Schweizerische Eidgenossenschaft
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Bundesamt für Energie BFE

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Programm Photovoltaik Ausgabe 2014
Überblicksbericht, Liste der Projekte
Jahresberichte der Beauftragten 2013

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Programm Photovoltaik Ausgabe 2014 Forschung

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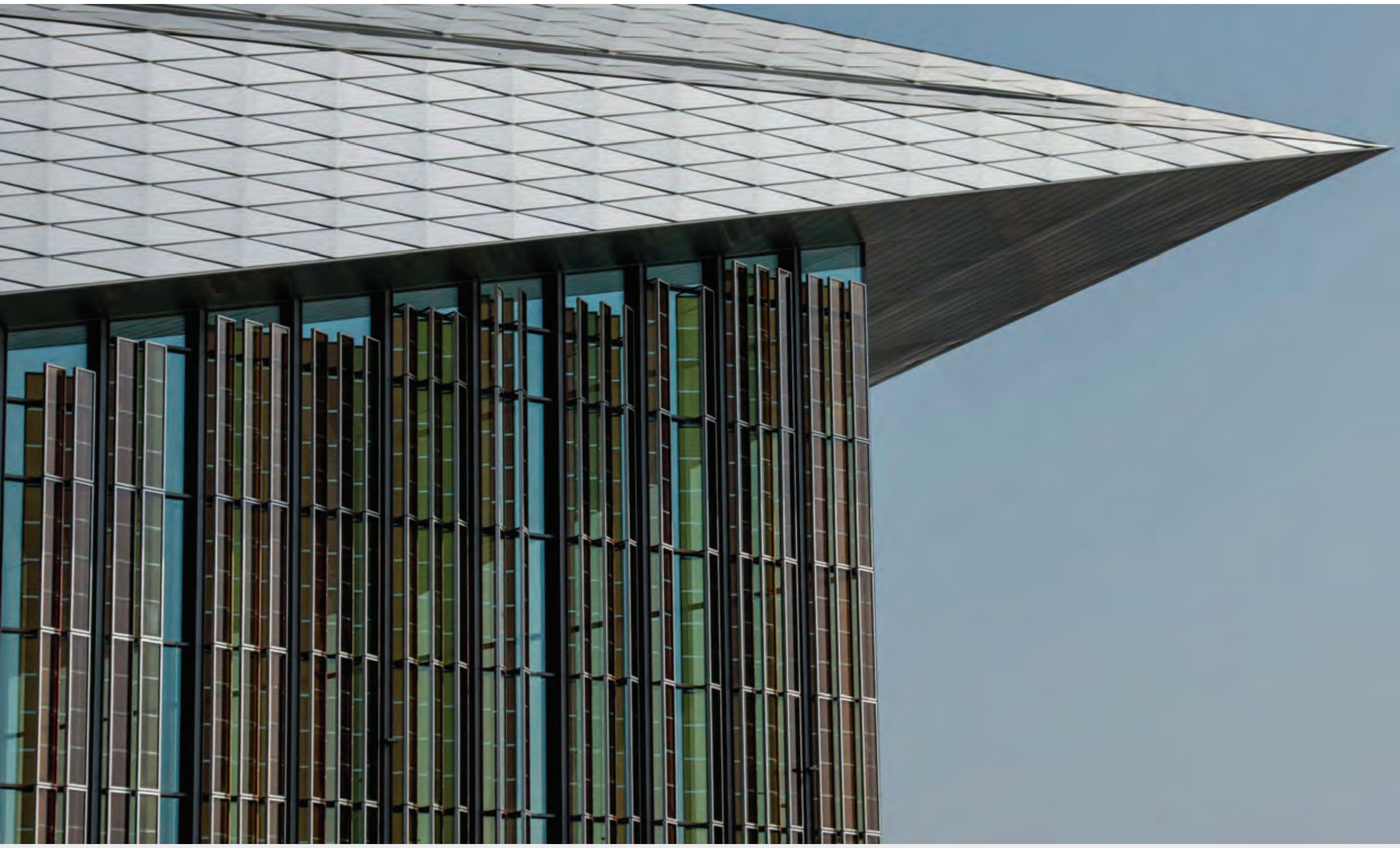

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Titelbild:

Neuartige farbige Photovoltaik Fassade

Am neuen SwissTech Convention Center an der EPFL in Lausanne wurde zum ersten Mal eine 300 m^2 grosse Fassade mit mehrfarbigen, transluziden Solarmodulen auf der Grundlage der farbstoffsensibilisierten «Graetzel»-Solarzellen realisiert. Die an der Westseite des Konferenzzentrums angebrachten, vorgehängten Fassadenelemente sind bis zu 36 m hoch und bilden einen Sonnenschutz für den lichtdurchfluteten Vorraum des Gebäudes (Solaranlage – Planung und Bau: Solaronix SA; Architekt: Richter - Dahl Rocha & Associés, Bildquelle: © IEA PVPS / Daniel Forster)

BFE Forschungsprogramm Photovoltaik
Überblicksbericht 2013

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Einleitung

In den letzten Jahren haben sich Technologie und Industrie der Photovoltaik, ihre Wettbewerbsfähigkeit, die politischen Rahmenbedingungen und die Bedeutung der Photovoltaik für den Elektrizitätsmarkt deutlich verändert. Zum einen fand eine beispiellose Preisreduktion insbesondere der Photovoltaik-Module statt, welche die Wettbewerbsfähigkeit der Photovoltaik in wenigen Jahren in vielen Märkten und Anwendungen massiv verbessert hat. Ausschlaggebend dafür ist die rasch wachsende Industrie mit entsprechenden Skaleneffekten, aber auch eine erhebliche globale Überproduktion. Damit einhergehend erfolgt weltweit ein rasches Marktwachstum, welches weiter anhalten dürfte. Gleichzeitig ist aufgrund des steigenden Wettbewerbsdrucks eine ausgeprägte Konsolidierungsphase in der Photovoltaikindustrie eingetreten. Nationale wie internationale Energiedebatten befassen sich immer intensiver mit der Photovoltaik, sowohl mit der Frage was ihr künftiger Beitrag im Energiemix sein wird als auch mit den marktbezogenen Rahmenbedingungen, welche zunehmend den Elektrizitätsmarkt als Ganzes erfassen.

Vor diesem Hintergrund findet weiterhin eine intensive Forschung statt, welche sich die anhaltende Kostenreduktion des ganzen Photovoltaiksystems, die rasche Industrialisierung neuer Prozesse, Produkte und Anwendungen wie die Integration in das Energiesystem als Ganzes zum Ziel setzt. Beispiele von wichtigen Photovoltaik Forschungsinitiativen sind die «Innovationsallianz Photovoltaik» in Deutschland, die «Sunshot Initiative» in den USA, das neue «AIST Fukushima Renewable Energy Institute» in Japan oder der «PV Implementation Plan 2013–2015» der Solar Europe Industry Initiative [1-4].

In der Forschung geht es um die anhaltende Weiterentwicklung der bestehenden Photovoltaiktechnologien sowie die Entwicklung neuer Materialoptionen und Konzepte. Nebst dem Kerngebiet der verschiedenen Solarzellen- und Modultechnologien beinhaltet die Photovoltaikforschung auch technologiespezifische Themen auf der Systemebene, z. B. der Gebäudeintegration, der elektrischen Systemtechnik oder der Umweltindikatoren und des Recyclings. Mit der derzeit anhaltenden Kostenreduktion bilden System-übergreifende Aspekte wie die Netzintegration, die Speicherung oder energetische Konzepte im Gebäude immer wichtigere Themen der Forschung. Neue Erkenntnisse und Resultate aus der Forschung werden möglichst rasch in die Industrie übergeführt.

Die Photovoltaik als wesentlicher Pfeiler einer nachhaltigen Stromversorgung hat in relevanten Szenarien inzwischen ihren festen Platz: Die im Jahr 2010 publizierte Photovoltaik-Roadmap der Internationalen Energie Agentur IEA [5] spricht bis 2050 von einem möglichen Beitrag von mehr als 10 % zur weltweiten Stromversorgung. Die kurzfristigen Marktprognosen der IEA zeigen ein noch dynamischeres Bild [6]. In aktuellen Schweizer Energieszenarien wird von der Photovoltaik bis 2050 ein Beitrag von mindestens 10 TWh Elektrizität als erwartet [7].

In den letzten bald 30 Jahren hat sich eine starke Schweizer Position in verschiedenen Gebieten der Photovoltaikforschung herausgebildet: Im Vordergrund stehen die Entwicklungen von verschiedenen Dünnschicht-Technologien, welche schon immer den Schwerpunkt der Schweizer Photovoltaikforschung bildeten. Im Jahr 2013 erfolgte dazu eine deutliche Steigerung der Aktivitäten, eine Stärkung der Forschungsinfrastruktur und Erfolge in verschiedenen Forschungsgebieten. Ausgehend von Arbeiten an neuen Solarzellen-Konzepten, z. B. auf dem Gebiet der CIGS-Technologie, werden diese sukzessiv in die industrielle Umsetzung übergeführt. Heute findet neben der Forschung an Instituten und Hochschulen auch seitens der Industrie eine intensive Technologieentwicklung statt, welche mittlerweile zu einer entlang der ganzen Wertschöpfungskette der Photovoltaik bedeutenden Schweizer Industrie geführt hat. Laufende Aktivitäten in Forschung und Entwicklung sowie Projekte im Bereich von Pilot- und Demonstrationsanlagen umfassen im Berichtsjahr 2013 rund 75 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 Projekte mit Unterstützung der Kommission für Technologie und Innovation (KTI) sowie zahlreiche EU-Projekte im Forschungsprogramm Photovoltaik eine tragende Rolle.

IEA Klassifikation:	3.1.2 Photovoltaics
Schweizer Klassifikation:	2.1.2 Photovoltaik

Programmschwerpunkte

Das Forschungsprogramm Photovoltaik des BFE verfolgt in der Periode 2013–2016 die folgenden Ziele [8]:

- Effizienzsteigerungen und Kostenreduktion von Dünnschicht-Solarzellen;
- Entwicklung von Hocheffizienzzellen (HIT-Zellen, Photonenmanagement);
- Materialoptionen für neue Solarzellenkonzepte (organische Solarzellen);
- Industrielle Fertigungsprozesse für verschiedene Dünnschichtsolarzellen (Silizium, CIGS);
- Neue multifunktionale Produkte für die Gebäudeintegration;
- Optimierung der Einbindung von Solardächern und -fassaden in die Gebäudetechnik;
- Netzintegration von hohen Anteilen von Photovoltaikstrom;
- Übergreifendende Zusammenarbeit zur Optimierung der Energieerzeugung in Kombination mit andern Erneuerbaren, insbesondere bezüglich Speicheroptionen und Verbrauchssteuerung.

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

Solarzellen (1a-e)

Verschiedene materialspezifische Ansätze zu Dünnschichtsolarzellen stellen hier den wichtigsten Schwerpunkt dar (Silizium, Verbindungshalbleiter, organische Materialien). Verstärkt werden Hocheffizienz-Zellen mit Heteroübergängen zwischen Dünnschicht- und kristallinem Silizium vorangetrieben. Organische und Polymersolarzellen, neuerdings verstärkt durch Forschung an Perowskitstrukturen, gewinnen als mögliche langfristige Technologieoptionen an Bedeutung. Ausserdem werden in der Grundlagenforschung fortgeschrittene Konzepte mit Photonen-Management erforscht, z. B. für Lumineszenz-Konzentratoren.

Module und Gebäudeintegration (2a-e)

Diese Gebiet ist eng mit der Anwendung der Gebäudeintegration verbunden. Im Vordergrund stehen zum Einen Modultechnologien, welche mit den in der Schweiz entwickelten Solarzellen einhergehen. Zum Anderen wird die Integration in funktionale Gebäudeelemente (z. B. Isolation, Wasserdichtigkeit) verstärkt verfolgt.

Elektrische Systemtechnik (3)

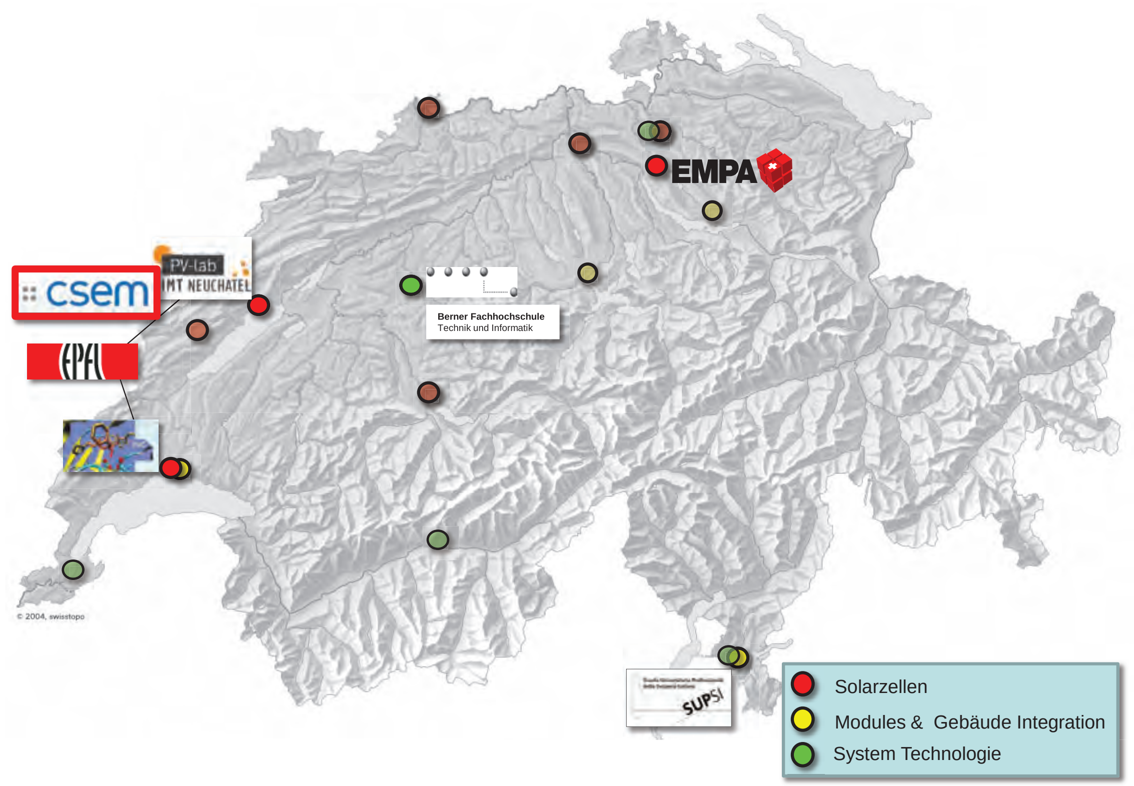
Im Vordergrund steht die Qualitätssicherung von Modulen und Wechselrichtern, einschliesslich entsprechender Normen. Ein in Zukunft wichtiger werdendes Thema ist die Wechselwirkung mit dem elektrischen Netz und die Integration der Photovoltaik ins Netz.

Begleitende Themen (4)

Zum einen geht es 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.

Internationale Zusammenarbeit (5)

Diese erfolgt projektbezogen auf allen Gebieten und im Rahmen des Implementing Agreements Photovoltaic Power System Programme (PVPS) der Internationalen Energieagentur (IEA), der europäischen SOLAR-ERA.NET-Kooperation (ERA: European Research



Die Schweizer Photovoltaik Forschungslandschaft

Area), der Europäischen Photovoltaik-Technologieplattform, der Solar Europe Industry Initiative (SEII) im Rahmen des SET-Plans und der Normen festlegenden Internationalen Elektrotechnischen Kommission (IEC).

