adaptiert werden. Das Potenzial der Technologie im Land sollten mehr verbreitet werden.  © SUPSI-ISAAC, Daniel Pittet
Wirkungen	Es hat im Laufe der Machbarkeitsstudie ein erheblicher Wissens- und Erfahrungstransfer im Bereich netzgekoppelte Photovoltaik zu nepalesischen Institutionen stattgefunden.
Dokumentation	Schlussbericht „ Development of PV grid-connected plants in Nepal“ [11], zu beziehen bei NET AG, SUPSI-ISAAC oder www.repic.ch

Pilotprojekt ur Einführung von Solarpumpen ur Nahrungsmittelproduktion durch leinbauern/-b uerinnen in ali	
Projektart	Pilotprojekt
Sch ei er Partner	WirzSolar GmbH, Sissach, Fredy Wirz
Technologie	Photovoltaik
Beschreibung	Die Nahrungsmittelkrise mit steigenden Nahrungsmittelpreisen und die Abhängigkeit Malis von Nahrungsmittelimporten erfordern für die Ernährungssicherheit eine Ausweitung der nationalen Nahrungsmittelproduktion. Der Bewässerungsfeldbau nimmt in Mali entsprechend zu. Das Wasser dafür wird momentan hauptsächlich mit fossilen und immer teurer werdenden Treibstoffen gepumpt. Solarpumpen, kombiniert mit Tröpfchenbewässerung, könnten hier zu einer Produktionskostensenkung und Einkommensförderung beitragen. In einem Pilotprojekt soll in Zusammenarbeit mit lokalen Partnern der Einsatz von 50 Solarpumpen für den Gemüseanbau von Kleinbauern und –bäuerinnen zeigen, ob der Aufbau eines eigenständigen Marktes für Solarpumpen möglich ist. Dabei wird ein Mikrofinanzsystem eingesetzt, um die hohen Investitionskosten tragbar zu machen. REPIC ko-finanziert die erste Phase mit 10 Solarpumpen, welche für die Demonstrations- und Promotionsarbeit mit Kleinbauerngenossenschaften und Produzentenorganisationen verwendet werden.
Land	Mali
Sch ei er Beitrag	Der Schweizer Partner unterstützt den lokalen Projektpartner mit seiner langjährigen Erfahrung mit dem Einsatz von Solarpumpen in Mali.
Projektstatus	Abgeschlossen – Bis im März 2010 konnten 15 meist mobile 300W Solarpumpensysteme installiert und die BetreiberInnen für Betrieb und Unterhalt ausgebildet werden. Die Anlagen stehen in den Regionen Koulikoro, Ségou, Mopti und Sikasso. Von den 15 Anlagen dienen 12 zur landwirtschaftlichen Produktion (Gemüseanbau) und 3 zur Trinkwasserversorgung. Technische und organisatorische Abklärungen für weitere 30 Anlagen wurden gemacht. Der Ausbau der regionalen Servicestellen musste noch zurückgestellt werden, da pro Region zuerst mehr Systeme funktionieren sollen. Die Erstellung eines subregionalen technischen und sozio-ökonomischen Referenzdokuments für die Kombination Solarpumpen – Tropfenbewässerung im Gemüseanbau in Mali, Elfenbeinküste, Burkina Faso, Guinée ist vorgesehen.  © Wirz
Wirkungen	Auf Anfrage bekannter Institutionen in Burkina Faso, der Elfenbeinküste und Guinée soll das Pilotprojekt in Bälde auf diese Länder mit 3 Demoanlagen ausgedehnt werden.
Dokumentation	Schlussbericht „ Pilotprojekt zur Einführung von Solarpumpen zur Nahrungsmittelproduktion durch Kleinbauern/-bäuerinnen in Mali“ [12], zu beziehen bei NET AG, WirzSolar oder www.repic.ch

Demonstrationsprojekt Solare Elektrofahr euge im ffentlichen erkehr in Clean Air Island, umbai	
Projektart	Pilotprojekt
Sch ei er Partner	Engineering Office Muntwyler, Zollikofen, www.solarcenter.ch, Urs Muntwyler
Technologie	Photovoltaik
Beschreibung	Die indische Partnerorganisation Clean Air Island ist seit mehreren Jahren bestrebt, die Lebensqualität im Stadtzentrum Mumbais zu verbessern. Ihre Aktivitäten stützen sich dabei hauptsächlich auf die drei Aktionsbereiche Begrünung von Strassen und Parks, Kompostierung von organischen Abfällen und Einsatz von Elektrofahrzeugen. Im Rahmen dieses Demonstrationsprojekt sollen nun zum ersten Mal Elektrofahrzeuge im öffentlichen Verkehr zum Einsatz kommen und gleichzeitig sollen die Batterien der Elektrofahrzeuge zum ersten Mal mit Solarstrom gespiesen werden. Der elektrische Bus (30 Personen) und das elektrische Sammeltaxi (10 Personen) werden auf Ringrouten zwischen zwei Bahnhöfen und dem Geschäftsviertel Nariman Point verkehren und damit einen Teil der tausenden von Pendlern in diesem Gebiet transportieren. Beim Busdepot, auf dessen Dach die Photovoltaikanlage installiert wird, werden die Fahrzeuge jeweils ihre leeren Batterien mit Hilfe eines Schnelladesystems aufladen oder gegen eine geladene Batterie austauschen können.
Land	Indien
Sch ei er Beitrag	Der Schweizer Experte bringt mit seinen umfassenden Erfahrungen sowohl im Bereich der Solarenergie als auch im Bereich der Elektrofahrzeuge eine optimale Kombination von Kenntnissen mit, um dieses Projekt zu unterstützen. Weitere Schweizer Technologiepartner werden nach Bedarf einbezogen.
Projektstatus	Laufend – Die technischen Abklärungen werden weitergeführt. Evaluationen der Batterietechnologien wurden extern beauftragt, aber es wurde noch kein definitiver Entscheid gefasst. Technische Bewertungen und Kalkulationen von Solarzellengruppen wurden durchgeführt. Eine Regierungsfinanzierung für die Ausbildung künftiger Taxifahrer von Elektrofahrzeugen könnte verfügbar sein.  © Clean Air Island

Solare Trink asseraufbereitung in Brasilien	
Projektart	Machbarkeitsstudie
Sch ei er Partner	Ecogeo GmbH, Bern, Ernesto Moeri
Technologie	Photovoltaik
Beschreibung	Die Versorgung mit sauberem Wasser ist ein elementares Grundbedürfnis, das aber in vielen Gegenden Brasiliens, insbesondere im trockenen Nordosten und im Amazonasgebiet nicht befriedigt wird. Die brasilianische Regierungs-Initiative Água Doce hat die bestehenden Defizite bisher nicht beseitigen können, viele Brunnen wurden wegen Versalzung stillgelegt, weitere wegen Wartungsproblemen. Die fehlende funktionierende Wasseraufbereitung führt zu Seuchen, Verarmung und Landflucht. Das langfristige Ziel des Vorhabens besteht deshalb darin, mit moderner, wartungsarmer und energieautarker Technologie Abhilfe für die Probleme zu schaffen. Dabei kommen solarbetriebene Entsalzungs- und Aufbereitungsanlagen mit einem Umkehr-Osmose-System aus Schweizer Produktion zum Einsatz. Als erster Schritt soll im Projekt die Technologie mit Hilfe einer Demonstrationsanlage ausgewählten Gemeinden in den betroffenen Gebieten nahe gebracht werden und in Zusammenarbeit mit diesen Gemeinden Muster-Problemlösungen erarbeitet werden. Begleitet werden diese Aktivitäten von Gesprächen mit Regierungsstellen und Finanzierungspartnern.
Land	Brasilien
Sch ei er Beitrag	Schweizer Partner steuern zum einen die technische Lösung für das Projekt bei, zum anderen wird das Projekt von einem brasilianischen-schweizerischen Beratungsunternehmen umgesetzt.
Projektstatus	Laufend – Die Ausrüstungen sind im August in Brasilien eingetroffen. Die 3 Module des Systems (Vor-Filtration, Umkehrosmose, Solarzentrum) wurden aufgebaut und zusammengeschaltet. Am ersten Tag konnte das Wasser während 3 Stunden aufbereitet werden. Nach der Montage des Solarpanels wurde die volle Kapazität von 700 l/Std Trinkwasser erreicht. Das System wurde erfolgreich 3 Wochen lang ohne Störfälle getestet. Eine Komponente für die Datenübertragung via GSM an Trunz Water Systems in der Schweiz wurde installiert. Das aufbereitete Trinkwasser wird durch die lokale Bevölkerung getrunken. Das Projekt wurde in vielen regionalen Zeitungen verbreitet.  © TRUNZ

Solarkompeten entrum an der Arba inch Universit t in thiopien	
Projektart	Ausbildung und Qualitätssicherung / Finanzierungsmodell
Sch ei er Partner	Sahay Solar Solutions GmbH,Winterthur, www.sahay-solar.com; Max Pohl ISAAC-SUPSI, Canobbio, www.supsi.ch, Roman Rudel
Technologie	Photovoltaik
Beschreibung	Der Aufbau von selbsttragenden Ausbildungs- und Marktstrukturen im Bereich Solarenergie ist das gemeinsame Ziel der Arba Minch Universität (AMU) in Äthiopien, der Fachhochschule der italienischen Schweiz (SUPSI) in Lugano, sowie der Sahay Solar Solutions, einer gemeinnützigen GmbH aus Winterthur. Der erste Schritt auf diesem Weg soll die Gründung eines äthiopischen Kompetenzzentrums für Solartechnik innerhalb der AMU sein. Das Kompetenzzentrum umfasst sowohl ein entsprechend ausgerüstetes Solarlabor für Forschungs- und Schulungszwecke als auch die Etablierung eines Lehrstuhls für erneuerbare Energien für die fachliche Ausbildung von Studenten und Technikern. Parallel zum Kompetenzzentrum soll ein soziales Unternehmenskonzept zur Realisierung von Solarelektrifizierungsprojekten entwickelt werden, um sukzessive zukunftsfähige Arbeitsplätze für die ausgebildeten Fachkräfte zu generieren und eine nachhaltige Entwicklung der Initiative unabhängig von Drittmitteln zu ermöglichen.
Land	Äthiopien
Sch ei er Beitrag	Mit der Schweizer Universität und der schweizerischen Sozialunternehmung steht den äthiopischen Partnern sowohl im technischen als auch im unternehmerischen Bereich umfassendes Know-How zur Verfügung.
Projektstatus	Laufend – Am Kick-off Workshop in Arbaminch konnte ein neuer Kooperationsvertrag bis 2012 unterzeichnet werden. Drei feste Positionen innerhalb der AMU zur Sicherstellung einer nachhaltigen Projektentwicklung wurden geschaffen. Zur Ausschreibung „Solarprojekt Stipendium für Studenten“ wurden Curricula eingereicht und analysiert. Im Herbst wurde der Sahay Solarverein Afrika e.V. in Deutschland gegründet mit dem Zweck, die Initiative am Ort zu unterstützen. Dieser Verein wird in Äthiopien registriert, um eine lokale NGO vor Ort zu etablieren. Im Hinblick darauf konnten wichtige Ansprechpartner identifiziert werden. Während der Vorbereitungs- und Monitoring-Reise zur Arbaminch University im Winter wurde die von der lokalen Verwaltung und der Universität ausgewählte Dorfschule besucht, die das Erste von und mit Studenten realisierte Solarprojekt darstellen wird.  © Sahay solution

Bau einer Photovoltaikanlage und eines d rflichen Stromnet es ur Speisung neuer Batterie- und Akkuladestationen in der l ndlichen Gemeinde Ankaranana in adagaskar	
Projektart	Infrastrukturorientiertes Projekt
Sch ei er Partner	Nouvelle Planète, Lausanne, www.nouvelle-planète.ch, Philippe Randin Mizara, Corseaux Philippe Meister
Technologie	Photovoltaik
Beschreibung	Mit dem Bau einer Photovoltaikanlage und einem Stromnetz in der madagassischen Gemeinde Ankaranana sollen neue Batterie- und Akkuladestationen gespeist werden. Durch diese Ladestationen können Einwegbatterien durch aufladbare ersetzt werden. Des Weiteren soll das Stromnetz ebenfalls der Beleuchtung öffentlicher Plätze und des Spitals dienen. Dadurch werden die Lebensbedingungen in der Gemeinde verbessert und so soll wiederum der Landflucht vorgebeugt werden. Das Projekt soll ebenfalls die Machbarkeit eines autonomen Stromnetzes in einer abgelegenen, ländlichen Region zeigen
Land	Madagaskar
Sch ei er Beitrag	Mit Nouvelle Planète wurde das Projekt von einem Schweizer Unternehmen initiiert, welches grosse Erfahrung in Projekten gegen Landflucht und Umweltschutz in armen Ländern hat. Das Projekt wird von Nouvelle Planète's Partnergruppe Mizara begleitet. Das Spezialgebiet des Projektleiters liegt im Bereich aufladbare Batterien, er war bereits in Madagaskar tätig und kennt die Tätigkeiten von Nouvelle Planète sehr gut.
Projektstatus	Laufend – Die ersten Teile der schlüsselfertigen Photovoltaik-Anlage wurden gekauft und im März fertig in der Schweiz aufgebaut. Gleichzeitig wurde in Ankaranana die Stiftung Fahazavanana für die Elektrizitätsverwaltung gegründet. Die Anlage wurde mit dem Schiff nach Madagaskar verschickt und erreichte das Land in Oktober. Ein unterirdisches elektrisches Netz wurde von den Dorfbewohnern gebohrt. Ende Oktober konnte die Elektrizität über das neue dörfliche Stromnetz verteilt werden. Die ersten öffentlichen und privaten Infrastrukturen sind an das Stromnetz angeschlossen. Eine Batterie- und Akkuladestation ist schon in Betrieb. Die Photovoltaik-Anlage wurde von ADER amtlich anerkannt.  © Nouvelle Planète

Beurteilung 2010 und Ausblick 2011

Die Plattform REPIC ist unterdessen gut etabliert und spielt im schweizerischen Kontext eine wichtige Rolle. Im Zuge der wachsenden Bedeutung der Themen erneuerbare Energien und Energieeffizienz in der internationalen Zusammenarbeit ist sie zu einer relevanten Koordinationsplattform des Bundes geworden, welche von allen beteiligten Bundesämtern rege genutzt wird.

2010 stand für REPIC im Zeichen der Wirkungsevaluation, der Konzepterarbeitung der REPIC Phase III sowie des Abschlusses der REPIC Phase II. Die Wirkungsevaluation zu den ersten beiden Phasen von REPIC, welche sich auf die politischen, ökonomischen, sozialen und umweltrelevanten Wirkungen von REPIC fokussierte, zeigte erfreuliche Resultate.

Bei der Projektförderung zeigt sich die wachsende Bedeutung der REPIC-Themen einerseits in den weiterhin steigenden Projektantragszahlen, andererseits in den sehr guten Besucherzahlen der von REPIC organisierten Veranstaltungen.

Auch 2010 konnten sich einige der früher durch REPIC unterstützten Projekte positiv weiterentwickeln:

- Das Projekt Topten China wurde bereits nach der ersten Phase des REPIC-Projekts durch das SECO weiter unterstützt.
- Verschiedene in der Frühphase durch REPIC unterstützte Projekte befinden sich auf dem Weg zur Konkretisierung bzw. haben Folgeaktivitäten ausgelöst.

Für 2011 steht der Beginn der REPIC Phase III im Vordergrund mit Weiterführung und Anpassung der operativen Abläufe und der Umsetzung einiger Änderungen. Dazu gehört auch die verstärkte Vernetzung zu anderen Initiativen, Finanzierungsgebern und Akteuren im Bereich CO2-Zertifikate-Handel.

Im Kommunikationsbereich sollen weitere themenspezifische Veranstaltungen organisiert werden. Der nächste Workshop ist zu Biomasse und der Nutzung von Kaffeepulpe vorgesehen.

Referen en

[1] *EPIC- eitfaden*

[2] *Interface, ir ungsevaluation Plattform f r erneuerbare Energien und Energieeffi ien in der internationalen usammenarbeit EPIC*

[3] *EPIC- on ept Phase III*

[4] *EPIC ogical Frame or pproach F , EPIC Phase III*

[5] *EPIC or shop iomasse, pril* (Vorträge)

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[13] *EPIC ahresbericht*

Alle Publikationen sind bei *a n i & c n i* oder unter http://www.repic.ch zu beziehen.

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IEA-PVPS Task 12: Swiss activities in 2010

ÖKOBILANZEN VON SOLARSTROM UND VON CHEMIKALIEN IN DER PHOTOVOLTAIK-INDUSTRIE

Annual Report 2010

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Project- / Contract Number	SI/500052 / SI/500052-02
Duration of the Project (from – to)	2008 - 2011
Date	01.12.2010

ABSTRACT

Life cycle assessment (LCA) is an environmental management tool for analysing, comparing and improving the environmental impacts of products or technologies. The ecoinvent database provides life cycle inventory data for currently more than 4000 unit processes. Amongst other datasets, photovoltaic life cycle inventory data are provided.

Within the Swiss contribution to the *P P tas* , *su tas* , new datasets of four chemicals used in the photovoltaic industry are established. These are polyvinyl butyral foil (PVB), ethylene-tetrafluorethylene (ETFE), nitrogen trifluoride (NF_3). The dataset of silane is updated.

Furthermore, 26 datasets of national photovoltaic electricity mixes are updated applying national and international statistics in order to include real open ground installations, real large photovoltaic power plants and theoretically modelled 3kWp photovoltaic power plants.

The update leads to a small reduction of less than 5 % of the carbon footprint of most national photovoltaic electricity mixes. However, exceptions are the two world's most important photovoltaic markets Spain and Germany, where a carbon footprint reduction of 32 % and 14 % is achieved due to the installation of efficient large photovoltaic power plants.

The carbon footprint of the Swiss photovoltaic electricity mix amounts to 72 g CO_2-eq. / kWh, the one of the German photovoltaic electricity mix to 75 g CO_2-eq. / kWh, and the one of the Spanish electricity mix to 38 g CO_2-eq. / kWh.

Einleitung / Projekt iele

Ökobilanzen sind ein Umweltmanagement-Werkzeug, um die Umweltauswirkungen von Produkten und Technologien zu analysieren, zu vergleichen und zu verbessern. Eine wesentliche Grundlage für Ökobilanzen sind Sachbilanzdaten, welche die Energie- und Massenflüsse über die verschiedenen Lebensphasen des zu untersuchenden Objektes beschreiben. Die ecoinvent Datenbank stellt zurzeit solche Sachbilanzdaten für mehr als 4'000 Einheitsprozesse bereit [1]. Diese Daten werden in allen bedeutenden Ökobilanz-Softwareprodukten angeboten und von über 2'500 Nutzern in über 40 Ländern weltweit verwendet.

Die letzte Aktualisierung der Photovoltaik(PV)-Sachbilanzdaten im Rahmen der ecoinvent Projekte wurde im Frühjahr 2009 durchgeführt [2-4]. Die Sachbilanzdaten im ecoinvent Datenbestand v2.2 beschreiben die Situation der amerikanischen und europäischen PV-Industrie sowie die Anwendung von 3 kWp PV-Anlagen auf Gebäuden in der Schweiz und in Europa im Jahr 2005.

Da sich der PV-Sektor rasch weiterentwickelt und signifikante Verbesserungen verschiedener PV-Systeme erreicht wurden, ist es von Interesse, diese Änderungen auch in den Sachbilanzdaten abzubilden. Zudem werden im aktuellen ecoinvent Datenbestand keine Sachbilanzdaten zu Grossanlagen und Freiflächenanlagen bereitgestellt.