Rückblick und Bewertung 2013

Gemessen an der Anzahl laufender Projekte mit öffentlicher Finanzierung und der gesamthaft gemeldeten Forschungsprojekte [9] kann eine anhaltende Verstärkung der Forschungsaktivitäten beobachtet werden. Diese Erhöhung ist in erster Linie auf eine Zunahme von KTI- und EU-Projekten zurückzuführen. Die zur spezifischen Förderung der Photovoltaik verfügbaren Forschungsmittel des BFE sind im Jahr 2013 beschränkt aber konstant geblieben. Die Mittel für Pilot- und Demonstrationsprojekte konnten hingegen deutlich erhöht werden, wobei hier keine für die Photovoltaik spezifischen Mittel reserviert sind. Neu ist 2013 mit Unterstützung des Staatssekretariats für Bildung, Forschung und Innovation (SBFI) das Photovoltaik-Kompetenzzentrum am Centre Suisse d'Electronique et de Microtechnique (CSEM) operativ geworden. Damit soll die industrienahe Forschung in Hinsicht auf die Umsetzung deutlich gestärkt werden.

Inhaltlich sind programmübergreifend drei wesentliche Trends zu erkennen: i) die verstärkte Fokussierung auf kurz- und mittelfristig relevante Fragestellungen der Industrie (anhaltende Kostensenkung und Effizienzsteigerung), ii) die waschsende Bedeutung von systemrelevanten Aspekten (z. B. Gebäude- und Netzintegration) sowie iii) langfristige Optionen in der Grundlagenforschung. Für die Photovoltaikindustrie hielt der ausgeprägte Wettbewerb und Kostendruck weiter an, aber es zeichnet sich gleichzeitig eine verstärkte Innovationstätigkeit in Hinsicht auf neue Prozesse und Produkte ab.

Ein nicht unwesentliches Element auf der nationalen Ebene ist der inzwischen auf mindestens 300 MW Jahreskapazität geschätzte Markt (total installierte Leistung Ende 2013 rund 740 MW), welcher seitens der Marktakteure zu vermehrten Kooperationen mit Forschungsinstituten und Innovationen führt. Insgesamt ist damit trotz Konsolidierung in der Industrie eine wachsende Industrietätigkeit zu verzeichnen.

Ausblick

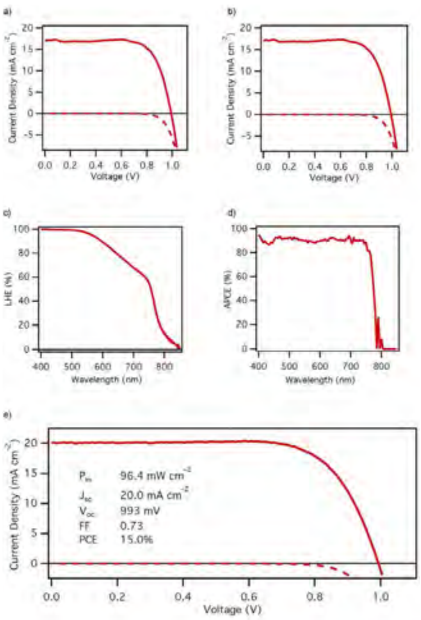
Die Schweizer Photovoltaik Forschungslandkarte (siehe Bild links) ist stark diversifiziert und gut verteilt. Für das Bestehen im internationalen Wettbewerb wichtig, dass die einzelnen Forschungsaktivitäten eine genügend grosse kritische Masse aufweisen und halten können.

Die Herausforderung der Schweizer Photovoltaikforschung und -industrie für die kommenden Jahre liegt deshalb darin, international, sowohl technologisch wie marktbezogen, mithalten zu können. Die Ausgangslage dazu ist grundsätzlich sehr gut: Die Schweiz hat in verschiedenen Forschungsgebieten weltweit weiterhin führende Forschungsaktivitäten und konnte diese in den letzten Jahren deutlich verstärken. Die Industrie ist trotz den derzeit schwierigen Zeiten in Bezug auf die Innovationstätigkeit weiterhin stark präsent und thematisch breit aufgestellt. Mit den verschiedenen Massnahmen zur Stärkung von Forschung und Umsetzung sollte sich auch die Forschungsinfrastruktur weiter entwickeln können. Zusammen mit dem kontinuierlich wachsenden Markt und der zunehmenden Wettbewerbsfähigkeit sind damit die Voraussetzungen für die weitere Entwicklung sowohl wissenschaftlich und technologisch wie industriell und marktbezogen anspruchsvoll aber aussichtsreich.

Highlights aus Forschung und Entwicklung

Die Schweizer Photovoltaik Forschungskompetenzzentren zu einzelnen Schwerpunktthemen konnten in den letzten Jahren ihre Forschungsaktivtäten vertiefen, neue Themen aufgreifen, die Industriekooperationen stärken und allgemein die Forschungsinfrastruktur ausbauen. Im Jahr 2013 sind dies insbesondere das Photovoltaik-Labor (PV-Lab) an der Eidgenössischen Technischen Hochschule Lausanne (EPFL) in Neuchâtel zusammen mit dem CSEM PV Center (Silizium-Dünnschicht-Solarzellen), das Institute of chemical sciences and engineering (ISIC) an der EPFL in Lausanne (Farbstoff-Solarzellen), die Empa in Dübendorf (Verbindungshalbleiter- und organische Solarzellen), die Scuola universitaria professionale della Svizzera italiana (SUPSI) in Lugano (Solarmodule und Gebäudeintegration) und die Berner Fachhochschule Technik und Informatik (BFH TI) in Burgdorf (elektrische Systemtechnik). Daneben sind auch verstärkte Forschungsaktivitäten an weiteren Hochschulen, z. B. an den Universitäten Bern, Basel und Fribourg sowie an der Empa in Thun (Grundlagenforschung), den Fachhochschulen ZHAW in Winterthur und Wädenswil und der heig-vd in Yverdon (Systemtechnik, Simulation), dem Laboratoire d'energie solaire (LESO) an der EPFL und der Hochschule HSLU in Luzern (Gebäudeintegration) oder der HSR in Rapperswil (insbesondere PVT-Hybridkollektoren) und dem NTB in Buchs (Kleinanwendungen) zu verzeichnen.

Forschung und Entwicklung auf 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) sowie Dünnschicht-Verbindungshalbleiter CIGS und CdTe (Empa). Die rasche Kostenreduktion bei den kristallinen Solarzellen zwingt die Vertreter der Dünnschicht-Technologien, ihre Konzepte kosten- und ef-



Figur 1: Charakterisierung von Perowskit-Solarzellen: a) I-V Kurven unter AM 1.5 G Spektrum (fest) bzw. im Dunkeln (gestrichen), b) IPCE (incident photon-to-current conversion efficiency) bzw. integrierter Photonenstrom, c) LHE (light harvesting efficiency), d) APCE (absorbed photon-to-current conversion efficiency), e) I-V Kurve der besten Zelle (Bildquelle EPFL [10], Copyright: Nature Publishing Group 2013).

fizienzmässig noch schneller weiter zu entwickeln. Dabei gewinnt auch das Konzept der hocheffizienten Solarzellen mit Heteroübergängen zwischen amorphen und kristallinen Zellen industriell rasch an Bedeutung. Fortgeschrittene Solarzellenforschung bedeutet aber immer mehr auch Materialforschung mit neusten Ansätzen, neuen Materialkombinationen und neuen Prozessen. Dabei spielen feinste Schichten und Strukturen im Nanometerbereich eine zunehmende Rolle. Im Jahr 2013 standen diesbezüglich vor allem die Forschungsarbeiten an Perowskit-Strukturen, namentlich am ISIC an der EPFL, im Rampenlicht.

Die Qualitätssicherung hat seit vielen Jahren ihren festen Stellenwert in der Photovoltaik Forschungslandschaft. Die Prüfung von Solarmodulen und deren Verhalten bei unterschiedlichen Betriebsbedingungen ist die Kernkompetenz des Istituto sostenibilità applicato all'ambiente costruito (ISAAC) an der SUPSI. Komplementär dazu wird an der Berner Fachhochschule HTI in Burgdorf das Verhalten von Wechselrichtern und Systemen untersucht. Beide Institute betreiben Prüflabors, in welchen Solarmodule oder Wechselrichter gemäss gängigen Normen geprüft werden können.

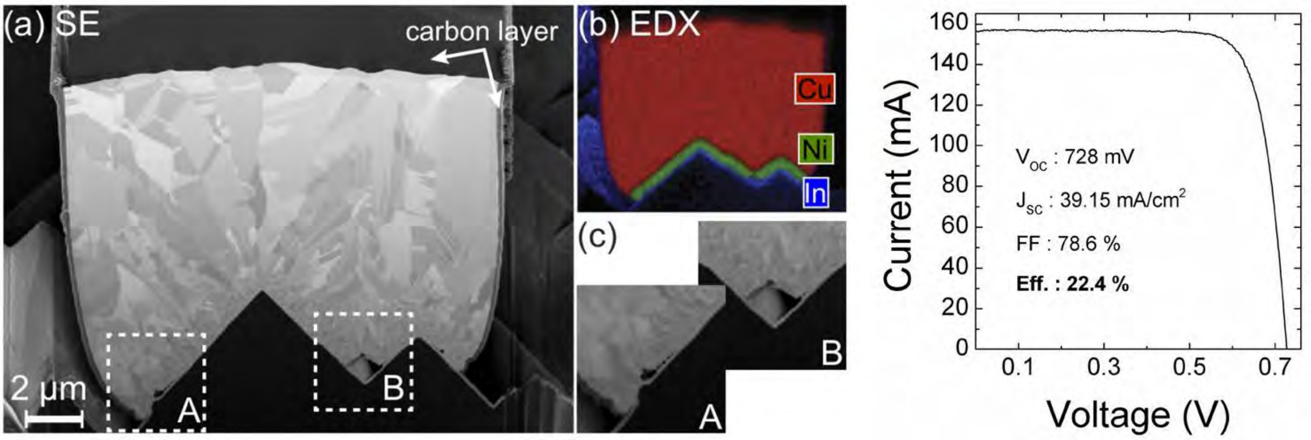
Dünnschichtsolarzellen – mit neuen Konzepten zu höchsten Wirkungsgraden

Besondere Beachtung fanden im Berichtsjahr die neusten Forschungsarbeiten des Teams um Prof. Michael Graetzel am ISIC an der EPFL in Lausanne, welcher seit vielen Jahren im Rahmen von nationalen und internationalen Projekten an vorderster Front an farbstoffsensibilisierten Dünnschichtsolarzellen (sogenannten «Graetzel-Zellen») forscht. Das neue «heisse» Thema sind lösungsmittelbasierte, metallorganische Perowskite (bleihaltige Perowskit-Kristalle), welche 2009 an der Universität Tokyo zum ersten Mal zur Sensibilisierung der Farbstoffsolarzellen eingesetzt wurden und damit in der internationalen Forschungsgemeinschaft grosses Interesse ausgelöst haben. In nur wenigen Jahren hat sich seither der Wirkungsgrad solcher Solarzellen von nur drei auf jetzt über 16 Prozent gesteigert, viel schneller als bei allen anderen Solarzellen-Technologien. Die Forschungsgruppe an der EPFL konnte zeigen, dass das Leistungsvermögen der Perowskit-Solarzellen von der Regelmässigkeit der Perowskit-Kristalle abhängt. Die Forscher schlugen dazu einen sequentiellen Herstellungsprozess der Perowskit-Kristalle vor. In einem ersten Schritt wird die anorganische Bleiverbindung aus einer Lösung auf die nanoporöse Titandioxid-Schicht aufgebracht. Anschliessend wird der Film einer organischen Lösung ausgesetzt, welche zur Bildung der Perowskit-Kristalle führt. Die Umwandlung zur Perowskitstruktur erfolgt beim Kontakt der zwei Komponenten in den Poren der Titandioxid-Schicht und führt dabei zu einer viel besseren Morphologie der Perowskit-Kristalle. Auf diese Weise konnten die Forscher an der EPFL den Wirkungsgrad im Jahr 2013 auf bis zu 15 Prozent steigern (Fig.1) [10]. Prof. M. Graetzel wurde 2013 auch mit dem bedeutenden Marcel Benoist Preis 2013 ausgezeichnet [11].

Die rasante Entwicklung des Wirkungsgrads dieses neuen Materials hat weltweit fieberhafte Forschungsarbeiten ausgelöst – treibende Kraft dafür ist die Hoffnung, hohe Wirkungsgrade mit günstigen Kosten zu verbinden, dem schlussendlichen Ziel jeder Solarzellenforschung. Ob und wann das vielversprechende Konzept diese Erwartungen in der Praxis erfüllen kann, welche Fragen sich dabei ergeben und welche Aufgaben gelöst werden müssen, bleibt weiter zu verfolgen. Dennoch zeigt dieses Beispiel eindrücklich, wie wichtig die anhaltende Forschung an neuen Konzepten ist und welches Potential in neuen Materialien und Prozessen immer noch steckt.

Das PV-Lab an der EPFL in Neuchâtel bearbeitet in einer Anzahl von eng verwandten Projekten aktuelle Fragestellungen zur weiteren Entwicklung von Silizium-Dünnschichtsolarzellen auf verschiedenen Substraten. Das aktuelle vom BFE unterstützte Projekt am PV-Lab ist in sechs komplementäre Aufgabenbereiche strukturiert: Einfluss der Plasmaeigenschaften auf die Siliziumschichten, neue Materialien und Schichten, Lichteinfang, Mehrfachübergänge, Zuverlässigkeit und Charakterisierung sowie allgemeine Infrastruktur. Im zweiten Projektjahr wurde das Verständnis der Materialeigenschaften von amorphem und mikrokristallinem Silizium mit verschiedenen Zwischenschichten vertieft. Auf der Zellenebene konnten wesentliche Fortschritte erzielt werden, namentlich ein Weltrekord für den Wirkungsgrad von mikrokristallinen Siliziumsolarzellen von 10,7 % sowie die sehr guten Werte von mikromorphen Siliziumsolarzellen von 12,3 % für Tandemzellen bzw. 13,0 % für Tripelzellen (Fig. 2).

Das Konzept von Hocheffizienz-Solarzellen mit einem Heteroübergang (*heterojunction technology HJT*) zwischen verschiedenen Schichten aus kristallinem und amorphem bzw. mikrokristallinem Silizium gewinnt unter dem aktuellen Kostendruck durch die marktübliche kristalline Technologie weiter an Bedeutung. Das PV-Lab erreichte hierzu bisher einen maximalen Wirkungsgrad 22,1 %. Wesentliche Industriekooperationen des PV-Lab er-

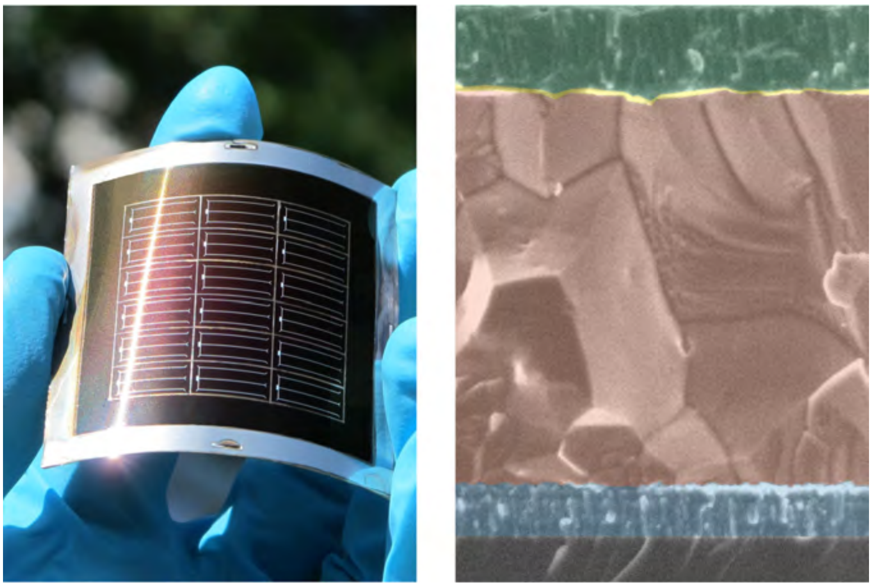


Figur 2: Als neue Kontaktelektroden von Silizium Heterjunction Solarzellen werden Ni/Cu Finger untersucht. Linker Bildteil: a) Sekundärelektronen SEM Bild eines Ni/Cu Fingers. b) EDX mapping von Kupfer, Nickel und Indium. c) Vergrösserte Sicht von zwei Defekten an der ITO/Ni Grenzschicht; rechter Bildteil: Strom-Spannungscharakteristik und Wirkungsgrad einer Silizium Heterjunction Solarzelle mit Kupfergitter, einem IO:H/ITO Front TCO Stack und einer MgF$_2$ Antireflexschicht. (Bildquelle EPFL [12], Copyright: IEEE).

folgen hierzu mit Meyer Burger und Roth & Rau in der Schweiz sowie mit verschiedenen weiteren in- und ausländischen Unternehmen.