Im Rahmen der *P P tas , su tas* werden verschiedene PV-Ökobilanz-Projekte durchgeführt. Die Schweizer Projektpartner stellten im Jahr 2009 neue Datensätze zu Freiflächen- und Photovoltaik-Grossanlagen für eine Implementierung in der ecoinvent Datenbank bereit [5]. Im Jahr 2010 führte der Schweizer Projektpartner folgende Arbeiten durch:

- Aktualisierung der 26 länderspezifischen Solarstrommixe unter Berücksichtigung aktueller nationaler und internationaler Statistiken.
- Erstellung von Sachbilanzdatensätzen zu vier Chemikalien/Materialien, die in der Photovoltaik-Industrie verwendet werden.
- Die Sachbilanzdaten von allen wichtigen PV-Technologien werden in einer öffentlich zugänglichen Datenbank bereitgestellt.
- Diskussion der Sachbilanzdaten mit IEA-PVSP Task 12 Projektpartnern.

Die Verantwortung über die Inhalte und Publikation der Sachbilanzdaten liegt bei *-s ic s* Es ist geplant, dass die Daten im Rahmen einer Aktualisierung des ecoinvent Datenbestand publiziert werden (verantwortlich: *c in nt nt*). Das Review der neu erstellten und der überarbeiten Datensätze durch ecoinvent ist hängig.

ur beschrieb des Projekts / der Anlage

Das Ziel des Gesamtvorhabens, Subtask 2 innerhalb des Task 12, LCA, ist das Erarbeiten von aktuellen Sachbilanzdaten zur Stromerzeugung mit Photovoltaikanlagen. In Tab.1 sind die einzelnen Aktivitäten und die hauptverantwortlichen Personen aufgelistet.

TAB.1 A TI IT TEN I SUBTAS 2 DES IEA-P PS TAS 12

Subtask 2. LCA	Countr	E perts
Activity 2-0 Guidelines for common approach in LCI and LCIA	NL/CH/US	Erik Alsema / Matthias Stucki / Rolf Frischknecht / Vasilis Fthenakis
Activity 2a Mono and multi- c-Si US	NL	Mariska de Wild-Scholten
Activity 2b Ribbon c-Si	NL	Mariska de Wild-Scholten
Activity 2c a-Si & tandem	US/NL	Vasilis Fthenakis & Mariska de Wild-Scholten
Activity 2d CIGS	DE/NL	Michael Held & Mariska de Wild-Scholten
Activity 2e CdTe	US/IT	Vasilis Fthenakis
Activity 2f Concentrator PV	ES/US/NL	Vasilis Fthenakis & Mariska de Wild-Scholten
Activity 2g Production of Si feedstock	NO	Ronny Glockner
Activity 2h LCI data management and publication	CH	Matthias Stucki & Rolf Frischknecht

Durchgeführte Arbeiten und erreichte Ergebnisse

Im Rahmen der Aktualisierung des ecoinvent Datenbestandes wurden folgende Arbeiten durchgeführt:

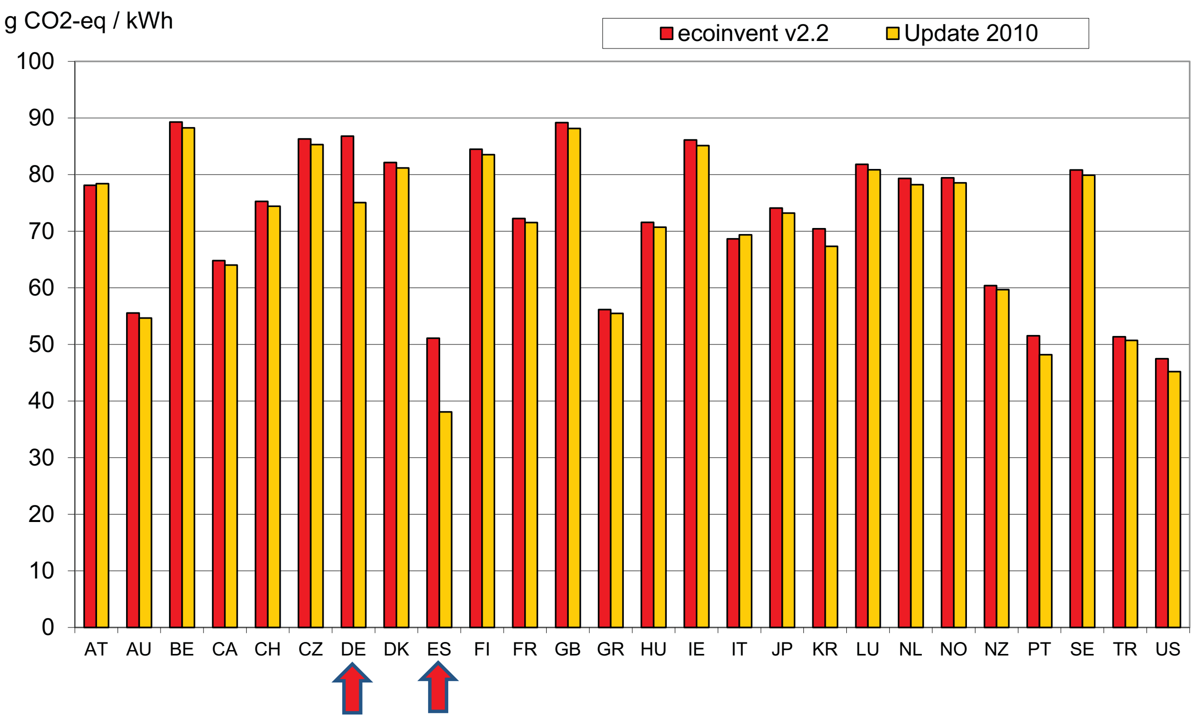
- Aktualisierung der länderspezifischen Photovoltaik-Produktionsmixe
- Erstellung von Sachbilanzdatensätzen für Polyvinylbutyral Folie (PVB), Ethylen-Tetrafluor-Ethylen (ETFE) und Stickstofftrifluorid (NF_3)
- Aufdatierung der ecoinvent Sachbilanz zu Silan (Siliziumtetrahydride)

Publikation eines Fachartikels im Bulletin SEV/VSE mit einer differenzierten Beurteilung inwiefern durch Photovoltaik die Umweltintensität des Schweizer Stroms reduziert werden kann.

A TUALISIERUNG DER L NDERSPE IFISCHEN PHOTO OLTAI -PRODU TIONS I E

Die 26 länderspezifischen Photovoltaik-Stromproduktionsmixe wurden unter Berücksichtigung nationaler und internationaler Statistiken aktualisiert. Neu sind diese Strommixe nicht nur mit theoretisch modellierten 3kWp-Anlagen auf Gebäuden verknüpft, sondern berücksichtigen anteilsmässig auch Photovoltaik-Grossanlagen und Freiflächenanlagen.
In FIG. 1 ist der Carbon Footprint dieser Photovoltaik-Strommixe dargestellt. Bei den meisten länderspezifischen Mixen zeigt sich eine Reduktion der Treibhausgase aufgrund der Datenaktualisierung von weniger als 5 %. Eine Ausnahme stellen Spanien und Deutschland dar, die zwei grössten Märkte von Photovoltaik-Anlagen. In diesen beiden Ländern wurde der Carbon Footprint um 32 % respektive 14 % verringert, da bei der Aktualisierung im Vergleich zu den Daten im ecoinvent Datenbestand v2.2 neu auch effizientere Photovoltaik-Grossanlagen mitberücksichtigt sind.

Der Carbon Footprint des Schweizer Solarstrom-Mixes beträgt 72 g CO_2-eq. / kWh, derjenige des Deutschen Solarstrom-Mixes 75 g CO_2-eq. / kWh und derjenige des Spanischen Solarstrom-Mixes 38 g CO_2-eq. / kWh.



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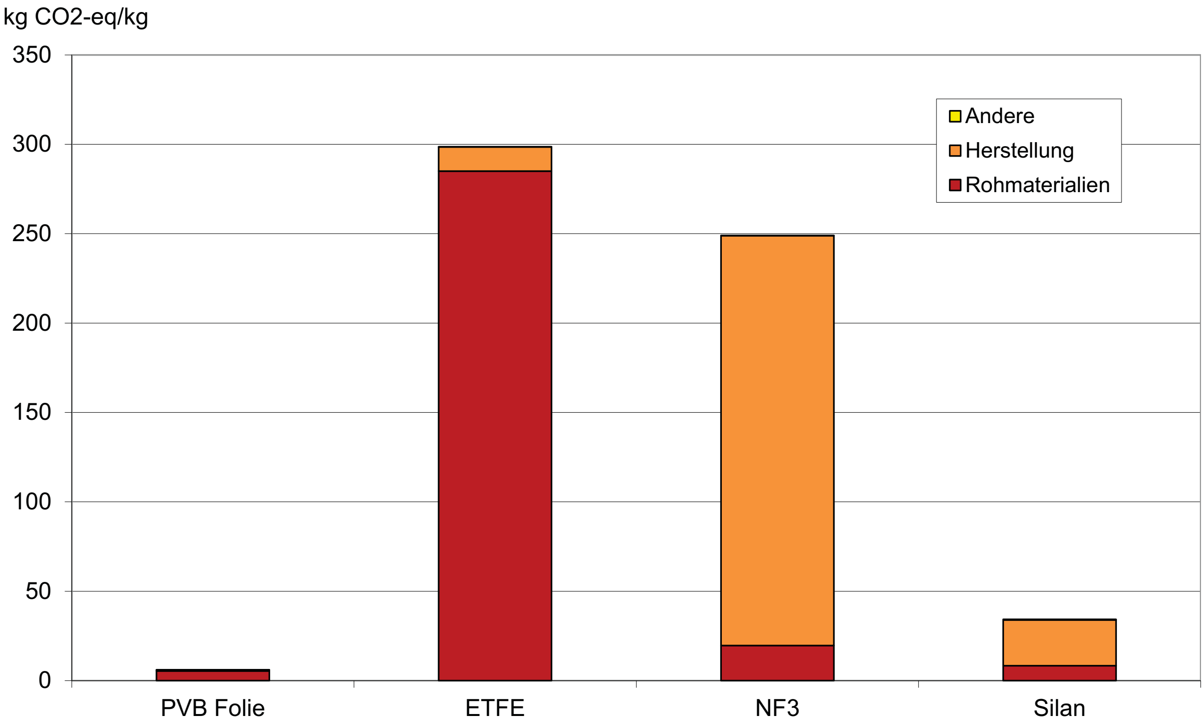
SACHBILAN IN ENTARE CHE I ALIEN

Zu den Chemikalien PVB, ETFE, NF_3 und Silan, welche in der Produktion der PV-Anlagen benötigt werden, wurden Sachbilanzen neu erstellt bzw. aufdatiert. In FIG. 2 ist der Carbon Footprint der vier untersuchten Chemikalien dargestellt. Der hohe Carbon Footprint von ETFE steht im Zusammenhang mit fluorierten Kohlenwasserstoffen, welche bei der Herstellung der Rohmaterialien (Teflon) emittiert werden und als hochwirksame Treibhausgase wirken. Stickstofftrifluorid (NF_3) stellt selbst ein hochwirksames Treibhausgas dar. Sein hoher Carbon Footprint resultiert vor allem daraus, dass gemäss Informationen aus dem Umweltbericht eines bedeutenden Produzenten bei der Herstellung 1.2 % des NF_s in die Umwelt emittiert werden.



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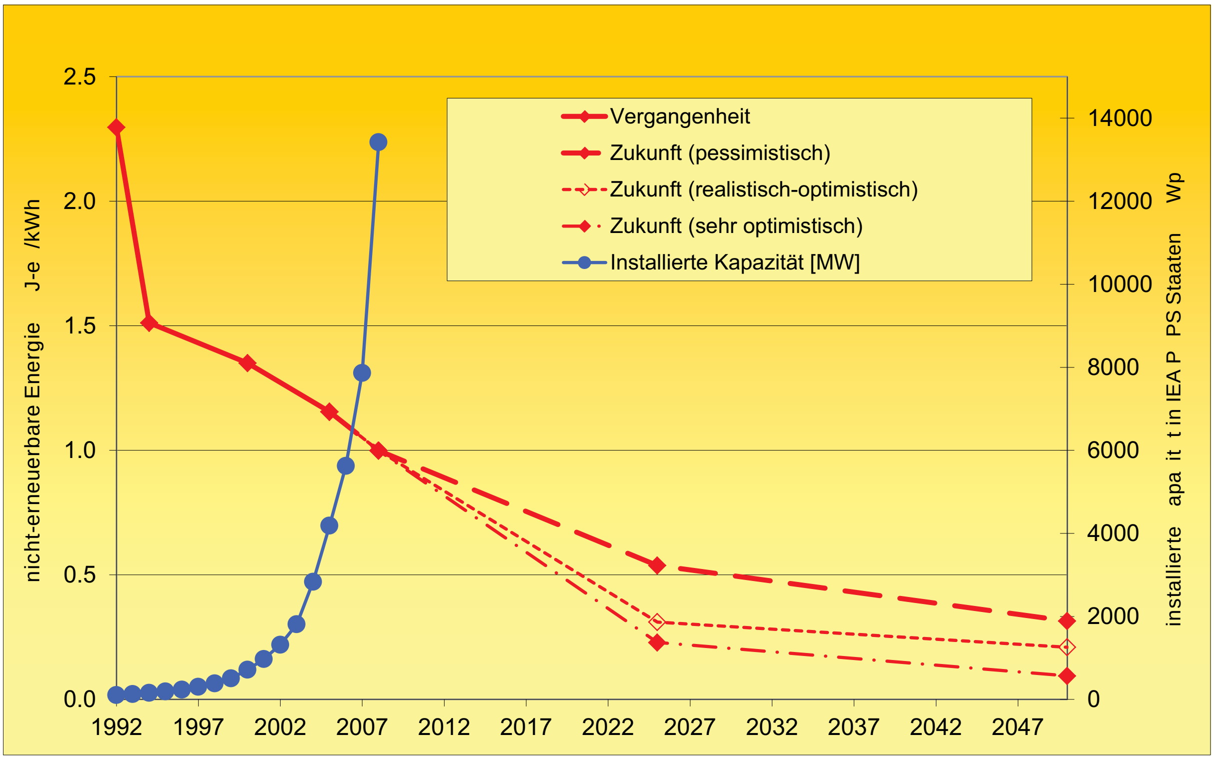
DIFFEREN IERTE BEURTEILUNG INWIEFERN DURCH PHOTO OLTAI DIE U WELTINTENSI-T T DES SCHWEI ER STRO S REDU IERT WERDEN ANN

In einem Fachartikel im Bulletin SEV/VSE wurden die Umweltauswirkungen von Solarstrom beurteilt und mit dem Schweizer Verbrauchermix verglichen [6]. FIG. 3 zeigt, dass sich die Photovoltaik in den letzten zwei Jahrzehnten aus Umweltsicht deutlich verbessert hat und der kumulierte Energieaufwand aus nicht-erneuerbaren Energieträgern heute weniger als ein Drittel ausmacht im Vergleich zu den Ergebnissen der ersten Ökobilanzstudien zu diesem Thema in den 90er-Jahren. Für die Zukunft sind weitere Effizienzsteigerungen und ein deutlicher Rückgang der Umweltbelastungen von Solarstrom zu erwarten. Der Vergleich mit dem Schweizer Verbrauchermix zeigt, dass sich mit Solarstrom insbesondere die Treibhausgasemissionen und die radioaktiven Abfälle reduzieren lassen.



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Nationale / internationale usammenarbeit

Auf nationaler Ebene erfolgt die Zusammenarbeit primär mit dem ecoinvent Zentrum, welches die Validierung der aktualisierten Datensätze übernehmen soll. Aufgrund der umfangreichen Anpassungsarbeiten an der ecoinvent Datenbank (inhaltlich und strukturell), war das ecoinvent Zentrum dieses Jahr nicht in der Lage, die bereitgestellten Daten zu validieren. Auf internationaler Ebene fanden insbesondere im Rahmen der geplanten Arbeiten zu Modul-Recycling Diskussionen statt. Wichtige Partner dabei sind Sylke Schlenker, Sunicon, Deutschland und Lisa Krueger, First Solar, USA.

Im Weiteren wurde ein Austausch von Sachbilanzdaten vereinbart. Hierbei können Sachbilanz-Primärdaten von Elkem Solar erwartet werden. Eine Aktualisierung der Sachbilanzdaten zu einer Bandbreite verschiedener Photovoltaik-Technologien wird von Mariska de Wild-Scholten, ECN, Niederlande im Jahr 2011 durchgeführ.

Be ertung 2010 und Ausblick 2011

Die Sachbilanzen konnten erfolgreich zusammengestellt werden und die neuen und aktualisierten Datensätze werden auf der Webseite der ESU-services GmbH[1] der Öffentlichkeit zur Verfügung gestellt. Zudem stehen sie dem ecoinvent Zentrum für das Durchführung des Reviews und eine Implementierung in den ecoinvent Datenbestand zur Verfügung.

Für Ende 2010 und erste Hälfte 2011 sind folgende Arbeiten geplant:

- Eine Ökobilanz von amorphem Silicon auf flexiblen Substraten eines Schweizer Herstellers
- Erstellung von Sachbilanzdatensätzen zu Modul-Take-Back-Systemen und Modul-Recycling
- Überarbeitung der Daten zum Wasserverbrauch während des Betriebs (Reinigung) von Photovoltaik-Anlagen.

Um die Wahrnehmung der Photovoltaik als umweltfreundliche Technologie aufrecht zu erhalten, sind seit zwei Jahren Bestrebungen im Gange ein Sammelsystem von Modulen nach dem Anlagerückbau

[1] http://www.esu-services.ch/projects/ecoinventdatenbank/ecoinvent-reports/

zu etablieren und ein Recyclingsystem für die Photovoltaik-Module aufzubauen. Mit den von den Schweizer Projektpartnern der IEA-PVPS-Task 12 geplanten Arbeiten wird beabsichtigt, diese Entwicklung in den Ökobilanzdaten zu berücksichtigen.

Falls von Mitgliedern der IEA PVPS Task 12 weitere Sachbilanzdaten zu Photovoltaik-Technologien zur Verfügung gestellt werden, wird angestrebt diese für eine Implementierung in den ecoinvent Datenbestand aufzubereiten.

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SCHWEI ER BEITRAG U IEA P PS PROGRA , IEA P PS TAS 13

Annual Report 2010

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Project- / Contract Number	SI/50021 / SI/50021-03
Duration of the Project (from – to)	2010 - 2013
Date	23.12.2010

ABSTRACT

Task 13 has been launched in the Kick-Off Meeting May 17th/18th 2010 in Cologne, Germany by TUV Rheinland, one of the two operating agents.

2010 the group had the first Kick-Off Meeting with a broad presents of total 14 countries. The second expert meeting has taken place October 25th/26th 2010 in Chambery, France.

The activities of Subtask 1: Statistical System Performance Analysis

Subtask 2: Analytical PV System Assessment

Subtask 3: PV Module Characterisation and Life Time Assessment

Subtask 4: Dissemination have been started as planned.