Die derzeit wichtigsten Vertreter der Verbindungshalbleiter-Solarzellen sind CIGS und CdTe. Nachdem sich CdTe Solarzellen im Markt etabliert haben gewinnt auch die CIGS Technologie zunehmende Bedeutung. Nebst diesen Hauptvertretern der Verbindungshalbleiter-Solarzellen werden weltweit neue Materialvarianten erforscht, insbesondere in der Materialklasse der Kesteriten. Das Labor für Dünne Schichten und Photovoltaik an der Empa arbeitet dazu an unterschiedlichen Fragestellungen zu CIGS- und CdTe Solarzellen sowie Kesteriten ($Cu_2ZnSn(S, Se)_4$). Dabei interessieren auch bei diesen Technologien die Materialeigenschaften, Depositionsprozesse und -temperaturen (sowohl unter Vakuum, als auch bei Atmosphärendruck), die notwendigen Pufferschichten und die Substratwahl. Von besonderem Interesse sind flexible Solarzellen auf Kunststoffsubstraten. Hier erfolgt eine intensive Zusammenarbeit mit dem Empa-Spin-off-Unternehmen FLISOM.

Das Team an der Empa liegt mit seinen Resultaten weltweit weiterhin an der Spitze: Der Rekord-Wirkungsgrad einer CIGS Solarzelle auf Kunststoff von 20,4 % wurde vom Fraunhofer-Institut für Solare Energiesysteme (ISE) in Freiburg (Deutschland) verifiziert. Ein vom BFE unterstütztes Projekt an der Empa in Zusammenarbeit mit FLISOM befasst sich mit dem Aufbau einer pilotmässigen Anlage zur mehrstufigen Abscheidung von CIGS Solarzellen auf Kunststofffolien in einem roll-to-roll Prozess. Damit soll die Übertragung der erzielten Forschungsresultate auf industrienahe Verhältnisse erreicht werden. Die Anlage konnte im Labor weitgehend aufgebaut werden. Im Berichtsjahr konnte auch für CdTe Solarzellen auf flexiblen Substraten wichtige Fortschritte erarbeitet werden. Der dabei erreichte Wirkungsgrad beträgt 13,.8 % in Superstrat-Konfiguration auf Polyimid und 11,5 % in Substrat-Konfiguration auf Metallfolien, in beiden Fällen ein neuer Weltrekord (Fig.3).

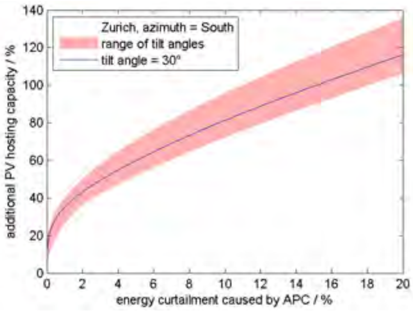


Figur 3: CdTe-Solarzellen auf einer flexiblen Metallfolie (links) und Elektronenmikroskop-Aufnahme (EM) des Zellaufbaus in der Substrat-Konfiguration (rechts) mit dem elektrischen Frontkontakt (oberste Schicht), der zentralen CdTe-Schicht und dem rückseitigen Kontakt aus Metall (unterste Schicht), deponiert auf einem Glasträger (Bildquelle Empa).

Integration von hohen Photovoltaik Anteilen im elektrischen Netz

Im Zusammenhang mit dem teils massiven Ausbau der installierten Photovoltaik Kapazität in verschiedenen Ländern ist die Frage nach der Integration dieser Anlagen im elektrischen Netz von einer konzeptionellen und theoretischen Frage rasch zu einer praxisrelevanten Problematik geworden. Das seit 2010 im Rahmen der PV-ERA.NET Kooperation laufende BFE-Projekt *Distribution Grid Analysis and Simulation with Photovoltaics* (DIGASP) wurde im Berichtsjahr durch Basler & Hofmann erfolgreich abgeschlossen [13]. Das Projekt untersucht die Frage, wie viel Photovoltaik ein Verteilnetz erträgt, und legt damit den Fokus auf Niederspannungs-Verteilnetze (Netzebene 6 und 7) in sowohl städtischen wie auch ländlichen Wohngebieten der Schweiz.

Dazu wurde ein spezifisches Simulationsmodell zur Lastflussanalyse erstellt und für unterschiedliche Annahmen ausgewertet. So konnte beispielsweise gezeigt werden, dass unter Berücksichtigung der Gleichzeitigkeit von Lasten und PV-Einspeisung fast 50 % mehr Solarstrom ans Netz abgegeben werden kann als ohne diese. Je mehr Standorte (Haushalte) einbezogen werden, desto höher wird die Aufnahmekapazität des Solarstroms. Ein anderes wichtiges Resultat betrifft die Abregelung von Leistungsspitzen der PV-Anlage. Der Verzicht von 2 % der Energie ermöglicht im untersuchten Beispiel eine zusätzliche PV-Aufnahmekapazität von rund 40 % (Fig. 4). Weitere Resultate betreffen die Auswirkung der Ausrichtung der PV-Module mit vermehrter Orientierung nach Osten und Westen auf die Leistung und den Energieertrag. Es zeigt sich, dass diese vieldiskutierte Massnahme die momentan abgegeben Leistung im Netz zwar reduziert, ebenso aber den Energieertrag, ausser bei sehr steilen Anstellungswinkeln der PV-Module. Im Weiteren wurde der Einfluss von dezentralen Speichereinheiten untersucht. Es konnte gezeigt werden, dass durch einen Speicher, welcher vier Stunden mal der nominalen Anlagenleistung entspricht, die Aufnahmekapazität des Verteilnetzes für PV-Anlagen um 200 % erhöht werden kann. Die Forschungsresultate fliessen auch in die Arbeiten des IEA PVPS Task 14 *High Penetration of PV Systems in Electricity Grids* ein.

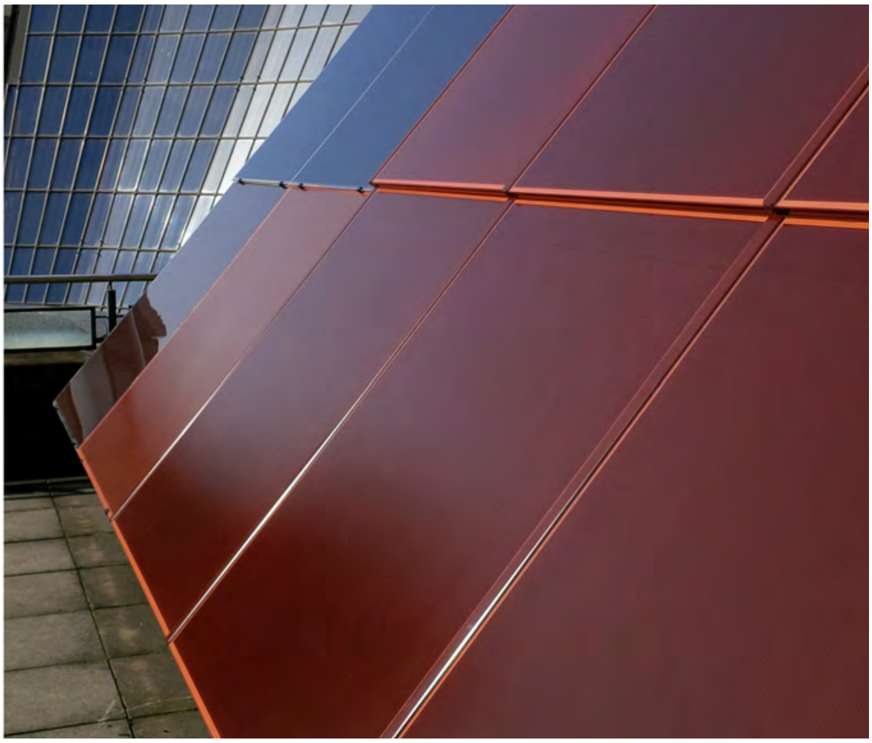


Figur 4: Einfluss der Wirkleistungsbegrenzung auf die bei der Netzeinspeisung von Photovoltaik-Anlagen mögliche Aufnahmekapazität, das Band gibt die Abhängigkeit vom Anstellwinkel der PV-Module wieder (Bildquelle Basler&Hofmann).

Pilot- und Demonstrationsprojekte

Photovoltaik Gebäudeintegration in vielen Farben

Das P+D-Projekt Archinsolar, welches verschiedene Partner und Förderorganisationen (BFE, swisselectric research, SIG, CCEM) vereint, wurde im Berichtsjahr durch das PV-Lab abgeschlossen. Es ging bei diesem Vorhaben in erster Linie darum, amorphe und mikromorphe Silizium-Dünnschichtsolarmodule mittels eines am LESO der EPFL in Lausanne entwickelten Interferenz-Verfahrens so zu gestalten, dass unterschiedliche Farben möglich werden. Damit soll eine neue und energetisch effizientere Art der Farbgebung (weniger Verluste) von Solarmodulen erzielt werden. Es wurden seit 2010 eine grössere Anzahl von verschiedenen farbigen und grossflächigen Demonstrationsmodulen sowie Dachziegel hergestellt (Fig.5). Dabei wurde der Verbundaufbau variiert und in Bezug auf Wirkungsgrad, Materialien, Funktionalität, Haftung, Dichtheit, Kosten sowie Umweltaspekte analysiert. Es zeigte sich anfänglich bei den Testmodulen, dass je nach Zusammensetzung der Farbfilter bei mikromorphen Solarmodulen eine bis zu rund doppelt so grosse Wirkungsgradreduktion beobachtet wird wie bei den amorphen Modulen. Durch geeignete Wahl der Interferenzstruktur konnte dieser Effekt weitgehend behoben werden. Nebst den eigentlichen Demonstrationsmodulen in unterschiedlichen Farben wurden Konzepte für farbige Solarziegel mit Komposit-Strukturen entwickelt und getestet.



Figur 5: Erste Prototypen von farbigen Dünnschicht PV-Modulen aus dem Projekt Archinsolar (Bildquelle PV-Lab, EPFL).

Figur 6: Grosse, leistungsfähige Photovoltaikanlagen, z. B. auf Gebäuden, entsprechen dem aktuellen Stand der Technik und sind immer häufiger anzutreffen. Neue Photovoltaiktechnologien müssen sich an diesen erprobten Konzepten messen können, in Bezug auf Wirkungsgrade, Kosten, Langlebigkeit wie auch die Ästhetik (Aufdachanlage mit Asbestsanierung, 1.928 MWp, Breitenbach (SO), Planung und Realisierung sowie Bildquelle: SOLVATEC AG).

Nationale Zusammenarbeit

Im Berichtsjahr wurde die vielfältige nationale Zusammenarbeit in verschiedenen Projekten weiter intensiviert. Die Schweizer Photovoltaik Kompetenzzentren arbeiten immer häufiger in gemeinsamen, häufig themenübergreifenden Projekten zusammen, z. B. in Projekten des CCEM. Damit hat sich der Austausch innerhalb der Schweizer Photovoltaik Forschungsgemeinschaft deutlich verstärkt. Die Zusammenarbeit mit Industrieunternehmen konnte ebenfalls ausgebaut werden, sowohl in neuen Projekten mit Unterstützung der KTI, als auch in der Form von direkten Mandaten der Industrie an ausgewählte Forschungsinstitute. Als wichtigstes neues Element ist das CSEM Photovoltaik Technologiezentrum zu erwähnen, welches anfangs 2013 seinen Betrieb aufgenommen hat. Es soll die industrienahe Forschung mit allen wichtigen Schweizer Photovoltaik Kompetenzzentren nachhaltig stärken. Auf Programmebene wurde die Zusammenarbeit mit vielen Stellen des Bundes, der Kantone und der Elektrizitätswirtschaft weiter gepflegt. Mit dem Aktionsplan Koordinierte Energieforschung, der Nano-Tera Initiative und den neuen Schwerpunktprogrammen NFP 70 und 71 des Schweizerischen Nationalfonds, dem erwähnten CSEM Photovoltaik Technologiezentrum mit Unterstützung des SBFI und der Erhöhung der BFE-Mittel für P+D Projekte haben sich wesentliche Randbedingungen für die beschleunigte Entwicklung und Umsetzung der Forschung positiv entwickelt.

Internationale Zusammenarbeit

Die institutionelle Zusammenarbeit innerhalb der IEA, der IEC und der europäischen Netzwerkprojekte wurde im Berichtsjahr kontinuierlich fortgesetzt. Auf der Projektebene konnte die Zusammenarbeit innerhalb der EU in bestehenden und neuen Projekten erfolgreich fortgesetzt werden. Im Jahr 2013 waren es 18 Projekte im 7. Rahmenforschungsprogramm der EU bzw. 4 Grundlagen-Projekte mit Unterstützung des European Research Council. Die Beteiligung am Photovoltaikprogramm der IEA (IEA PVPS) wurde im Berichtsjahr fortgesetzt, sowohl auf der Projektebene als auch im Executive Committee (ExCo) [14]. Im Berichtsjahr begann die 5. Phase dieses Programms mit einer neu definierten Strategie. 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 2012 [15] ausgearbeitet. Auf dieser Grundlage wurde die 18. Ausgabe des jährlichen internationalen Berichtes (Trends Report) über die Marktentwicklung der Photovoltaik in den IEA-Ländern erstellt [16]. Im Rahmen der interdepartementalen (SECO, DEZA, BAFU, BFE) REPIC Plattform zur Förderung der erneuerbaren Energien und der Energieeffizienz in der internationalen Zusammenarbeit [17] leistet das Beratungsunternehmen 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. Treeze 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. TNC vertritt die Schweiz im IA PVPS Task 13 zu Performance und Zuverlässigkeit von Photovoltaikanlagen, welcher in der Schweiz durch den IEA PVPS Pool (aktuell getragen von ewz., Gesellschaft Mont Soleil und Swissolar) gefördert wird. Im Berichtsjahr hat TNC eine internationale Datenbank für Photovoltaik fertiggestellt [18], mit welcher weltweit Erfahrungen und Resultate aus vermessenen Photovoltaik Anlagen gesammelt und analysiert werden können. Im Projekt werden zudem Methoden zur Charaktierisierung und normierten Messung von Photovoltaikmodulen entwickelt sowie entsprechende Erfahrungen, z. B. zu Fehlverhalten von Modulen, ausgetauscht. In diese Aktivität ist auch das ISAAC SUPSI mit seinen relevanten Aktivitäten eingebunden. Eine Arbeitsgruppe unter Leitung von Planair vertritt die Schweiz im IA PVPS Task 14 zur hohen Penetration von PV-Anlagen in elektrischen Netzen. Auch dieser Schweizer Beitrag wird durch den IEA PVPS Pool unterstützt. Das Projekt gewinnt aufgrund des starken Wachstums der Photovoltaik in einzelnen Ländern bzw. Regionen rasch an Bedeutung und stösst damit auf grosses internationales Interesse. Erste Projektresultate betreffen hier Vorhersagemodelle und Fallstudien zu hoher Photovoltaik Netzpenetration [19]. Das Unternehmen Meteotest und die Groupe Energie an der Universität Genf erbringen zusammen den Schweizer Beitrag zum Task 46 Solar resource assessment and forecasting. Task 46 ist Bestandteil des IA Solare Wärme und Kälte (SHC) der IEA [20], 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 werden die Auswirkungen von Strahlungsänderungen und Vorhersagen auf die solare Energieproduktion bei hoher Dichte von Solaranalgen sowie die Verfügbarmachung der entsprechenden Daten bearbeitet. Basler & Hofmann vertritt die Schweiz im Auftrag von Swissolar im TC 82 der IEC zu Photovoltaik-Normen [21]. Das neue EU-Projekt SOLAR-ERA.NET [22] nahm im Berichtsjahr seine Aktivitäten voll auf. Es umfasst nebst der Photovoltaik auch die konzentrierende solarthermische Energie und soll die Umsetzung der Solar Europe Industry Initiative unterstützen. Das Projekt führt rund 20 nationale und regionale Forschungs- und Innovationsprogramme zusammen und wird durch die Schweiz (Programmleitung Photovoltaik) koordiniert. Im Berichtsjahr wurde eine erste gemeinsame Ausschreibung durchgeführt, welche auf grosses Interesse stiess. Die entsprechenden Projekte sollen im Verlauf von 2014 konkret beginnen. Die Schweiz ist zudem in der Europäischen Photovoltaik-Technologie-Plattform sowohl im Steuerungsausschuss, als auch in der Mirror Group vertreten [23].

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Laufende und im Berichtsjahr abgeschlossene Projekte

(* IEA-Klassifikation)

THIN LAYERS FOR HIGH-EFFICIENCY SILICON SOLAR CELLS THROUGH IDEAL COUPLING OF INDIVIDUAL COMPONENTS

R+D (1a) 3.1.2*

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	BFE
Contact:	Ballif Christophe christophe.ballif@epfl.ch	Period:	2012–2014

Abstract: The project focuses on the increase in efficiency of thin film silicon devices, and also contributes to developments that can be implemented for high efficiency crystalline heterojunction solar cells. The final objective is to bring new findings to the research field that provides new routes for increased module efficiencies for similar costs, without impacting the reliability.

DEMONSTRATION OF HIGH PERFORMANCE PROCESSES AND EQUIPMENTS FOR THIN FILM SILICON PHOTOVOLTAIC MODULES PRODUCED WITH LOWER ENVIRONMENTAL IMPACT (PEPPER)

R+D (1a) 3.1.2

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

Abstract: The FP7 EU PEPPER project aims at achieving high efficiency (11%) micromorph (amorphous/microcrystalline silicon tandem) modules at low cost (CoO ≤ 0.5 €/Wp) while reducing the environmental impact of fabrication processes.

ACCELERATED DEVELOPMENT AND PROTOTYPING OF NANO-TECHNOLOGY-BASED HIGH-EFFICIENCY THIN-FILM SILICON SOLAR MODULES (FAST TRACK)

R+D (1a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	EU
Contact:	Ballif Christophe christophe.ballif@epfl.ch	Period:	2012–2015

Abstract: The main project goals are the development of innovative photovoltaic cell processes and their up-scaling to the level of pilot lines. These goals should be reached in terms of stable device efficiency higher than 14% and a prototype module with stable efficiency higher than 12%.

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:	2009–2013

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

HIGH RATE DEPOSITION OF MICROCRYSTALINE SILICON FOR SOLAR CELL APPLICATIONS BY MEANS OF A RESONANT NETWORK RF ANTENNA

R+D (1a) 3.1.2

Lead:	EPFL - CRPP	Funding:	KTI
Contact:	Tran Minh Quang minhquang.tran@epfl.ch	Period:	2013–2015

Abstract: To change from the traditional capacitively coupled plasma reactor to inductively coupled devices might reduce the cost and increase the efficiency of thin film solar cells. In the present project a plasma box reactor equipped with a resonant network RF antenna will be constructed and, as main topic, PV related material will be aimed for under these conditions. The project will lead to a concept and design of a novel PECVD production reactor.

HIGH EFFICIENCY TRIPLE JUNCTION THIN FILM SILICON SOLAR CELLS IMPLEMENTING AMORPHOUS SILICON GERMANIUM ALLOY (TRIGGER)

R+D (1a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	KTI
Contact:	Ballif Christophe christophe.ballif@epfl.ch	Period:	2012–2015

Abstract: Advanced triple junction solar cell will be developed to further enhance the conversion efficiency of thin film silicon solar cells. High quality silicon germanium alloys will be synthesized on textured substrates, and implemented in the triple junction solar cells. Record devices will be developed on state-of-the-art substrates as well as on advanced electrodes.

NOVEL REFLECTIVE LAYER ALLOWING A CONTROL OF THE QUALITY OF THE MICROCRYSTALLINE SOLAR CELL IN THIN FILM MICROMORPH DEVICES

R+D (1a) 3.1.2

Lead:	HE-ARC	Funding:	KTI
Contact:	Keppner Herbert herbert.keppner@he-arc.ch	Period:	2011–2013

Abstract: The project aims to create an innovative smoothening reflective layer SRL that will be inserted between the top and bottom cell of a Micromorph tandem device deposited on as-grown thick highly textured LPCVD ZnO layer.

HISOCEL: IMPROVEMENT OF FRONT CONTACTS MORPHOLOGY FOR ENHANCEMENT OF EFFICIENCY IN THIN FILM SILICON SOLAR CELLS

R+D (1a) 3.1.2

Lead:	CSEM	Funding:	KTI
Contact:	Dadras Massoud massoud.dadras@csem.ch	Period:	2012–2013

Abstract: The aim of this project is to improve the front contacts of tandem microcrystalline & amorphous silicon solar cells to reach an efficiency of 13% by producing denser and nearly defect free silicon layers.

CONTROL OF TRAVELING EM WAVES IN LARGE AREA (VHF) PECVD REACTORS FOR THE PRODUCTION OF COMPETITIVE SOLAR PANELS

R+D (1a) 3.1.2

Lead:	NTB Fachhochschule Buchs	Funding:	KTI
Contact:	Würsch Christoph christoph.wuersch@ntb.ch	Period:	2013–2014

Abstract: In order to increase market share and the economic viability of silicon thin film photovoltaic electricity, the production costs must be reduced and module efficiency improved. This project evaluates alternative concepts for the Plasma Enhanced Chemical Vapour Deposition of silicon films deposited over large areas substrates (>1.4 m2) and sustained at very high frequencies (40–200 MHz).

FEASIBILITY STUDY FOR THE ATMOSPHERIC PLASMA JET DEPOSITION OF TRANSPARENT CONDUCTIVE OXIDE FOR THIN-FILM SOLAR CELL APPLICATIONS (JETCO)

R+D (1a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	KTI
Contact:	Wyrsch Nicolas nicolas.wyrsch@unine.ch	Period:	2012–2014

Abstract: This project will investigate the possibility to use the atmospheric arc plasma jet technology developed by Swissnanocoat in order to deposit transparent conductive oxide films to be used as thin film silicon solar cells front electrodes. These films should be characterized by high transmission (above 85%), low resistivity (below 10-3 Ohm cm) and offer the possibility to achieve surface texturation for light scattering in the solar devices.

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: Optical gratings can be used to increase the light absorption in thin film solar cells. 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 crossed gratings rigorously.

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

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	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.

DEVELOPMENT OF THIN HIGH-EFFICIENCY LARGE-AREA INTERDIGITATED BACK CONTACT SILICON HETEROJUNCTION SOLAR CELLS FOR MASS PRODUCTION (HET-IBC)

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	KTI
Contact:	Ballif Christophe christophe.ballif@epfl.ch	Period:	2012–2014

Abstract: The HET-IBC project aims at the development of an industrial process for the manufacture of high efficiency large-area interdigitated back contact silicon heterojunction solar cells on thin Si wafers. This type of device is amongst the most promising ones for ultra-high conversion efficiencies, low production costs and easier assembly into solar modules.

ENTWICKLUNG VON KRISTALLINEN SILIZIUM-SOLARZELLEN UND -MODULEN MIT HÖHEREM WIRKUNGSGRAD UND BESSERER ENERGIEAUSBEUTE (NODHID)

R+D (1b) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB	Funding:	Axpo Naturstrom
Contact:	Ballif Christophe christophe.ballif@epfl.ch	Period:	2011–2013

Abstract: Entwicklung von kristallinen Silizium-Solarzellen und -modulen mit höherem Wirkungsgrad und besserer Energieausbeute

CIGS MULTI-STAGE INLINE DEMONSTRATION

P+D (1c) 3.1.2

Lead:	EMPA Dübendorf	Funding:	BFE
Contact:	Tiwari Ayodhya N. ayodhya.tiwari@empa.ch	Period:	2011–2013

Abstract: The goal of the project is to develop and demonstrate a CIGS deposition system where the innovative multi-stage co-evaporation process developed in the lab for small area substrates in static positions can be scaled up for coating on in-line moving large area substrates.

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

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf	Funding:	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.

ROLL-TO-ROLL MANUFACTURING OF HIGH EFFICIENCY AND LOW COST FLEXIBLE CIGS SOLAR MODULES (R2R-CIGS)

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf	Funding:	EU
Contact:	Tiwari Ayodhya N. ayodhya.tiwari@empa.ch	Period:	2012–2015

Abstract: The aim of R2R-CIGS is to develop efficient flexible solar modules by implementing innovative cost-effective processes such that production costs below 0.5€/Wp can be achieved in large volume factories with annual capacity of 500MWp in future.

FLEXIBLE PHOTOVOLTAIC CELLS OPTIMIZED FOR HIGH CONVERSION EFFICIENCY FROM INDOOR TO OUTDOOR ILLUMINATION CONDITIONS, USED IN NEW WRISTWATCH PRODUCTS

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf	Funding:	KTI
Contact:	Tiwari Ayodhya N. ayodhya.tiwari@empa.ch	Period:	2013–2015

Abstract: This project aims at developing flexible CIGS photovoltaic (PV) cells optimized for high conversion efficiency from low (indoor) to high (outdoor) illumination intensity. The project includes the development of CIGS PV dials for classic wristwatches, as well as a second generation for solar wristwatches integrating highly flexible CIGS PV cells in the bracelet with conversion efficiencies above 8 % under low illumination intensity.

PERFORMANCE STABILITY OF FLEXIBLE CIGS SOLAR MODULES

R+D (1c) 3.1.2

Lead:	EMPA Dübendorf	Funding:	KTI
Contact:	Tiwari Ayodhya N. ayodhya.tiwari@empa.ch	Period:	2013–2015

Abstract: Development of flexible CIGS solar modules for high performance and low cost are essential for diverse applications. Long term performance evaluation of encapsulated solar modules through accelerated tests and analyses of degradation and failure mechanisms on microscopic and macroscopic levels are necessary for proving improved long term performance stability and enabling market entry readiness.

ALL LASER SCRIBING OF CIGS PHOTOVOLTAIC PANELS ON RIGID SUBSTRATES

R+D (1c) 3.1.2

Lead:	Berner Fachhochschule HTI	Funding:	KTI
Contact:	Romano Valerio valerio.romano@bfh.ch	Period:	2012–2013

Abstract: In the whole manufacturing process the laser scribing step is one of the key processes to produce high efficient solar modules. With narrow scribing line widths and high precision processing tools the non effective zone on solar panels (dead zone) can be reduced to a minimum. Within this project an industrial scribing machine will be developed for an all laser scribing process for CIGS.

TRAINING FOR SUSTAINABLE LOW COST PV TECHNOLOGIES: DEVELOPMENT OF KESTERITE BASED EFFICIENT SOLAR CELLS

R+D (1c) 3.1.2

Lead:	EMPA	Funding:	EU
Contact:	Romanyuk Yaroslav Yaroslav.Romanyuk@empa.ch	Period:	2012–2016

Abstract: The project proposes the development of new technologies compatible with the cost, efficiency, sustainability and mass production requirements that are needed to become a reliable and future alternative to conventional non renewable energy sources. With this objective in mind, the project will focus on the development of kesterite based solar cells.

DEVELOPMENT AND SCALE-UP OF NANOSTRUCTURED BASED MATERIALS AND PROCESSES FOR LOW COST HIGH EFFICIENCY CHALCOGENIDE BASED PHOTOVOLTAICS (SCALENANO)

R+D (1c) 3.1.2

Lead:	SUPSI ISAAC	Funding:	EU
Contact:	Virtuani Alessandro alessandro.virtuani@supsi.ch	Period:	2012–2015

Abstract: This project will exploit the potential of chalcogenide based thin film photovoltaic technologies for the development and scale-up of new processes based on nano-structured materials for the production of high efficiency and low cost photovoltaic devices and modules compatible with mass production requirements.

DURSOL - EXPLORING AND IMPROVING DURABILITY OF THIN FILM SOLAR CELLS

R+D (1d) 3.1.2

Lead:	EMPA	Funding:	diverse
Contact:	Nüesch Frank frank.nuesch@empa.ch	Period:	2011–2013

Abstract: The project's objectives are focused towards the understanding of fundamental degradation phenomena in thin film solar cells and enhancement of lifetime.

DYE SENSITISED NANOCRYSTALLINE SOLAR CELLS

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI	Funding:	diverse
Contact:	Graetzel Michael michael.graetzel@epfl.ch	Period:	2000-

Abstract: Key activities concerning dye sensitised nanocrystalline solar cells at EPFL.

ESCORT - EFFICIENT SOLAR CELLS BASED ON ORGANIC AND HYBRID TECHNOLOGY

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI	Funding:	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.

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

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI	Funding:	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.

SANS - SENSITIZER ACTIVATED NANOSTRUCTURED SOLAR CELLS

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI	Funding:	EU
Contact:	Graetzel Michael michael.graetzel@epfl.ch	Period:	2011–2013

Abstract: Plastic electronics and solution-processable inorganic semiconductors can revolutionise the photovoltaic industry due to their relatively easy and low cost processability (low embodied energy). The project aims at achieving significant progress in the materials for this type of solar cells.

FARBSTOFF-SOLARZELLEN AUF SEFAR PRÄZISIONSGEWEBEN

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI	Funding:	KTI
Contact:	Graetzel Michael michael.graetzel@epfl.ch	Period:	2012–2014

Abstract: The project aims to enhance market readiness of dye sensitized solar cells (DSC) by developing electrodes based on transparent and conductive precision fabrics.

NOVEL ENVIRONMENTALLY FRIENDLY SOLUTION PROCESSES NANOMATERIALS FOR PANCHROMATIC SOLAR CELLS

R+D (1d) 3.1.2

Lead:	EPFL ISIC-LPI	Funding:	EU
Contact:	Graetzel Michael michael.graetzel@epfl.ch	Period:	2013–2015

Abstract: In this project a disruptive approach is proposed for dye-sensitized solar cells (DSSC); to replace titania with a novel electron accepting nanoporous semiconductor with a bandgap suitable for optimized solar harnessing and a very high absorption coefficient to allow total light absorption within 2 um across its absorption spectrum.

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

R+D (1d) 3.1.2

Lead:	Solaronix SA	Funding:	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.