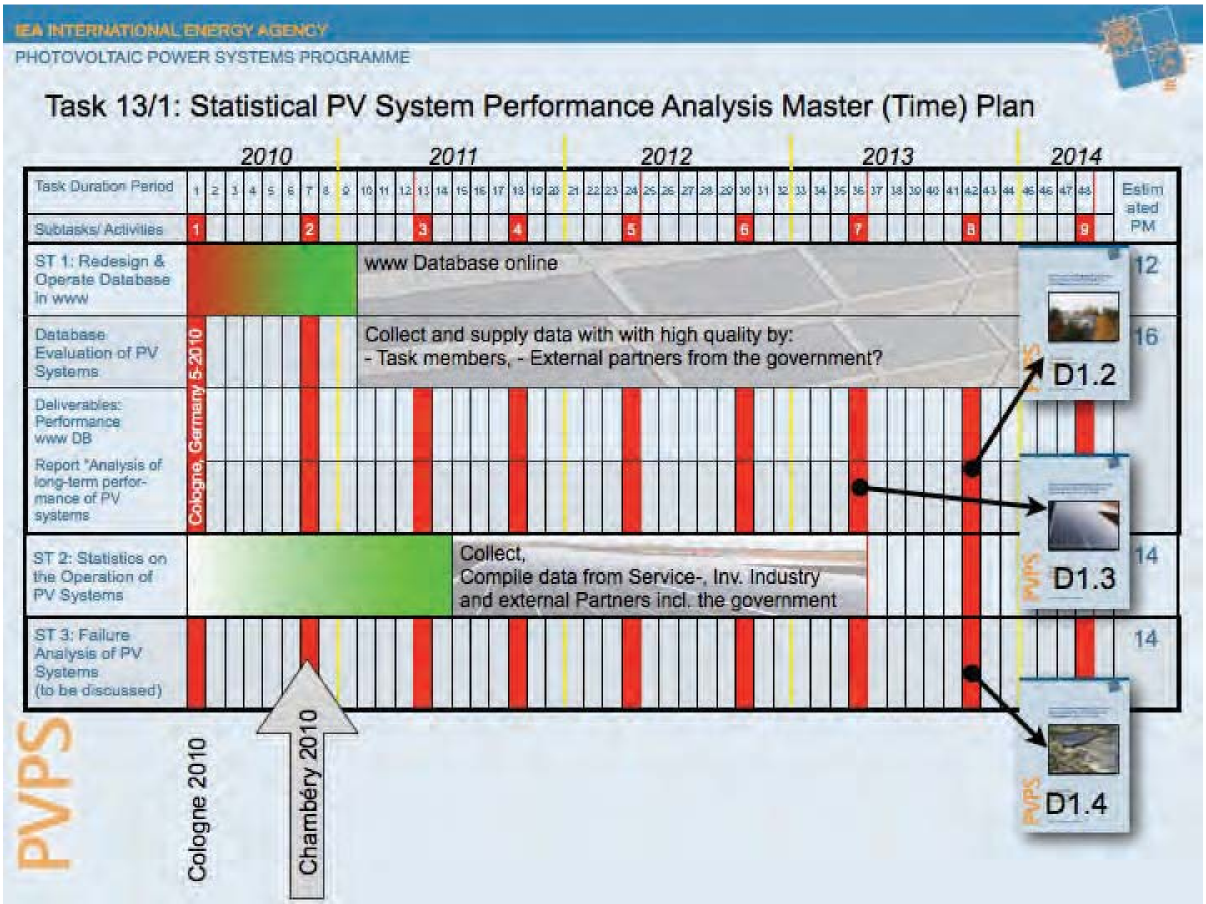
TNC is the responsible Subtask 1 leader and also the activity leader 1.1 Database and Analysis of PV Systems as well as activity 1.2 Statistics on the Operation of PV Systems.

Arbeiten TNC

- Mitarbeit bei der Vorbereitung und Gestaltung des Kick-off-Meetings vom 17./18. Mai 2010 in Köln/TÜV
- Teilnahme am Kick-Off Meeting, Präsentation des Subtask 1, 1.1 und 1.2
- Zusammenstellung eines Informationspaketes für die neuen Task-Mitglieder
- Mitarbeit bei der Vorbereitung des 2. Expert-Meeting vom 25./26. Oktober 2010 in Chambery Frankreich
- Teilnahme am Expert-Meeting

ick-off- eeting vom 17./1 . ai 2010 in In

Schwerpunkt des Meetings war es, gegenseitiges Vorstellung und Kennenlernen der Task-Teilnehmer. Dabei haben die Ländervertreter individuell ihr beabsichtigtes Commitment vis-à-vis dem Workplan dargestellt. Die grafische Darstellung (Figur 1) zeigt die vorgesehene Arbeitsweise des Tasks für die Jahre 2010 bis zum Abschluss 2014.



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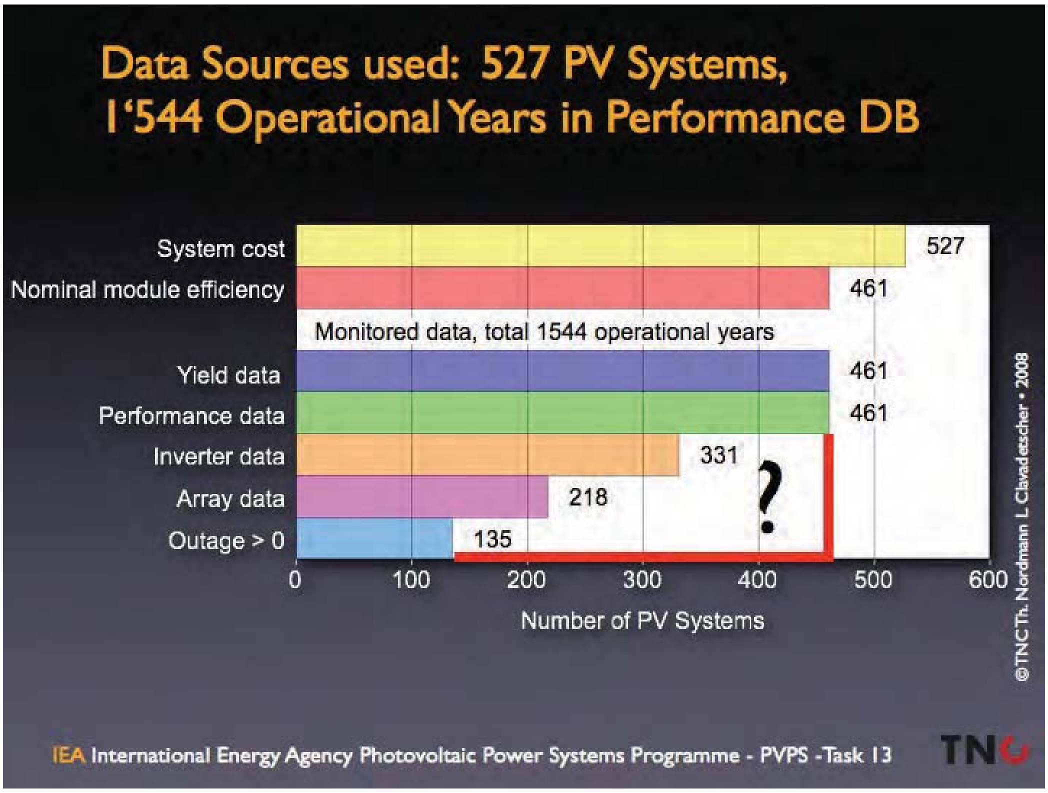
Erl uterungen u den L ndervertretern

Im Vergleich zu den Arbeiten im Task 2 ist die Ländergruppe deutlich breiter aufgestellt. Insbesondere neue Länder wie Israel, Libanon, Norwegen, Spanien, Schweden, USA stossen neu zum Team der Know-How-Träger. Als strategisch wichtig werden die Beiträge von Kanada, USA, evtl. Israel und Norwegen angesehen.

2. E pert- eeting vom 25./26. Oktober 2010, Chamber , Frankreich

Die Stellungsnahmen der einzelnen Ländervertreter zum vorgeschlagenen Vorgehen im Activity 1.1 wurden vom Gremium diskutiert und in den Grundsätzen genehmigt. Die Struktur der Datenbank (Feldliste) wurde vorgelegt, diskutiert und genehmigt. Die zusätzlichen Eigenschaften der neuen Datenbank wurden festgelegt.

Ausgehend von den vorliegenden Endresultaten vom Task 2 wird die Arbeitsweise des neuen Task 13/1 definiert und verabschiedet. Eine der noch ungenügend rapportierten Informationen im Task 2 betrifft die unvollständigen Datensätze bei den Invertern und den Arrays sowie Angaben über die Systemausfälle. Vollständige Datensätze waren nur bei 135 der insgesamt 527 Anlagen vorhanden (vergl. Figur 2). Ein Teil der Anstrengung vom Task 13 konzentriert sich auf die Auswertung vollständiger Datensätze.