FIRST PRINCIPLES SIMULATIONS OF THE ELECTRON DYNAMICS IN DYE SENSITIZED SOLAR CELLS

R+D (1d) 3.1.2

Lead:	ETH Zürich	Funding:	SNF
Contact:	VandeVondele Joost joost.vandevondele@mat.ethz.ch	Period:	2011–2016

Abstract: The research focus is on the development of new methods to enable ab initio molecular dynamics simulations of complex systems with modern density functional theory. New methods, implemented for massively parallel computers, are applied to a wide range of systems such as radicals in clusters and the condensed phase, surface physics, and interfacial systems such as dye sensitized solar cells.

MESOLIGHT - MESOSCOPIC JUNCTIONS FOR LIGHT ENERGY HARVESTING AND CONVERSION

R+D (1d) 3.1.2

Lead:	EPFL	Funding:	ERC
Contact:	Graetzel Michael michael.graetzel@epfl.ch	Period:	2010–2015

Abstract: Research will focus on the generation of electric power by mesoscopic solar cells. The target is to increase the photovoltaic conversion efficiency from currently 11 to over 15 percent rendering these new solar cells very attractive for applications in large areas of photovoltaic electricity production.

UPCON - ULTRA-PURE NANOWIRE HETEROSTRUCTURES AND ENERGY CONVERSION

R+D (1d) 3.1.2

Lead:	EPFL	Funding:	ERC
Contact:	Anna Foncuberta i Morral anna.fontcuberta-morral@epfl.ch	Period:	2010–2014

Abstract: This project is devoted to the synthesis of ultra pure semiconductor nanowire heterostructures for energy conversion applications in the photovoltaic domain.

TRANSPARENT ELECTRODES FOR LARGE AREA, LARGE SCALE PRODUCTION OF ORGANIC OPTOELECTRONIC DEVICES

R+D (1d) 3.1.2

Lead:	EMPA Dübendorf	Funding:	EU
Contact:	Nüesch Frank frank.nuesch@empa.ch	Period:	2011–2015

Abstract: TREASORES will demonstrate the production of large area organic electronics using high throughput manufacturing technologies based on roll-to-roll (R2R) wet deposition processes.

SUSTAINABLE NOVEL FLEXIBLE ORGANIC WATTS EFFICIENTLY RELIABLE

R+D (1d) 3.1.2

Lead:	CSEM Muttenz	Funding:	EU
Contact:	Nisato Giovanni giovanni.nisato@csem.ch	Period:	2011–2015

Abstract: The project addresses the current challenges of organic photovoltaics (OPV) which reside in the combination to increase efficiencies to 8-10% (module level), increase expected lifetime up to 20 years and decrease production costs to 0.7 Eur/Wp, while taking into account the environmental impact and footprint.

DEVELOPMENT OF LUMINESCENT SOLAR CONCENTRATORS

R+D (1e) 3.1.2

Lead:	ZHAW IEFE		Funding:	diverse
Contact:	Brühwiler Dominik	dominik.bruehwiler@zhaw.ch	Period:	2011–2015

Abstract: Das hier untersuchte Konzept von Lumineszenzkonzentratoren baut auf der Grundlage der Förster Resonance Energy Transfer (FRET) Frequenzverschiebung auf. Hierzu werden geeignete Materialien mit den gewünschten Eigenschaften entwickelt.

LUMINESCENT SOLAR CONCENTRATORS - GEWINNUNG ELEKTRISCHER ENERGIE AUS TÖNUNGEN FÜR FENSTERSCHEIBEN UND FASSADENELEMENTE

R+D (1e) 3.1.2

Lead:	Optical Additives GmbH		Funding:	BFE
Contact:	Andreas Kunzmann	andreas.kunzmann@optical-additives.com	Period:	2013–2015

Abstract: Mit dem Projekt soll das Konzept des Lumineszenzkonzentrators für die Bedingungen in Aussenanwendungen, insbesondere in Fenstern und Fassaden, weiter entwickelt werden. Dabei stehen lichtstabile Farbstoff-Zeolithen im Vordergrund, welche eine angemessene Langzeitstabilität erreichen.

OPTIMIZED METHODS FOR INCREASED PERFORMANCE PHOTOVOLTAIC CELLS BY NANOPARTICLES INTEGRATION (OPTINOGEN)

R+D (1e) 3.1.2

Lead:	EIA-FR		Funding:	Sciex
Contact:	Niederhaeuser Elena Lavinia	Elena-Lavinia.Niederhaeuser@hefr.ch	Period:	2011–2013

Abstract: The project targets the optimization and the development of new improved methods for enhancing of the overall performance and stability of nanocomposite solar cells (NSC) by introducing new physical principles.

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

R+D (1e) 3.1.2

Lead:	Universität Bern, Dep. Chemie & Biologie		Funding:	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.

DIAMOND: DISCOVERY AND INSIGHT WITH ADVANCED MODELS OF NANOSCALE DIMENSIONS

R+D (1e) 3.1.2

Lead:	ETH Zürich		Funding:	ERC
Contact:	VandeVondele Joost	joost.vandevondele@mat.ethz.ch	Period:	2011–2016

Abstract: In this project, it is proposed to advance the current state of the art in atomistic modeling of complex systems. The goals are providing and establishing new tools that will allow for the description of large multi-component/multi-phase systems at experimental temperature and pressure with predictive power and controlled error.

LIGHT-IN, LIGHT-OUT: CHEMISTRY FOR SUSTAINABLE ENERGY TECHNOLOGIES (LILO)

R+D (1e) 3.1.2

Lead:	Uni Basel, Institut für Anorganische Chemie		Funding:	ERC
Contact:	Constable Edwin Charles	Edwin.Constable@unibas.ch	Period:	2011–2016

Abstract: The project is concerned with a coordinated approach to the development of of novel chemical strategies for light harvesting by photovoltaic cells and light generation using light emitting electrochemical cells.

NOVEL PRODUCTION EQUIPMENT FOR NOVEL PHOTOVOLTAIKC MODULE DESIGNS USING NEW ENCAPSULANTS

R+D (2a) 3.1.2

Lead:	EPFL STI IMT-NE PV-LAB		Funding:	KTI
Contact:	Ballif Christophe	christophe.ballif@epfl.ch	Period:	2012–2014

Abstract: The main target of this project is the development and the market launch of novel laminating lines optimized for the production of PV modules based on novel module designs using new encapsulants.

SMARTWIRE - DEVELOPMENT OF MULTI-WIRE MODULE DESIGN TECHNOLOGY AND PRODUCTION EQUIPMENT

R+D (2a) 3.1.2

Lead:	CSEM	Funding:	KTI
Contact:	Despeisse Matthieu matthieu.despeisse@csem.ch	Period:	2013–2015

Abstract: The SmartWire project goals are the development of a new generation of crystalline silicon (c-Si) solar cells interconnection technology, the design of an associated module technology and the prototyping of dedicated high-end production equipment, which can allow for modules with increased efficiency (> 5 % relative gain) and reduced manufacturing cost (> 10 % relative reduction) for high efficiency c-Si cell technologies.

UNIQUE AND INNOVATIVE SOLUTION OF THIN SILICON FILMS MODULES BUILDING INTEGRATION (ARCHINSOLAR)

P+D (2a) 3.1.2

Lead:	CSEM	Funding:	BFE
Contact:	Perret-Aebi Laure-Emmanuelle laure-emmanuelle.perret@csem.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).

CONSTRUCT PV - CONSTRUCTING BUILDINGS WITH CUSTOMIZABLE SIZE PV MODULES INTEGRATED IN THE OPAQUE PART OF THE BUILDING SKIN

R+D (2a) 3.1.2

Lead:	SUPSI ISAAC	Funding:	EU
Contact:	Frontini Francesco francesco.frontini@supsi.ch	Period:	2013–2017

Abstract: Construct-PV will develop and demonstrate customizable, efficient, and low cost BIPV for opaque surfaces of buildings. Opaque surfaces are selected because they represent massive wide-area spaces of untapped harvesting potential across Europe. To develop highly efficient systems, most promising PV technologies have been selected, i.e. back contact cells fabricated with MWT technology.

LOW-COST PV BITUMINOUS-MODIFIED ROOFING MEMBRANE WITH FULL INTEGRATION OF HIGH EFFICIENCY FLEXIBLE THIN-FILM SILICON PV MODULES (PV-GUM)

R+D (2a) 3.1.2

Lead:	nolax AG	Funding:	EU
Contact:	David Koch david.koch@nolax.com	Period:	2010–2013

Abstract: The PV-GUM project aims at developing new manufacturing technologies and equipments which will produce a low cost highly efficient flexible BIPV solar cell on a bituminous roofing membrane.

PRODUKTENTWICKLUNG SOLAR DEVICE

R+D (2a) 3.1.2

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

Abstract: In diesem Projekt wird die Technologie der hocheffizienten textilen Photovoltaik bis zur Produktionsreife weiterentwickelt. Diese Produktentwicklung wird die Markteinführung von textiler Photovoltaik beschleunigen.

OPTIMIZATION OF THIN FILM MODULE TESTING AND PV MODULE ENERGY RATING AT SUPSI

R+D (2c) 3.1.2

Lead:	SUPSI ISAAC	Funding:	BFE
Contact:	Friesen Gabi gabi.friesen@supsi.ch	Period:	2011–2014

Abstract: This project aims to improve the measurment accuracy for thin film technologies throgh th definition of new test procedures and the up-grade of the test equipment.

TOOLS FOR ENHANCED PHOTOVOLTAIC SYSTEM PERFORMANCE

R+D (2c) 3.1.2

Lead:	SUPSI ISAAC	Funding:	EU
Contact:	Chianese Domenico domenico.chianese@supsi.ch	Period:	2012–2015

Abstract: For a continued decrease of levelised costs of energy from photovoltaics (PV), the prices of PV system components have to be further decreased while performance, functionality, reliability and lifetime on the component and system level need to be increased. The Performance Plus project focuses on the PV system rather than on the component level. The main idea of the project is to optimise the system as a whole rather than the separate components.

ENTWICKLUNG EINES TESTPRÜFSTANDES ZUR ÜBERPRÜFUNG DES EINFLUSSES VON WIND- UND SCHNEELASTEN AUF SOLARTHERMISCHE ODER PHOTOVOLTAISCHE ANLAGENSYSTEME

R+D (2c) 3.1.2

Lead:	HSR		Funding:	KTI
Contact:	Bohren Andreas	andreas.bohren@solarenergy.ch	Period:	2012–2013

Abstract: Die in den letzten Jahren gemachten Erfahrungen mit Sonnenenergiesystemen auf Schrägdächern haben gezeigt, dass die in den Normen beschriebenen Wind- und Schneelasten nur bedingt auf solche Anlagen anwendbar sind. Um die Widerstandsfähigkeit solcher Anlagen beurteilen zu können, ist ein Teststand zur unabhängigen Aufbringung von Flächenlasten und Parallellasten (Hangabtrieb von Schneelasten) nötig.

CARACTÉRISATION DES MODULES PHOTOVOLTAÏQUES À COLORANT DE L'ENTREPRISE G2E

P+D (2d) 3.1.2

Lead:	HEIG-VD		Funding:	BFE
Contact:	Affolter Jean-François	jean-francois.affolter@heig-vd.ch	Period:	2012–2014

Abstract: A solar simulator for measuring the performance of solar panels based on dye sensitised solar cells is going to be realized. The panels will be installed in real conditions and monitored over a complete year, in order to characterize and have the necessary perspective on this new technology and product.

PHOTOVOLTAIK IM VERBUND MIT DÄMMSTOFF FOAMGLAS

P+D (2d) 3.1.2

Lead:	Basler & Hofmann AG		Funding:	BFE
Contact:	Eric Langenskiöld	eric.langenskioeld@baslerhofmann.ch	Period:	2010–2013

Abstract: The scope of this project is the development and realisation of building integrated photovoltaic (BIPV) including the feature of thermal insulation. A pilot plant with modules combined of photovoltaic modules and Foamglas insulation shall be build.

SOLAR BRICK: INNOVATIVE PHOTOVOLTAIC AND THERMAL INSULATING BUILDING MATERIALS

R+D (2d) 3.1.2

Lead:	SUPSI ISAAC		Funding:	KTI
Contact:	Rudel Roman	roman.rudel@supsi.ch	Period:	2011–2013

Abstract: The goal of this project is to develop a photovoltaic and thermal insulating building material and in parallel to plan and construct a prototype installation including said material.

NEUARTIGES LEICHTBAU PHOTOVOLTAIK SYSTEM, DAS DIE DOPPELNUTZUNG VON FLÄCHEN IM URBANEN BEREICH FÜR DIE ERZEUGUNG VON ERNEUERBARER ENERGIE ERMÖGLICHT

R+D (2d) 3.1.2

Lead:	ZHAW IEFE		Funding:	KTI
Contact:	Baumgartner Franz	franz.baumgartner@zhaw.ch	Period:	2013–2014

Abstract: Entwicklung eines Leichtbau-Solarkraftwerks mit einerseits neuartigen Meteo Algorithmen zur Sicherstellung der Robustheit und Minimierung der Ertragsverluste und andererseits Machbarkeitsabklärungen (einschliesslich Konzeptsstudie) für ein Leichtbau-Tragwerk unter Verwendung von Faserverbundkunststoff Hybrid-Bauelementen.

PRODUKTENTWICKLUNG PV/T SOLARKOLLEKTOR MIT INSTALLATIONSSYSTEM

R+D (2d) 3.1.2

Lead:	Hochschule für Technik Rapperswil HSR		Funding:	KTI
Contact:	Rommel Matthias	matthias.rommel@solarenergy.ch	Period:	2011–2014

Abstract: Das Ziel des Projekts ist die Entwicklung eines unabgedeckten Niedertemperatur PV/T-Kollektors und eines dazu optimierten Installationssystems. Ausgangspunkt für die Entwicklung sind Standard PV-Module on 3S für den Kollektor sowie auf dem Markt erhältliche Komponenten für das Installationssystem.

PV FASSADEN - ENTWICKLUNG UND PRÜFUNG VON VORGEHÄNGTEN HINTERLÜFTETEN FASSADEN AUS PV MODULEN UND PERFORIERTEM METALL

R+D (2d) 3.1.2

Lead:	HTA Luzern		Funding:	KTI
Contact:	Wittkopf Stephen	stephen.wittkopf@hslu.ch	Period:	2013–2015

Abstract: Im Rahmen dieses Projekts werden neuartige hinterlüftete Photovoltaik Fassaden Module (PV-FM) entworfen, hergestellt und gestestet. Sie bestehen aus einer Kombination von PV-Modulen und Lochblechen zur Verwendung in Fassaden und Steildächern. Dabei werden architektonische, energetische und konstruktive Aspekte berücksichtigt, die einzeln und im Zusammenspiel untereinander optimiert werden.

LANGZEIT-MESSUNG VON PV-ANLAGEN

R+D (3) 3.1.2

Lead:	BFH Burgdorf	Funding:	Diverse
Contact:	Muntwyler Urs urs.muntwyler@bfh.ch	Period:	2012–2016

Abstract: Das PV Labor führt Langzeit-Messungen an unterschiedlichen PV-Anlagen durch und dokumentiert damit das längerfristige Verhalten dieser Anlagen.

PRÜFSTAND FÜR MULTISTRING SOLARWECHSELRICHTER

R+D (3) 3.1.2

Lead:	BFH Burgdorf	Funding:	BFE
Contact:	Muntwyler Urs urs.muntwyler@bfh.ch	Period:	2013–2015

Abstract: The goal of this project is the development and the construction of a low EMI test bench for research and testing of multistring PV inverters. The test bench shall be able to simulate three independent sub arrays with open circuit voltage of up to 1'000V and maximum power of 11.52kW each. The thermal stability of the generated I/V characteristics shall be sufficiently high to allow measurements of the inverter's MPP tracking accuracy.

PHOTOVOLTAÏQUE ET NEIGE: HORIZON DES SOLUTIONS POUR L'INSTALLATION SUR LES TOITS DANS LES RÉGIONS ENNEIGÉES

P+D (3) 3.1.2

Lead:	Planair SA	Funding:	BFE
Contact:	Perret Lionel lionel.perret@planair.ch	Period:	2011–2014

Abstract: Seven different photovoltaic fields and three snow clearing solutions were implemented. Measures on different parameters such as production and consumption of each field will occurre during the winters of 2012, 2013 and 2014. The evaluation of the measures will enable to determine snow impact and compare different photovoltaic technologies and snow clearing solutions.

DISTRIBUTION GRID ANALYSIS AND SIMULATION WITH PHOTOVOLTAICS (DIGASP)

R+D (3) 3.1.2

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

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.

DIGITALER LICHTBOGENDETEKTOR FÜR PV-WECHSELRICHTER

R+D (3) 3.1.2

Lead:	BFH Burgdorf	Funding:	KTI
Contact:	Muntwyler Urs urs.muntwyler@bfh.ch	Period:	2012

Abstract: In diesem Projekt besteht die Innovation in der Entwicklung eines digitalen Lichtbogen-Detektionsalgorithmus und der Industrialisierung eines Lichtbogendetektors für dessen Integration in einen Wechselrichter.

HIGH CONCENTRATION PHOTOVOLTAIC THERMAL SYSTEM USING LOW-COST INNOVATIVE MATERIALS

R+D (3) 3.1.2

Lead:	NTB Fachhochschule Buchs	Funding:	KTI
Contact:	André Bernard andre.bernard@ntb.ch	Period:	2013–2016

Abstract: The present project aims at the development of a high efficiency cost-competitive High Concentration PhotoVoltaic Thermal (HCPVT) system able to convert 80% of the collected solar energy in useful electrical and thermal energy at a Levelized Cost of Energy (LCOE) between 0.07 and 0.1 $/KWh when industrialised.

DEICING VON PHOTOVOLTAIKANLAGEN

R+D (3) 3.1.2

Lead:	NTB Fachhochschule Buchs	Funding:	KTI
Contact:	Egli Roland roland.egli@ntb.ch	Period:	2013–2014

Abstract: Die Firma Hassler ist Spezialist für Solarenergie im alpinen Raum. Wegen der erhöhten Strahlungsintensität ist Photovoltaik in den Alpen sehr attraktiv. Durch das Einschneien der Anlagen kann jedoch nicht das gesamte Potential ausgeschöpft werden. Mit der Entwicklung einer Lösung zur Schneeentfernung von Photovoltaikanlagen kann der Jahresertrag wesentlich erhöht werden.

MOBILES PV MESSSYSTEM

P+D (3) 3.1.2

Lead:	ZHAW IEFE	Funding:	diverse
Contact:	Baumgartner Franz franz.baumgartner@zhaw.ch	Period:	0

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.

PV TESTANLAGE DIETIKON

P+D (3) 3.1.2

Lead:	ZHAW IEFE	Funding:	diverse
Contact:	Baumgartner Franz franz.baumgartner@zhaw.ch	Period:	0

Abstract: Die Arbeiten an der PV Testanlage EKZ Dietikon wurden weitergeführt. Dabei wurde in diesem Jahr der Fokus auf die DC und AC Performance der Inverter, die Gewichtungsfaktoren des Euro-Wirkungsgrades, aber auch den Wirkungsgradverlaufes an klaren und bewölkten Tagen für die fünf unterschiedlichen PV Modultechnologien gelegt.

PV-CARPORTS PUBLIKUMSWIRKSAME PHOTOVOLTAIKANLAGE

P+D (3) 3.1.2

Lead:	ZHAW IEFE	Funding:	diverse
Contact:	Baumgartner Franz franz.baumgartner@zhaw.ch	Period:	2011–2012

Abstract: Es wird die Nutzung von mit Photovoltaik überdachten Parkplätzen im Zusammenhang mit der Elektromobilität untersucht. Anhand von konkreten Fallstudien wird das Potenzial dieser Anwendung abgeschätzt.

POTENTIAL VON PHOTOVOLTAIK AN SCHALLSCHUTZWÄNDEN ENTLANG DER NATIONALSTRASSEN (ASTRA)

R+D (4) 3.1.2

Lead:	TNC Consulting AG	Funding:	ASTRA
Contact:	Nordmann Thomas nordmann@tnc.ch	Period:	2010–2013

Abstract: Das Projekt prüft das Anwendungspotential der Kombination von Photovoltaik und Schallschutz ausgehend vom kurz- und mittelfristigen Realisierungsumfang bestehender und neuer Schallschutzvorhaben in der Schweiz entlang von Nationalstrassen.

MACHBARKEITSSTUDIE: MODULARES SOLARINSELKONZEPT „MONTAVENT LOTUS" ZUR ERZEUGUNG VON SOLARSTROM BEI HÖHERER SPEZIFISCHER ENERGIEAUSBEUTE

R+D (4) 3.1.2

Lead:	NTB Fachhochschule Buchs	Funding:	KTI
Contact:	Stöck Max stoeck@ntb.ch	Period:	2012–2013

Abstract: Unter Einbezug von Standard PV-Systemkomponenten werden auf geeigneten Gewässern mit montavent LOTUS weltweit erste Solarinseln als grosse Solarkraftwerke realisiert. Die Solarinseln können dem Sonnenstand einfach nachgeführt werden. Die Anforderungen des Umwelt- und Landschaftsschutzes und des Wasserbaus werden geklärt und die technische Machbarkeit untersucht.

LITERATURRECHERCHE ZU DEN EMISSIONEN VON NICHTIONISIERENDER STRAHLUNG VON PHOTOVOLTAIKANLAGEN

R+D (4) 3.1.2

Lead:	maxwave AG	Funding:	BAFU
Contact:	Georg Klaus 0	Period:	2013

Abstract: Im Zusammenhang mit Photovoltaikanlagen (PV-Anlagen) wird vermehrt die Frage aufgeworfen, inwiefern PV-Anlagen eine Quelle von nichtionisierender Strahlung (NIS) darstellen und wie stark diese nichtionisierende Strahlung in Räume einwirkt, in denen sich Menschen längere Zeit aufhalten können.

SCHWEIZER BEITRAG IEA PVPS TASK 1

R+D (5) 3.1.2

Lead:	Nova Energie GmbH	Funding:	BFE
Contact:	Hüsser Pius pius.huesser@novaenergie.ch	Period:	2013

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 - 2013 ÖKOBILANZEN VON SOLARSTROM

R+D (5) 3.1.2

Lead:	Treeze GmbH	Funding:	BFE
Contact:	Frischknecht Rolf frischknecht@treeze.ch	Period:	2013

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.

SCHWEIZER BEITRAG IEA PVPS TASK 13

R+D (5) 3.1.2

Lead:	TNC Consulting AG	Funding:	IEA PVPS Pool
Contact:	Nordmann Thomas nordmann@tnc.ch	Period:	2011–2013

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.

SCHWEIZER BEITRAG IEA PVPS TASK 14 - HIGH PENETRATION OF PV SYSTEMS IN ELECTRICITY GRIDS (SWISS CONTRIBUTION)

R+D (5) 3.1.2

Lead:	Planair	Funding:	IEA PVPS Pool
Contact:	Renaud Pierre pierre.renaud@planair.ch	Period:	2010–2014

Abstract: The main purpose of Task 14 is to analyze the role of grid connected PV as an important source in electric power systems on a high penetratin level where additional efforts may be necessary to integrate the dispersed generation in an optimum manner. The aim of these efforts is to reduce the technical barriers to achieve high penetration levels of distributed renewable systems on the electric power system.

SOLAR RESOURCE ASSESSMENT AND FORECASTING, IEA SOLAR HEATING & COOLING PROGRAMME, TASK 46

R+D (5) 3.1.2

Lead:	Meteotest	Funding:	BFE
Contact:	Kunz Stefan stefan.kunz@meteotest.ch	Period:	2011–2016

Abstract: In the framework of IEA Solar Heating and Cooling (SHC) Task 46, Meteotest investigates the possibilities and quality of global radiation forecast, the trend of recent global radiation data and distribution of atmospheric aerosols.

NORMENARBEIT FÜR PV SYSTEME

WTT (5) 3.1.2

Lead:	Basler & Hofmann AG	Funding:	BFE
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.

Solarzellen

THIN LAYERS FOR HIGH-EFFICIENCY SILICON SOLAR CELLS THROUGH IDEAL COUPLING OF INDIVIDUAL COMPONENTS

2013 Report

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Project- / Contract Number	SI/500750 / SI/500750-01
Duration of the Project (from – to)	1.01.2012-31.12.2014
Date	09.12.2013

ABSTRACT

This project is divided in six axis, ranging from a better understanding of the key parameters of the fabrication processes (notably the plasma deposition of silicon layers), to improving the reliability and the precision of the characterization of the obtained devices. Developing new layers, improving the light trapping and the opto-electrical coupling of multi-junction devices complete the panel, with also a part dedicated to updating and improving the infrastructure park. The final objective is to bring new findings to the research field that provides new routes for increased module efficiencies for similar costs, without impacting the reliability.

In the first parts of this 3-year project, progress in the understanding of amorphous silicon material was made possible thanks to the fair comparison of various material types. The findings will enable a more effective orientation towards different types of processes for different applications. For microcrystalline silicon, the major role of the interface between doped layers and the intrinsic layer was evidenced. Buffer layers to improve electrical properties of the devices have been introduced at the p-i and i-n interfaces (respectively based on SiO and a-Si). Also, an innovative way to reach high absorption with thin devices with a new precursor gas (SiF_4) was initiated. Improved light trapping was demonstrated through the use of ZnO / metal back reflectors.

On the device side, significant progress was made in terms of efficiency, with a new certified world record microcrystalline silicon device (10.7%), and world-class efficiencies for multi-junction cells (12.3% in tandem and 13.0% in triple-cell configuration). Several strategies for device improvement are in early stage of development and are still to be implemented in high-efficiency devices.

More than ever, an efficiency boost of record thin-film silicon devices is required, and this project contributes to bring the technology one step ahead.

In parallel several of the layers developed in this project were applied and tested in high efficiency crystalline silicon heterojunction solar cells. In particular intrinsic SiO_x layers are shown to modify electronic transport, reducing slightly the fill factor but allowing the achievement of ultra-low temperature coefficient (down to -0.1%/°C).

Introduction

In 2012 and 2013, several thin film silicon companies could show good progresses in ramping-up production lines with high yield. Also remarkable architectural products could be developed (e.g.Chüco, now with a part taken over by Masdar). In Switzerland it was also marked by the take over of Oerlikon Solar by TEL which maintains strong activities at its Neuchâtel and Trübbach site. However in parallel, the industrial crisis faced by small volumes crystalline silicon and thin film companies has been reinforced. It affects also thin-film silicon companies This puts a strong pressure on thin-film silicon manufacturers and solution providers, making efficiency improvement and cost reduction mandatory to find a good position in the photovoltaic market.

Project goals

By aiming at improving the efficiency of thin-film silicon modules, this project fits the present main defy of the technology. A combination of improvements in material deposition techniques, in layer – but also interface – properties, and in light trapping is thought to be necessary to bring thin-film silicon devices one step further. Yet, this is not enough as a key challenge still to be addressed is the coupling of the sub-cells in a multi-junction device. Mastering all these aspects is needed to push upwards the efficiency and bring the technology to its full potential.

Short project description (2012-2014)

The project aims at obtaining high-efficiency thin-film silicon solar cells, through an optimal coupling of individual sub-cells in a multi-junction device. As sketched in Figure 1, the fulfilling of this task goes through improvements in three major areas:

- Impact of plasma conditions on layers quality (typically formation of porous areas, pinching)
- Doped layers, buffers and new materials (more transparent, diffusion barriers, more absorbing material)
- Light trapping (higher light incoupling, new light trapping mechanisms)

To help in these tasks, two other areas complete the view. The first one concerns reliability and characterization, which are the key bases of scientific progress, and the second one is updating of the infrastructure to maintain an adequate technology park for future developments.

For beginning of 2013, major objectives have been to

- Initiate the work on SiF4 gas-precursor for high-current microcrystalline cells.
- Develop alternative approaches to fabricate smoothening intermediate reflectors.
- Initiate the development of metallic back reflectors as an alternative to white paste.
- Push the efficiency of all devices to set a proper benchmark for future integration of innovative approaches.
- Consolidate the major findings of last period in journal papers and contribution to international scientific conferences.

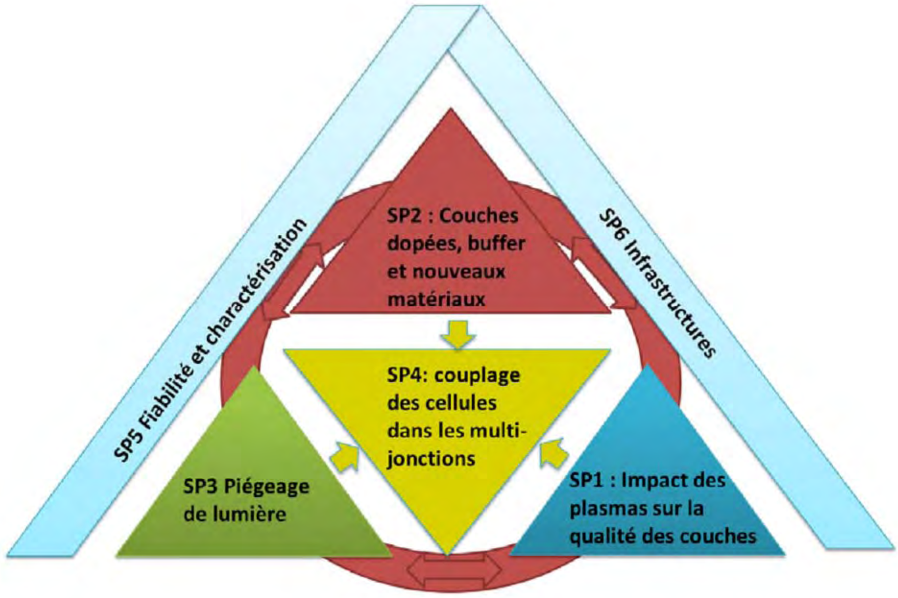


Figure 1: Summary of workpackages of SFOE-EPFL PV-Lab project 2012-2014.

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

Work performed and results achieved in 2013

In 2013, the theoretical and practical bases for a significant efficiency increase were gathered. The advances of the latest years were consolidated and assessed through certified efficiency devices. Processes for a high-efficiency base-line were also obtained. This document summarizes the most striking results obtained during this year; more complete descriptions are available through the publications listed at the end of the report.

1. Impact of plasma conditions on the quality of silicon thin films

1.1 Realization of µc-Si:H layers with very high absorption

A new promising approach to fabricate highly crystalline microcrystalline silicon layers with still high quality from SiF_4 instead of SiH_4 was introduced by the work of J.-C. Dornstetter from CNRS, Palaiseau, France. First depositions of µc-Si:H cells using SiF_4 as a precursor were made in the KAI reactor. Layers with high crystallinity (>80%) were obtained and pressure and power regimes leading to a deposition rate of a few angstroms per seconds were identified. Complete p-i-n cells were made, using standard p- and n-doped layers, showing efficiency values up to 8.3% for a 1.1-µm-thick i-layer (462 mV, 69.2% of Voc and FF and 25.9 mA/cm2 of Jsc). The EQE can be seen in Fig. 1.1, left. For thicker cells, remarkably high responses in the infrared part of the spectrum were obtained, thanks to the high crystallinity of these films (see Fig. 1.1, right). Even though collection issues, especially in the blue part of the spectrum, were identified, this is extremely promising for future applications in tandem and even triple devices.