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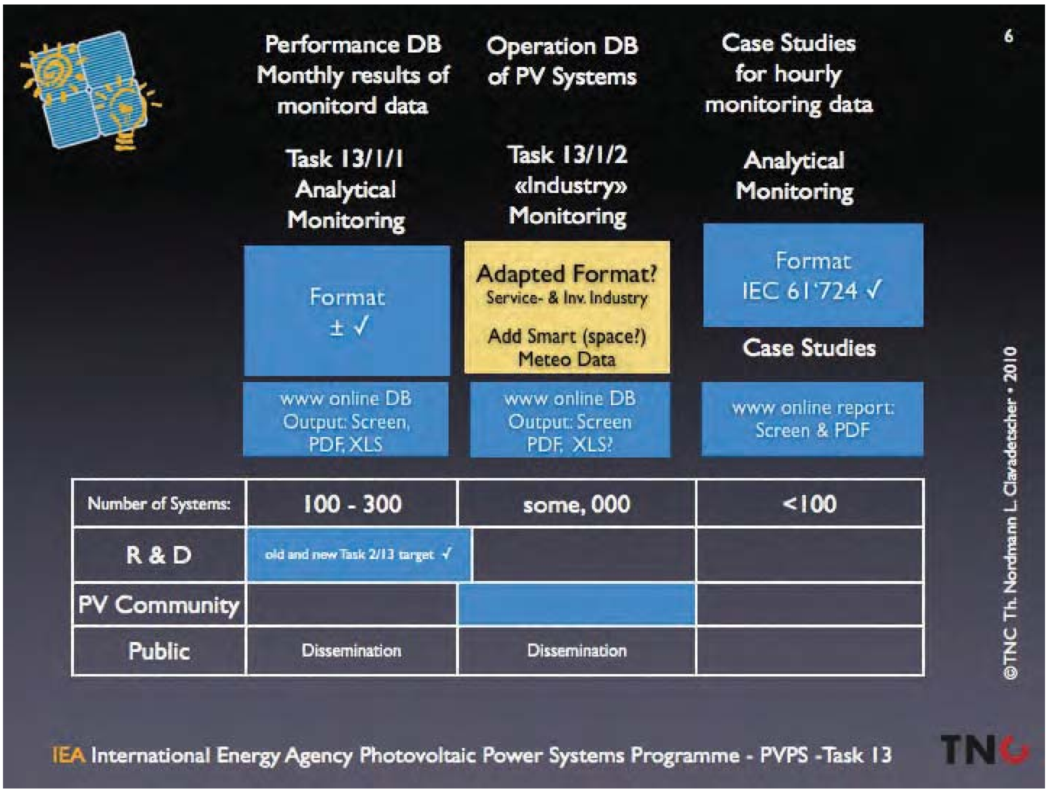
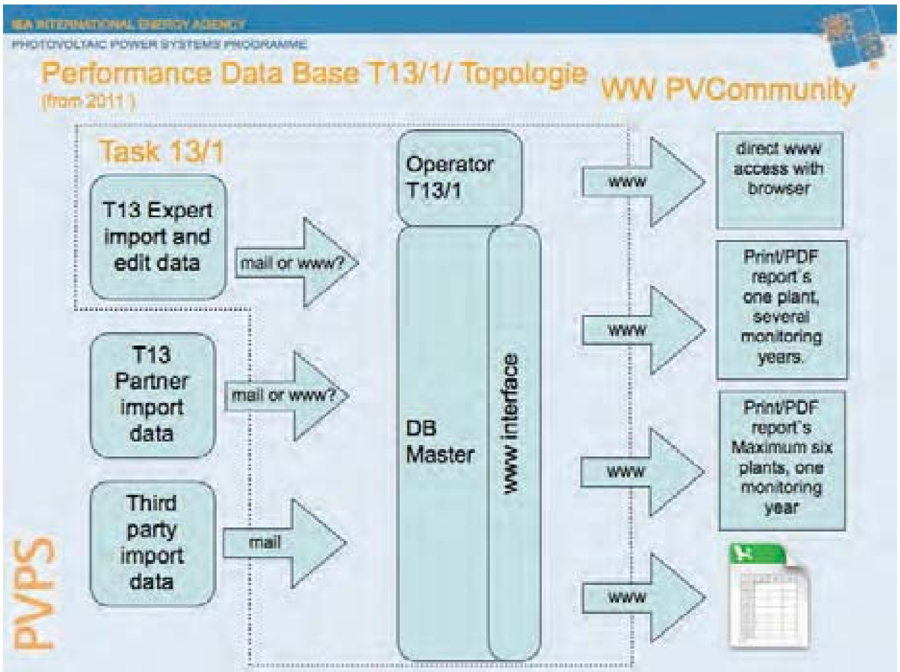
Die Struktur vom Task 13/1. Einerseits soll die Performance-Datenbank im kompatiblen Format zum Task 2 weitergeführt werden ohne ökonomische Daten aber möglichst vollständig. Andererseits soll im Subtask 13/1/2 ein gemeinsam akzeptiertes Format der Auswertung von einer viel grösseren Anzahl Photovoltaikanlagen festgelegt werden. Damit können die Vielzahl der Messungen, die heute von der Inverterindustrie als Kundendienstleistung gebracht werden, mit ausgewertet und verglichen werden.

Für Case-Studies sind objektbezogene Datensätze auch mit hoher zeitlicher Auflösung notwendig, um zum Beispiel das transiente Verhalten von Invertern vertieft zu untersuchen. (Figur 3)



i u s n Dat n an st u tu n inn a as

Vorgesehene Topologie der Internetanwendung für den Subtask 1.1. Sowohl die Task-Mitglieder wie externe Partner stellen die vorgeprüften Datensätze zur Verfügung, die dann in der Masterdatenbank aufbereitet und über das Internet auf verschiedene Arten genutzt werden kann. Einerseits im direkten Zugriff über Webbrowser, andererseits auch als Print und auch Excel Download (vergl. Figur 4). Standardauswertungen werden vorgehalten. Für individuelle Auswertungen können auch ausgewählte, anonymisierte Rohdaten als Excel-Datei zur Verfügung gestellt werden.



i u nt n t at n an i as

Referen en / Publikationen

[1] T. Nordmann, L. Clavadetscher: Reliabilit of Grid-Connected Photovoltaic S stems, the learning Curve in ield and S stem Cost, 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, 5BP.1.5 September 2008

[2] COST AND PERFOR ANCE TRENDS IN GRID-CONNECTED PHOTO OLTAIC S STE S AND CASE STUDIES, Report IEA-PVPS T2-06:2007 December 2007.

[3] IEA PVPS Task 2, Countr Reports on P S stem Performance, Report IEA-PVPS T2-05:2004, December 2004.

Datenbank

[4] Performance Database, Version 1.19, Edition: Sept 2006, auf CD-ROM für EUR 20.- erhältlich bei der Taskleitung: Ulrike Jahn, ZAE Bayern, D-91058 Erlangen, E-Mail: ulrike.jahn@.de.tuv.com, als Download oder interaktiv auf der Task 2 Homepage: http://www.iea-pvps-task2.org

IEA P PS

[5] Info auf Webseite: http://www.iea-pvps.org/

Schweizerische Eidgenossenschaft
Confédération suisse
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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

IEA SHC TAS 36: SOLAR RESOURCE NOWLEDGE ANAGE ENT

GLOBAL RADIATION SHORT TERM FORECAST AND TRENDS / AEROSOL CLIMATOLOGY

Annual Report 2010

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Project- / Contract Number	101498 / 151784
Duration of the Project (from – to)	July 2005 – June 2011
Date	10.12.2010

ABSTRACT

In the framework of IEA Solar Heating and Cooling (SHC) task 36 Meteotest investigates the possibilities and quality of global radiation forecast, the trend of recent global radiation data and distribution of atmospheric aerosols.

In the fifth year 2010 of task 36 – the project had been prolonged by one year – the work within the tasks has been finished and the final report has been started to write. Additionally the definition of the follow on task 46 – the task has been approved in November 2010 – has been made in two meetings. The new task will start mid 2011.

wrote two chapters in the final report, which will be published in 2011. One is dealing about aerosol climatologies and one about long term trends of global radiation. presented the advances of the solar radiation forecast based on regional weather forecast models of the last few years at the PVSEC 2010 in Valencia, as well as the long term trends of global radiation at the Bad Staffelstein PV meeting and Eurosun 2010. It could be showed, that the uncertainty of the weather forecast models used at has been lowered significantly during the last years.

Introduction

In the framework of IEA Solar Heating and Cooling (SHC) task 36 “Solar Resource Knowledge Management” [1] Meteotest investigates mainly the possibilities and quality of global radiation forecast. The task 36 is divided into 3 main subtasks:

A) Standard qualification for solar resource products (includes benchmarking of different radiation estimation models based on satellite measurements).

B) Common structure for archiving and accessing solar resource products (includes prototype of online tool for accessing data).

C) Improved techniques for solar resource characterization and forecast; improve satellite retrieval methods for solar radiation products; conduct climatological analysis of solar resources.

The aim in the radiation forecast subtask is to define the quality of the existing models and to enhance the quality. Main partners in this subtask are listed in Table 1.

Additionally this year work has been done within part c). on estimation of trends of recent global radiation data and on a new aerosol climatology.

Work done and results

The year 2010 was used to finalize the task and report about the work done. No additional work parts have been started.

Here the state of all three subtasks:

Subtask A: This subtask has been completed. Final subtask deliverables as well as inputs for the Handbook on Solar Radiation are in preparation.

Subtask B: This task has been completed. Final subtask deliverables as well as input for the Handbook on Solar Radiation are in preparation.

Subtask C: This subtask is nearing completion. Further analysis of long-term climate trends, and additional solar resource forecasting studies, including benchmarking with PV system outputs as well as high quality ground solar measurements, will continue, as well as preparation of materials for the Handbook on Solar Radiation.

FINAL REPORT

wrote two chapters of the final reports, which will be published in 2011. One is dealing with aerosol climatologies and another with long term trends of global radiation (see BFE Jahresbericht 2009 of IEA SHC Task 36).

PRESENTATION OF THE WOR

presented the recent advances of the solar radiation forecast based on regional weather forecast models at the PVSEC 2010 in Valencia [2] as well as the long term trends of global radiation at the PV Symposium at Bad Staffelstein [3] and at Eurosun 2010 [4]. Additionally the whole task 36 was presented at Eurosun 2010 [5].

In the presentation for the PVSEC we could show, that with relatively low effort the uncertainty of hourly global radiation forecasts could be lowered (Tab. 1 and Fig. 1).

Table 1: Validation results of different setups for forecast day 1 (1 – 24 h). PP is the post processing scheme where DMO means direct model output. PP = post processing (making changes to the direct model output).

Setup	odel	Resolution	Output	Bias	rmse
1	MM5	90 km	Direct model output	0.2%	55.0%
2	MM5	30 km	Direct model output	2.2%	48.6%
3	WRF	5 km	Direct model output	1.6%	51.2%
3 + PP 1	WRF	5 km	smoothing of 10x10 model pixels	1.3%	44.2%
3 + PP 1 & 2	WRF	5 km	smoothing of 10x10 model pixels, fixed bias correction	-0.9%	41.3%

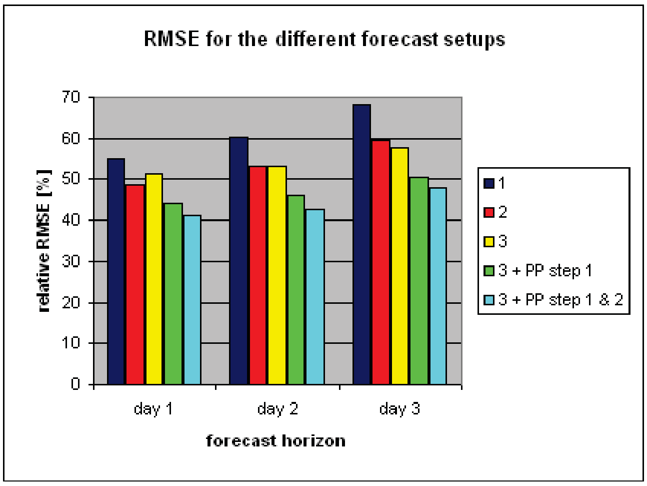

Figure 1: Error development over the three forecasting days.

The accuracy of the direct model output (DMO) for Switzerland lies in the order of 50% in the rmse on hourly values and in the mean it is quite bias less. A statistical post-processing and a more sophisticated model setup lowered the rmse by an absolute value of 14%. In relative units the improvement since the first tries is 25%. The uncertainty of 40% is in the range of other solar radiation forecast models for Switzerland [6].

NEW TAS

The new task (Nr. 46) has been defined in two task meetings. It will include the following subtasks:

Subtask A: Solar Resource Applications for High Penetration of Solar Technologies

- Solar variability and specifically ramp rates for particular systems
- Spatial and temporal characterization of intermittency
- Integration of solar with other RE technologies

Subtask B: Standardization and Integration Procedures for Data Bankability

- Measurement best practices
- Integration of data sources
- Evaluation of the use of TMY data
- Data uncertainties over various time frames
- Gap-filling, QC, and Flagging

Subtask C: Solar Irradiance Forecasting

- Short-term forecasting
- Integration of solar forecasts into operations
- Long-term variability and impact of climate change of solar resources

National / international cooperation

The work was done in the framework of IEA Solar Heating and Cooling task 36. From Switzerland there is also University of Geneva part of the task team.

Outlook

The task will be finished next year. The follow on task 46 has been approved in November 2010. The new task will start in July 2011 and end in June 2014.

References

[1] Homepage of IEA Solar Heating and Cooling task 36: http://re.jrc.cec.eu.int/iea-shc-task36/index.htm

[2] S. C. Müller and J. Remund, 2010: Advances in radiation forecast based on regional weather models MM5 and WRF. European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC), Valencia, Spain, Sep. 6th to 9th 2010.

[3] J. Remund, 2010: Zeitliche Entwicklung der Globalstrahlung von 1950 bis 2099, 25. SYMPOSIUM "PHOTOVOLTAISCHE SOLARENERGIE", Bad Staffelstein, Germany, 3. – 5. März 2010.

[4] J. Remund and S.C. Müller, 2010: Trends in global radiation between 1950 and 2100, EuroSun Conference, Graz, Austria, Sep. 29th to Oct 1st 2010

[5] C. Hoyer-Klick, H.G. Beyer, D. Dumortier, M. Schroedter-Homscheidt, L. Wald, M. Martinoli, C. Schillings, B. Gschwind, L. Menard, E. Gaboardi, L. Ramirez-Santigosa, J. Polo, T. Cebecauer, T. Huld, M. Suri, M. de Blas, E. Lorenz, C. Kurz, J. Remund, P. Ineichen, A. Tsvetkov, J. Hofierka, (2010): Management and Exploitation of Solar Resource Knowledge", EuroSun Conference, Graz, Austria, Sep. 29th to Oct. 1st 2010

[6] Lorenz et al. 2009, Benchmarking of different approaches to forecast solar irradiance, 24th European Photovoltaic Solar Energy Conference (EUPVSEC), Hamburg, Germany, Sep. 21st to 25th 2009.

P ERA NET

NETWORKING AND INTEGRATION OF NATIONAL AND REGIONAL PROGRAMMES IN THE FIELD OF PHOTO-VOLTAIC (PV) SOLAR ENERGY RESEARCH AND TECHNOLOGICAL DEVELOPMENT (RTD) IN THE EUROPEAN RESEARCH AREA (ERA)

Annual Report 2010

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Project- / Contract Number	CA-011814-PV ERA NET
Duration of the Project (from – to)	1 December 2009 – 30 November 2011
Date	December 2010

ABSTRACT

PV ERA NET is a European network of programme coordinators and managers in the field of photo-voltaic solar energy (PV) research and technological development (RTD). The consortium comprises major key stakeholders in the field of national and regional RTD programmes involving photovoltaics (PV), which is considered a key technology and industry.

The general objectives of the network are to further enhance the cooperation between regional and national RTD programmes in an efficient, pragmatic and flexible way, thereby providing substantial added value to the individual programmes, to the network and to the European Research Area as a whole. This cooperation shall result in further improving the effectiveness of the RTD programmes both on an individual and global level in terms of programme management and RTD activities.

Introduction and Goals

PV ERA NET is a European network of programme coordinators and managers in the field of photovoltaic solar energy (PV) research and technological development (RTD). The consortium comprises major key stakeholders in the field of national and regional RTD programmes involving photovoltaics (PV), which is considered a key technology and industry.

The Photovoltaic European Research Area Network PV ERA NET is open to any other interested country or region in Europe, which carries out PV RTD programmes and projects.

PV ERA NET started in October 2004 as a project supported by the EC within the ERA-NET scheme. After the official project end in 2009, the network continued its activities supported and managed by the participating partners.

The general objectives of the network are to further enhance the cooperation between regional and national RTD programmes in an efficient, pragmatic and flexible way, thereby providing substantial added value to the individual programmes, to the network and to the European Research Area as a whole. This cooperation shall result in further improving the effectiveness of the RTD programmes both on an individual and global level in terms of programme management and RTD activities.

PV ERA NET is based on two premises: First, PV is seen as a relevant RTD area and a specific thematic focus is desired. Second, international cooperation is understood as a strategic element strengthening the regional / national programmes.

PV ERA NET brings together expertise and ownership, i.e. stakeholders that can actually define and implement concrete actions within and between RTD programmes in the European Research Area.

The working principles are:

- PV ERA NET develops and uses a set of tools that enable and facilitate information exchange and implementation of PV RTD projects. The tools are pragmatic and target-oriented.
- PV ERA NET is complementary to other types of international bodies and flexible in providing essential contributions to international initiatives and activities in a highly dynamic context.
- PV ERA NET taps synergies and seizes opportunities for fomenting PV RTD activities between programmes creating benefits for research and industry both on a national and international level.
- PV ERA NET operates on trustful face-to-face relationships and willingness to actively cooperate.

Nine states (eight countries and one region) are the founding members of PV ERA NET (see Table 1). Any other interested country or region in Europe, which carries out PV RTD programmes and projects, can become member of the network.

Brief Description of the Project

According to the objectives and approach, six key activities and tools are identified for transnational cooperation:

1. To lead the update and to publish survey reports on regional/national PV RTD programmes
2. To coordinate the database on ongoing PV RTD projects
3. To publish relevant information on the Website
4. To co-organise and hold consortium meetings and workshops with external stakeholders (one or two times a year according to the needs)
5. To support the implementation of RTD projects
6. To assist the identification of joint activities with other relevant RTD networks (e.g. smart grids; materials)

The first four items are summarised as structured information exchange which is carried out by the individual partners and managed by the PV ERA NETwork secretariat providing basic support and guidance to keep the network running.

The fifth and sixth items lead to dedicated transnational activities (e.g. clustering of projects, joint calls, pooling of experts and evaluators) involving the individual partners effectively interested. The PV ERA NETwork secretariat supports the process of identifying, selecting and implementing RTD projects on photovoltaics and related areas.

Table 1: P ERA NET Partners and Contact Points		
State	Partner	Contact
Austria	Federal Ministry for Transport, Innovation and Technology / Bundesministerium für Verkehr, Innovation und Technologie (BMVIT)	Michael Hübner
Denmark	Energinet.dk	Jesper Bergholdt Soerensen
France	French Agency for Environment and Energy Management / Agence de l'environnement et de la maîtrise de l'énergie (ADEME)	Yvonnick Durand
Germany	Research Center Jülich GmbH / Forschungszentrum Jülich GmbH (FZJ)	Hermann Bastek
Greece	General Secretariat for Research and Technology, Ministry of Development (GSRT) Γενική Γραμματεία Έρευνας και Τεχνολογίας, Υπουργείο Ανάπτυξης (ΓΓΕΤ)	Chrysoula Diamanti
	Centre for Renewable Energy Sources (CRES) / Κέντρο Ανανεώσιμων Πηγών Ενέργειας (ΚΑΠΕ)	Stathis Tselepis
The Nether-lands	NL Agency, Directorate Energy and Climate Change	Otto Bernsen
North-Rhine-Westphalia	Cluster EnergyResearch.NRW/ Cluster EnergieForschung.NRW	Stefan Rabe
Sweden	Swedish Energy Agency / Statens energimyndighet	Linus Palmblad
Switzerland	Swiss Federal Office of Energy (SFOE) / Bundesamt für Energie (BFE) / Office fédéral de l'énergie (OFEN) / Ufficio federale dell'energia (UFE)	Stefan Oberholzer
	NET Nowak Energy & Technology Ltd.	Stefan Nowak

The added value for participating programmes and states are:

- Direct and regular contacts to RTD programme peers
- First hand information and experience on PV, RTD and programming
- Compact and comprehensive information tools (survey, database)
- Strategic basics for RTD programme management and positioning
- Efficient assessment of synergies and opportunities for transnational activities
- More effective PV RTD projects and research by reaching critical mass, defragmentation, and cross fertilisation

The network activities result in the following deliverables:

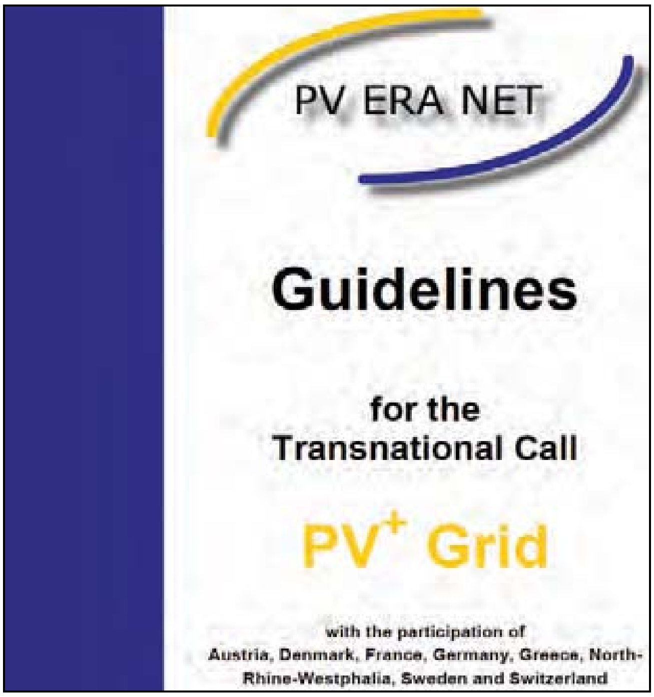
- Survey Report on regional/national PV RTD programmes (1 / year)
- Updated PV RTD Projects Database
- Update website
- Workshops for programme peers (1 - 2 times a year)
- International PV RTD projects
- Coordinated network

Work Performed

Transnational Call P Grid

The transnational Call PV+ Grid – a dedicated call on *i u ati n an s- t R ui nts i P n - t ati n P t taics in t ct icit i* with the participation of Austria, Denmark, France, Germany, Greece, North-Rhine-Westphalia, Sweden and Switzerland – was launched end of September 2009 and closed mid-March 2010.