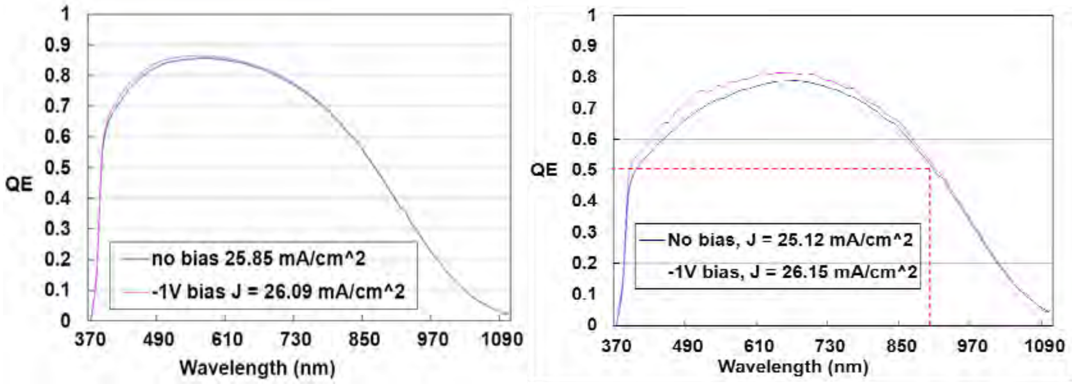


Figure 1.1, left: EQE characteristics of the best SiF4-based cell so far (1.1-µm-thick i-layer). Figure 1.1, right: EQE of a 2.3-µm-thick cell using SiF4 for the i-layer. Red dashed lines highlight the high response at 900nm (50%).

1.2 Development of new a-Si materials and study of their stability

The thorough comparison of a-Si:H materials made in the Octopus system last year was completely analyzed this year and presented at the ICANS and published in a journal paper [1]. This study is the first reliable and fair comparison of different deposition regimes for amorphous silicon to be made with a single deposition system and identical parameters except for the intrinsic material deposition. Amongst the multiple lessons that can be learned from this exhaustive study, a good correlation was found between the microstructure factor—that can be probed with Fourier transform infrared spectroscopy—and the degradation rate upon light illumination, for all investigated conditions. Also, whereas cells using low-diluted i-layers show little Voc difference as a function of the substrate roughness, highly diluted layers are much more sensitive to substrate roughness.

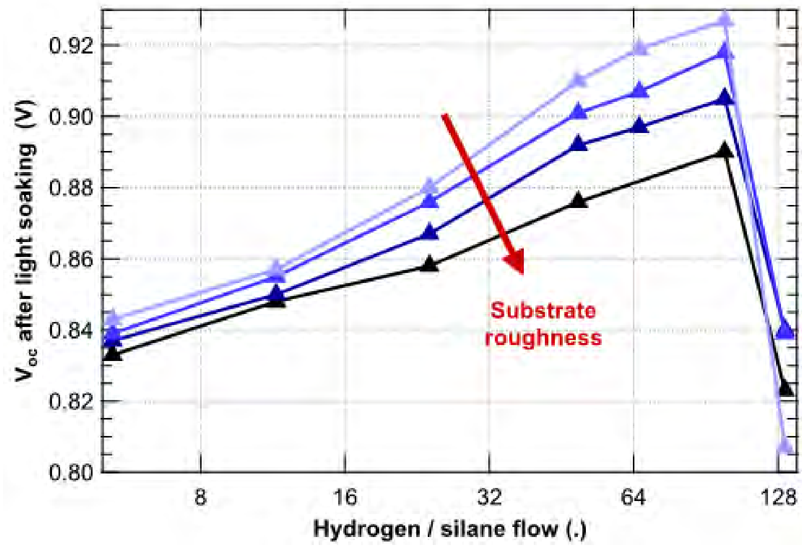


Figure 1.2: Voc of stabilized aSi cells as a function of the hydrogen dilution in the i-layer, when deposited on electrodes with different roughness.

1.3 Annealing and plasma post treatments

Analysis of the effects of the H2 plasma post-deposition treatment that was shown to improve significantly the efficiency of microcrystalline cells was performed. A comparison of the properties of single-junction µc-Si cells after a H2 plasma or a simple annealing was done for rough and smooth electrodes—to probe the influence of the presence of the 2-D nanoporous areas ("cracks") [3]. It was shown that a very similar improvement of Voc was observed for both treatments, stronger improvement being observed for the cells deposited on the rough electrode (thus with more "cracks"). A double mechanism of both curing of intrinsic defects in the bulk silicon, as well as improvement of the “cracks” areas is therefore occurring. Interestingly, the gain after treatment is mostly maintained after storage in dark: Voc slightly improves after storage for smooth electrodes, whereas it slightly degrades for rough electrodes.

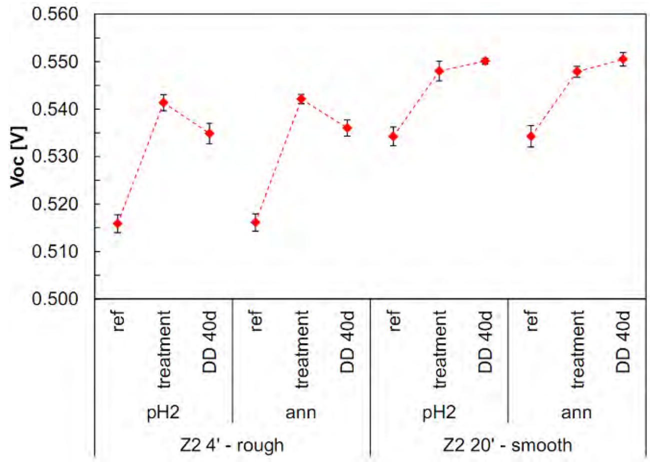
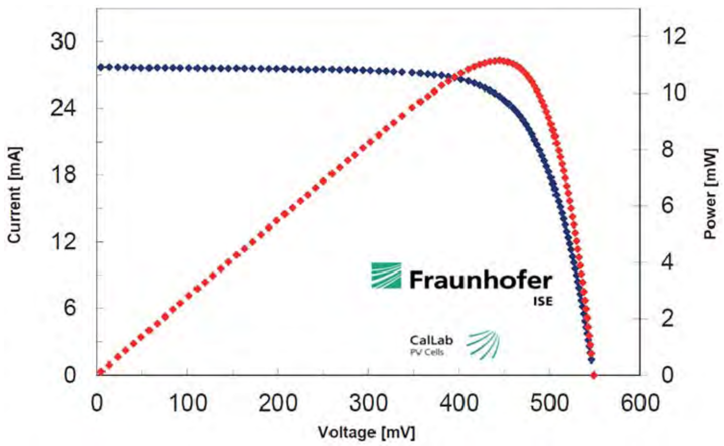


Figure 1.3: Voc of microcrystalline cells deposited on rough or smooth substrate, as-deposited, after a hydrogen plasma (pH2) or annealing (ann) treatment, and after 40 days of storage in dark (DD 40d).

1.4 Certified record eficiency

Combining all recent advances in a champion device, a new certified world record microcrystalline silicon single junction device was obtained (Fig. 1.4). The efficiency of 10.7% (as certified by Fraunhofer ISE) is significantly higher than the previous value of 10.1% held by Kaneka corporation [2].



Mismatch factor : (for spectral correction)	=	1.0157			
Area (da) :	= (	1.0437	±	0.0032	) cm^2

IV-curve parameter under standard testing conditions (STC):

V_{OC}	= (	549.0	±	2.7	) mV
I_{SC} (Ed.2 - 2008)/3/	= (	27.71	±	0.69	) mA
J_{sc}	= (	26.55	±	0.67	) mA/cm^2
I_{MPP}	=	25.17			mA
V_{MPP}	=	443.1			mV
P_{MPP}	= (	11.15	±	0.33	) mW
FF	= (	73.31	±	0.73	) %
η	= (	10.69	±	0.32	) %

Figure 1.4: IV curve and parameters of the new certified world record microcrystalline silicon single junction device.

2. New doped layers and buffers

2.1 SiO buffer layer at the p-i interface

A silicon-oxide buffer layer was introduced at the p-i interface, both for amorphous and microcrystalline silicon devices. For microcrystalline silicon, it was shown to improve the Jsc, FF and Voc. This comes from antireflecting effect (in combination to the p-doped SiO layer) and collection efficiency improvement, and from shunt-quenching effect and reduction of boron contamination in the i-layer. Indeed, cells without any reactor cleaning between the p and i layers in a single-chamber process showed much lower boron content when an SiO buffer layer was used. Similarly, in the case of a-Si single junctions, it was shown that the traditional water flush between the p-doped and i-layer can be omitted without strong degradation of the cell parameter when an SiO buffer layer is substituted to the carbide buffer. Even when a water flush was used, an improvement in stabilized efficiency was observed for SiO buffer compared to standard carbide buffer, from 8.3% to 8.6% (without ARC), as seen in table 1. Further details are available in [4].

Table 1: Parameters of aSi:H cells with different types of buffer layers at the p-i interface.

	Voc (mV)	FF (%)	Jsc (mA/cm2)	Eff (%)	LID (%)
Standard aSiC	897 (852)	76.6 (64.4)	15.6 (14.9)	10.7 (8.2)	23
New SiO	882 (877)	75.2 (66.3)	16 (14.7)	10.6 (8.6)	19

2.2 Passivating layers for high-Voc microcrystalline cells

The effect of thin a-Si:H buffer layers at the i-n interface of microcrystalline devices—that were introduced last year—has been investigated. It was shown that a strong improvement of Voc is observed already for thin a-Si buffer layers, whereas for thick devices, only a moderate improvement is seen and only for quite thick buffer layer thicknesses. In the latter case, this effect is ascribed to quenching of the current drains induced by locally lower-quality junction, whereas in the former case, a real passivation effect is supposed. Simple one-dimensional simulations were used to validate this, and it was shown that thin complete p-i-n devices are inherently limited by the defects at the interface between the i-layer and the doped layers, even for relatively low material quality (<1 µs of bulk lifetime). The highest Voc obtained so far is 608 mV, even at high Raman crystallinity factor of the i-layer (>50%), representing a gain above 20 mV compared to our standard design with n-SiOx for the n-layer. Most importantly this high Voc could be achieved together with a very high cell fill factor of 77%, leading to a remarkable cell efficiency of 9.5% for an absorber layer as thin as 600 nm. These results were presented at the ICANS in Toronto, and will be subject to a publication in 2014.

2.3 Development of low-index SiO layers at the recombination junction

A new process was developed in the octopus to obtain low-index n-doped SiO layer. It was seen that with a relatively high pressure (4 mbars compared to typically < 1 mbar), impressively high CO_2 to silane flow ratios of over 6:1 was shown to still be usable without any additional series resistance in a thin-film silicon device. Very low refractive indexes can be obtained for such high oxygen incorporation, as low as 1.75 at 600 nm (Fig. 2.3, left). When used as IRL in a micromorph device, this translates into a very large top cell current boost, as shown in Fig. 2.3, right, where a standard layer with a refractive index of 2.05 is taken as reference.

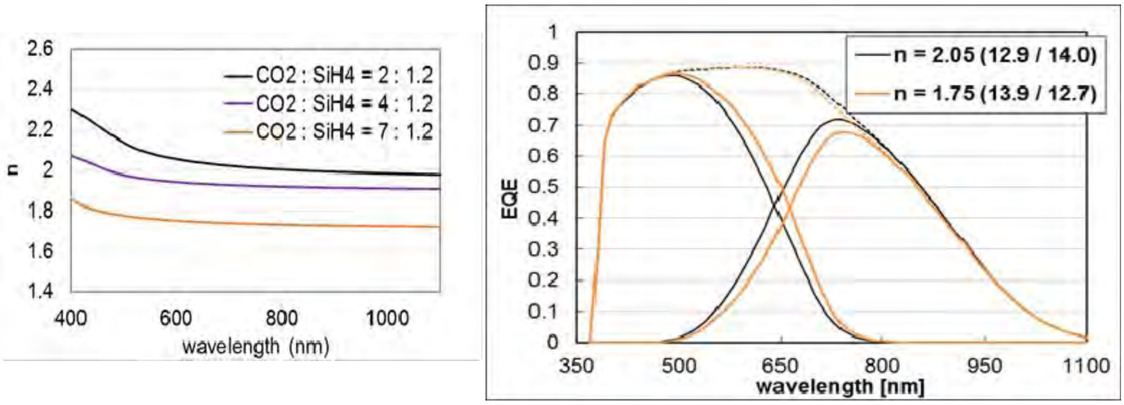


Figure 2.3, left: refractive index as a function of the CO2 and SiH4 flow in the SiO-based IRL
Figure 2.3, right: EQE of the top and bottom subcells of micromorph devices incorporating the highest- and lowest-index SiO-based IRL.

2.4 New doped and buffer layers in silicon heterojunction solar cells

The standard intrinsic amorphous silicon (i a-Si:H) was replaced by a stack of a-Si:H and amorphous silicon oxide (*i* a-SiO_x:H) which was used to passivate double-side polished crystalline silicon wafers. This resulted in good passivation quality, exhibiting effective minority carrier lifetimes (τ_{eff}) of up to 5 ms (see Fig. 2.4.1), i.e. surface recombination velocities below 3 cm/s. Implementing these layers into devices, we could show their influence on the cell performance. Increasing the oxygen content in the a-SiO_x:H layer the changes in performance manifest mainly in a drop in fill factor (*FF*) and a gain in short-circuit current density (J_{sc})—up to 0.4 mA/cm^2 for layers with high oxygen content that on the other hand lead to strongly s-shaped curves.

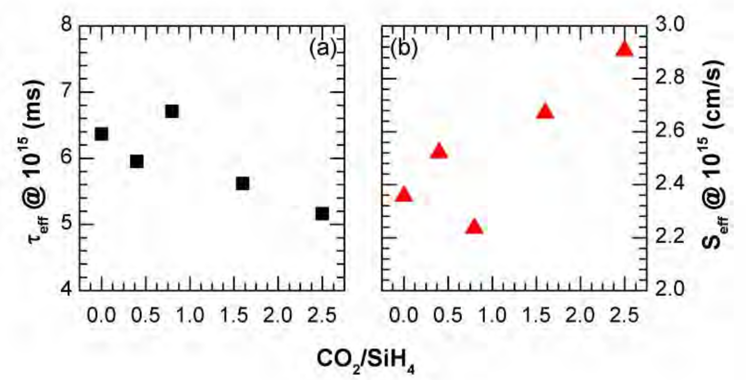


Fig. 2.4.1: (a) Effective minority carrier lifetime τ_{eff} and (b) effective surface recombination velocity S_{eff} as function of input gas flow ratio. Obtained with i a-Si:H/i a-SiO_x:H of approx. 16 nm on n-type double-side polished wafers (300 µm, 4 Ωcm).

The drop in *FF* can be explained considering the increased valence band offset (barrier for holes) introduced by the wide bandgap a-SiO_x:H—which helps to increase the current density—and a resulting impeded charge carrier transport. Even though, these cells perform worse than the reference under standard testing conditions (AM1.5g, 25°C), a specific oxygen content (CO2 to silane ratio of 0.8) in the front side passivation layer can lead to an improved thermal stability and cells that outperformed the standard cell design at higher temperatures—those closer to the ones encountered in the field. This could be explained with an improved temperature coefficient for the cell efficiency of -0.1 %/K compared to -0.3 %/K as obtained for the reference (see inset Fig. 2.4.2). Furthermore this effect could be related to a positive temperature coefficient for the *FF* in the investigated temperature range which we link to an improved carrier transport across the barrier at higher temperatures.