According to the schedule (see figure below), proposals were processed. Six full proposals were successfully submitted amounting to a total budget of approximately 3,3 MEUR, of which 2,6 MEUR funding requested. The ranking of the proposals was based on the evaluations done by two internationally renowned experts (provided by Austria and Denmark) and on evaluations done within the national (programme) framework.



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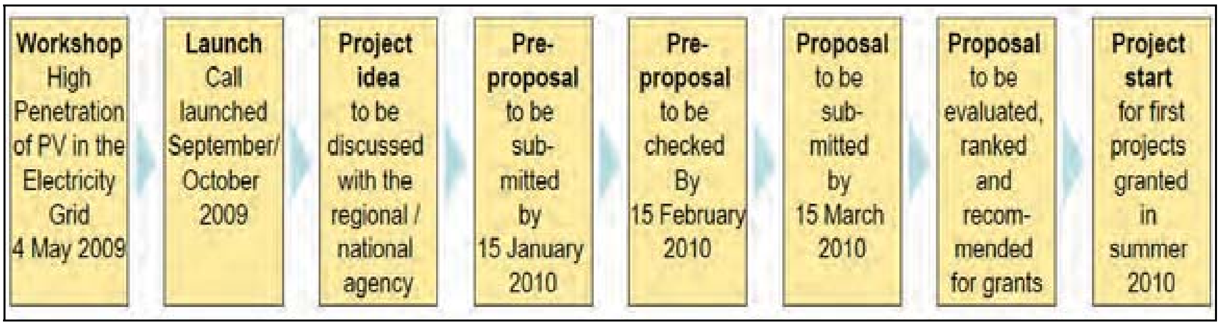
Contracts are concluded between the project partners and national / regional RTD programme. The transnational monitoring of the projects is done by the PV ERA NET Secretariat.



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The projects (to be) funded by the participating states are listed below. Effective project funding and amount of funding are partly still under negotiation thus the table below may be subject to changes.

Table 2: P Grids Projects Suggested for Funding												
PV+Grid Proposals	Project full title	Austria	Denmark	France	Germany	Greece	NRW	Sweden	Switzerland	Other	Project costs in kEUR	Requested funds in kEUR
PV+Grid_04_ SmoothPV	Smart modelling of optimal integration of high penetration of PV		x		o		x	x		x	1'101	827
PV+Grid_06_ DPVG	Simulation approach to investigate the impact of distributed power production with PV on a power grid	x			x				o		442	240
PV+Grid_05_ HiPe-PV	High-penetration of PV systems in electricity grids	o			x	x			x		773	719
PV+Grid_03_ PV-LASIRES	PV large scale integration in island grids with currently high RES penetration			x		o					350	260

o = coordinating project partner; x = participating project partner(s)

Transnational Call POL OL

POLYMOL – a dedicated transnational call on *P an cu a a P t taic s an u s* with the participation of Denmark, Flanders (Belgium), the Netherlands, Sweden, Switzerland and the United Kingdom – was launched late 2007 and resulted in four projects funded (see Table 3 and annex). The transnational monitoring of the projects is done by the Secretariat.

Table 3: Ongoing POL OL Projects Funded b P ERA NET embers										
POLYMOL Proposals	Project full title	Denmark	Flanders	The Netherlands	Sweden	Switzerland	United Kingdom	Other	Project costs in kEUR	Requested funds in kEUR
APOLLO (Power Plastic)	Efficient areal organic solar cells via printing			x		o		x	1'286	586
POLarge	Polymer solar cells; stabilised morphology and upscaling			x	o				741	636
HIOS-Cell	Nanoscale structuring of hetrojunction ionic organic solar cells by liquid-liquid dewetting			x		o			250	250
PolyStaR	Novel materials and processes for polymer solar cells with improved stability and reliability	o	x						2'960	1'202

o = coordinating project partner; x = participating project partner(s)

Reports

The Survey Report was updated and published in September 2010. It presents key features of the PV ERA NET states and their programmes, namely:

- Organisations Involved in PV ERA NET and PV RTD Programming
- Set-up and strategy of the programme involved
- Objectives
- Priorities

The states and their programme(s) are presented side by side in the same format. The goal of this report is to provide an essential overview over each of the country and the programme(s) involved. The internal report sent to partners provides some additional, mainly financial information.

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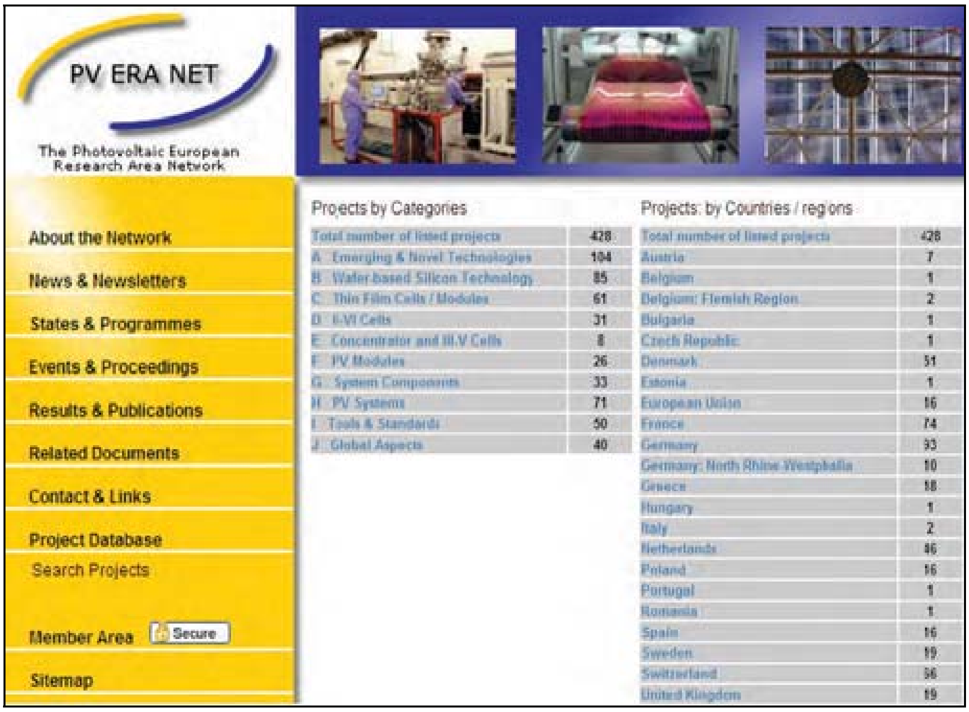
Database Tools

The Projects Database is continuously completed and updated by the individual PV ERA NET partners. The number of projects assessed has grown to 428.

With respect to the call management, first steps were undertaken in order to set up a tool to be eventually operated with the next joint call.

The website provided up-to-date information on the network's ongoing activities and results. It also lists the most recent related documents like PV Status Report, PV NMS NET Status Report, IEA PV Roadmap.



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Coordination

The first PV ERA NET meeting was held in Vienna on 12 + 13 April 2010. Main topics were:

- PV+ Grid call evaluation & ranking part I with all „call members“ and external expert
- PV+ Grid call evaluation & ranking part II with „members only“ for finalisation of the ranking and definition of (actions needed to fix) funding opportunities
- Status of on-going joint activities (POLYMOL, database, etc.)
- Communication and administration issues of PV ERA NET
- (New) member issues
- Recent developments and open calls in the member countries
- Current developments in EU policy (SET plan, Solar Energy Industry Initiative (SEII), etc.)
- Strategic Positioning of PV ERA NET
- (New) Joint transnational activities

An intermediate meeting was held at EU PV SEC in Valencia on 8 September 2010. Main topics were the status of PV+ Grid projects and the strategic positioning of the network.

Some PV ERA NET members are part of the European Photovoltaic Technology Platform and the PV Mirror Group and can therefore provide precious communication links.

Outlook 2011

The Photovoltaic European Research Area Network PV ERA NET is open to any other interested country or region in Europe, which carries out PV RTD programmes and projects. It therefore welcomes new participating partners. Some potentially interested partners could not yet join the network due to the national or international context (e.g. redefinition process of programmes and strategies, lack of financial support).

The network will strive to corroborate its strategic position and European Research Area (ERA) dimension not only in terms of a broader membership basis but also in strengthening its coordinative role in transnational PV RTD programming. The visibility of the network shall be improved with concrete new actions as best marketing approach considered. The further development of the Strategic Energy Technology Plan (SET-Plan) and Solar Europe Industry Initiative (SEII) may affect the future of the network.

According to the areas of cooperation agreed in the Memorandum of Understanding, the following activities are to be undertaken in 2011:

a) Structured information exchange
- To exchange information and experience between the programme owners and managers (i.e. organise a coordination meeting)
- To provide key data and information on regional/national PV RTD programmes (i.e. to update and complete the survey report but also regular information on new national calls offering opportunities for international RTD cooperation)
- To keep up an overview on ongoing PV RTD projects (i.e. to update the projects database)
- To communicate with the target audiences (programme managers and owners, experts from industry and research) (i.e. to stay in touch with other networks and stakeholders’ groups)

b) Implementation of RTD projects
- To identify and define common subjects for RTD on photovoltaics and related areas
- To select project proposals with added value for RTD programmes involved
- To co-fund, implement and monitor common RTD projects
- To stimulate cooperation between research groups from different countries and increase competitiveness of stakeholders involved

The monitoring of the ongoing projects initiated through the transnational calls POLYMOL and PV+ Grid will provide additional visibility for the activities undertaken in the PV ERA NET context. New joint activities of European outreach are to be discussed and defined at the next meeting probably hosted by North-Rhine Westphalia in the beginning of 2011.

Bibliograph

The website www.pv-era.net provides information on participating RTD programmes and ERA NET with respect to PV technology.