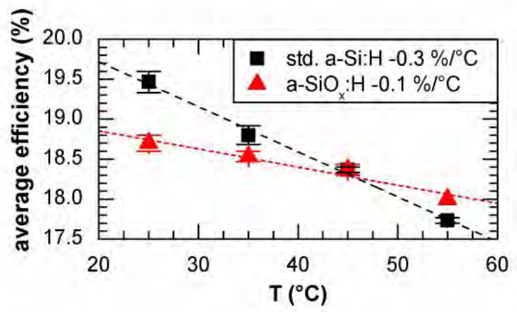


Fig. 2.4.2: Evolution of the cell conversion efficiencies with temperature.

In general the layers developed in this project are used or adapted for various device configurations, including into interdigitated back-contacted solar cells.

3. Light trapping

3.1 Development of metallic back reflectors

Promising preliminary results were obtained with metallic back reflectors compared to white paste approach. Deposition of silver or ZnO by sputtering was shown to lead to poor electrical properties. A buffer layer deposited by LPCVD was shown to suppress this issue, making devices with thin ZnO / Ag back reflectors perform electrically as well as devices with thick ZnO and white paste. Strong parasitic absorption was however seen due to the metallic layer. This was ascribed to the promotion of plasmonic interaction at the ZnO-Ag interface via the natural roughness of the ZnO grown by LPCVD. A plasma smoothening treatment of the surface of the ZnO buffer layer was introduced as an efficient way of drastically reducing this parasitic absorption. By substituting the thick ZnO / white paste back reflector by a thin ZnO / smoothening treatment / Ag stack (as sketched in Fig. 3.1, a and b), a current gain in the infrared part of the spectrum could be shown for state-of-the-art devices, together with a slight FF increase thanks to the better electrical conduction of the Ag (Fig. 3.1, b). A publication relating these findings is in preparation.

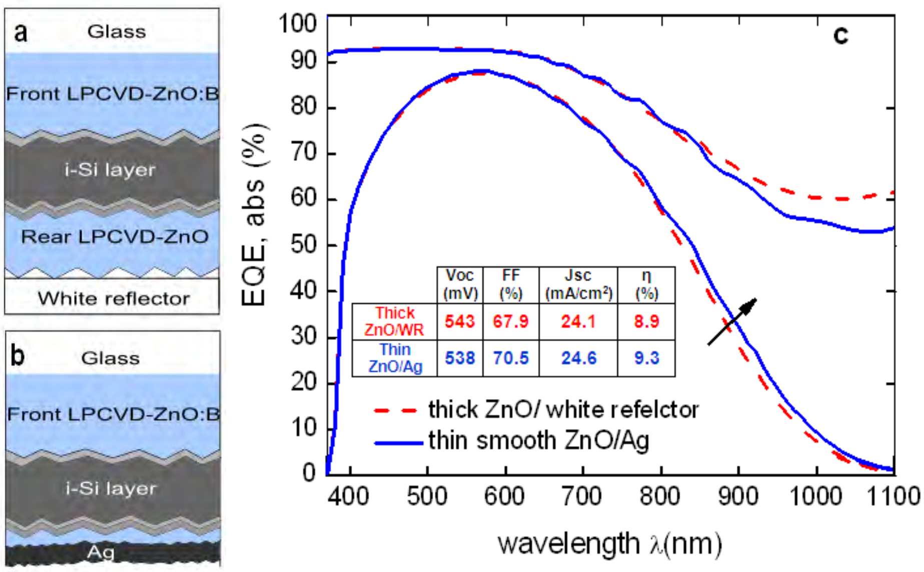


Fig. 3.1: Sketch of the two back reflector configurations compared here (a,b). EQE and total absorptance of the two devices (c). A 10-min smoothening plasma treatment was performed for the thin ZnO layer.

3.2 Stability of LPCVD ZnO films under light soaking

The change in the opto-electrical properties of LPCVD ZnO films exposed to simulated sunlight, under the conditions used to test light-induced degradation of solar cells was investigated. The evolutions of the front and the back electrodes were studied, by filtering the light source. Exposure to the complete simulated light spectrum is demonstrated to induce "persistent photoconductivity" response in the front contact. This is due to an increase in the free-electron concentration and mobility, as the potential barrier at grain boundaries is reduced due to desorption of oxygen traps. the optical property also change: indeed, all films exhibit increased free-carrier absorption after light soaking, but the boron doped films also show an increase in absorptance in the visible range, which translates to a darkening of the film. In contrast, LPCVD ZnO films exposed to NIR light only, simulating the conditions of rear electrodes, present no change in their optical properties and only a decrease in conductivity due to a decrease in electron mobility. This is ascribed to oxygen and moisture ingress during storage for 1000 h in air at 50°C.

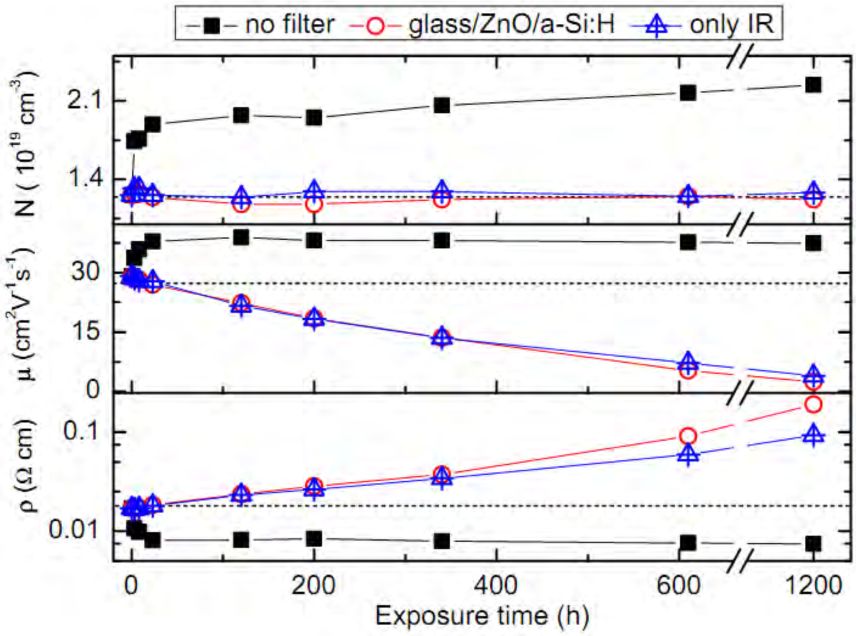


Fig. 3.2: Electrical properties of 2-µm-thick n-i-d ZnO films exposed to full AM1.5 G (no filter), through a colored filter transparent to nIR (IR only), or through a stack of glass coated with ZnO and a-Si:H (glass/ZnO/a-Si:H). The dashed lines indicate the initial value as guideline for the eyes. While the electron concentration and mobility of the ZnO film exposed without filter due to UV light interaction, the mobility of the ZnO flms exposed to nIR light only decreases.

These modifications in the properties of ZnO electrodes affect the performance of degraded solar cells: part of the decrease in the photogenerated current of stabilized a-Si:H cells is shown to be due to increased parasitic absorption in the ZnO when deposited on highly doped ZnO. These results highlight the advantage of using lightly B-doped ZnO films, possibly post-deposition treated in H_2 plasma to increase their conductivity, not only for their initial higher visible-to-nIR transparency, but also for their higher stability to light soaking darkening.

3.3 Exploration of TCO layers using new materials

Using the new Clusterline 2000 (PVD system) installed in our laboratory, we have studied Sn, Ga and In doped ZnO layers as possible alternatives to the standardly used Al doped ZnO. The materials have been developed with comparable electrical and optical properties. Damp heat tests are being performed to evaluate the effect of the different dopings. Amorphous ZnO-based compounds have also been developed by PVD with the main goal of applying these materials in flexible optoelectronic devices. As an example, the optical transmittance and absorption properties of Al doped ZnSnO—a fully amorphous and In-free TCO—are presented in Fig. 3.3.

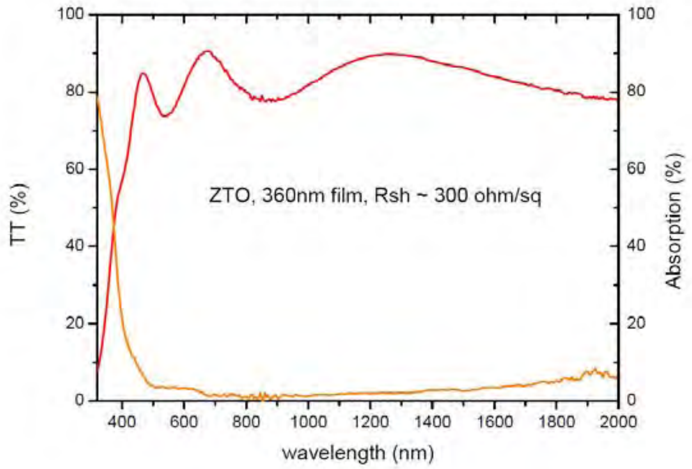


Figure 3.3: transmittance and absorptance of a 360-nm-thick Al doped ZnSnO layer.

4. Coupling in multijunction

4.1 Multi-junction devices in substrate configuration

By using the SiO-based IRL described in section 3.1, a micromorph device with a stabilized efficiency of 12.3% was obtained. This efficiency is amongst the highest reported value for the technology (present world record by Kaneka, 12.3%). This device incorporates many of the recent advances in terms of process and device architecture, including SiO doped and buffer layers, a-Si buffer layer at the i-n interface of the bottom cell, and a post-deposition annealing treatment. A lot of effort was also put to improve the precision of our measurement method to get close to the procedures used at certification institutes. With a test device, a certified efficiency of 11.75% was received for an in-house measurement of 11.9% efficiency. The difference was evidenced as being due to the difference in the illumination spectra between our institute and the certification lab (Fraunhofer ISE).

Area (da)[1]:	=	(1.0031	±	0.0062	) cm²

IV-curve parameter under standard testing conditions (STC):

V_{OC}	=	(1.3500	±	0.0068	) V
I_{SC} (Ed.2 - 2008) /7/	=	(12.88	±	0.32	) mA
J_{sc}	=	(12.84	±	0.33	) mA/cm²
I_{MPP}	=	11.22			mA
V_{MPP}	=	1.0510			V
P_{MPP}	=	(11.92	±	0.52	) mW
FF	=	(67.80	±	0.68	) %
η	=	(11.75	±	0.52	) %

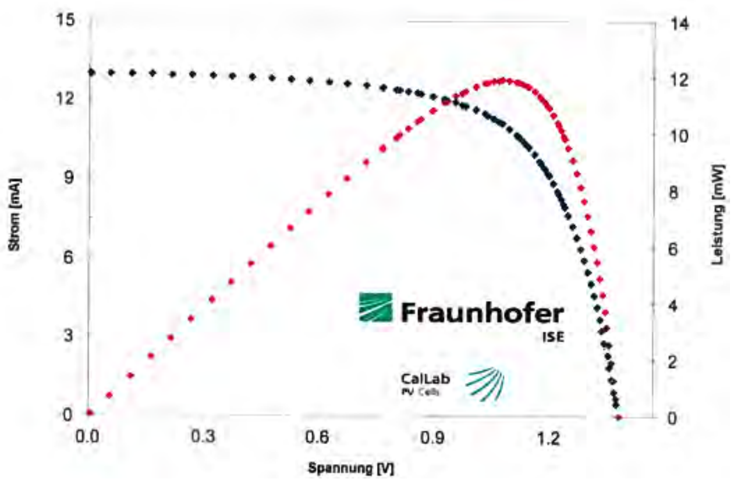


Fig. 4.1 Certified IV characteristic for a test micromorph device of 11.75% stable efficiency from Fraunhofer ISE.

4.2 Multi-junction devices in substrate configuration

By combining a flat light scattering substrate (FliSS) with a nano-imprinted antireflective texture, a triple-junction a-Si:H/µc-Si:H/µc-Si:H nip solar cell with a stable efficiency of 13.0% after 1000h of LID (1000W/m2, 50°C) was obtained (0.65cm2 cell area). The highest reported certified efficiency for triple junction devices is 13.4%. In tandem configuration, an 11.6% stable efficiency was demonstrated by using an asymetric IRL based on rough ZnO. This results could be achieved thanks to oxygen and argon plasma treatement of the ZnO IRL, and to an advanced multiscale substrate morphology [6].

4.3 Planarization of the a-Si cell

Following the promising results obtained using lacquer as an intermediate reflector, new materials were tested and implemented as planarizing intermediate reflectors in micromorph devices. We utilized the semiconducting p-type polymer poly-N-vinyl carbazole (PVK) to form a smoothening intermediate reflector between the top a-Si and bottom µc-Si cells. PVK layers with varying thicknesses are deposited by spin coating at several spin speeds from a solution of PVK in an organic solvent. This solution processing leads to a partial flattening of rough surface features as the PVK itself possesses a very smooth surface, as shown by the atomic force microscope images in Figure 4.3.1.

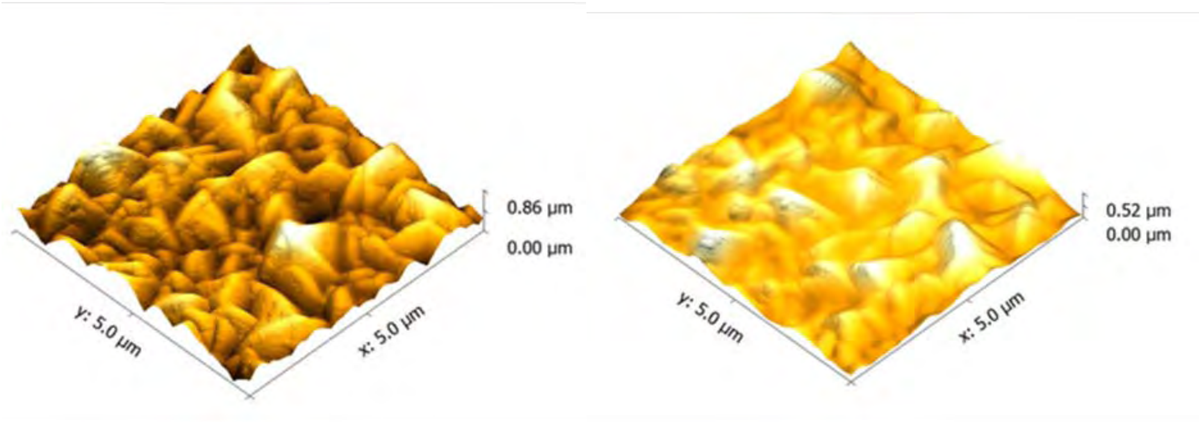


Figure 4.3.1: Atomic force micrographs of the 200 nm thick a-Si top cell on a 3.5 µm thick ZnO substrate (left) and of the same a-Si top cell covered with a PVK smoothening layer (right).

When introduced as an intermediate reflector in a p-i-n micromorph tandem cell, the PVK smoothening layer enhances the Voc of the cell, indicating an improved Si absorber layer quality due to the smoother growth substrate for the µc-Si layer (Figure 4.3.2 a). The Voc gain that can be obtained by the smoothening layer increases with the roughness of the substrate (i.e. with the thickness of the ZnO front electrode). As PVK has a significantly lower refractive index than Si, the layer acts as an efficient intermediate reflector, reflecting light partially back into the a-Si top cell, which allows to reduce its thickness and therefore to limit light-induced degradation. This is demonstrated by the strong increase in top cell current for cells with a PVK intermediate reflector compared to a reference cell without intermediate reflector, as shown by the external quantum efficiency (EQE) spectra in Figure 4.3.2 b.

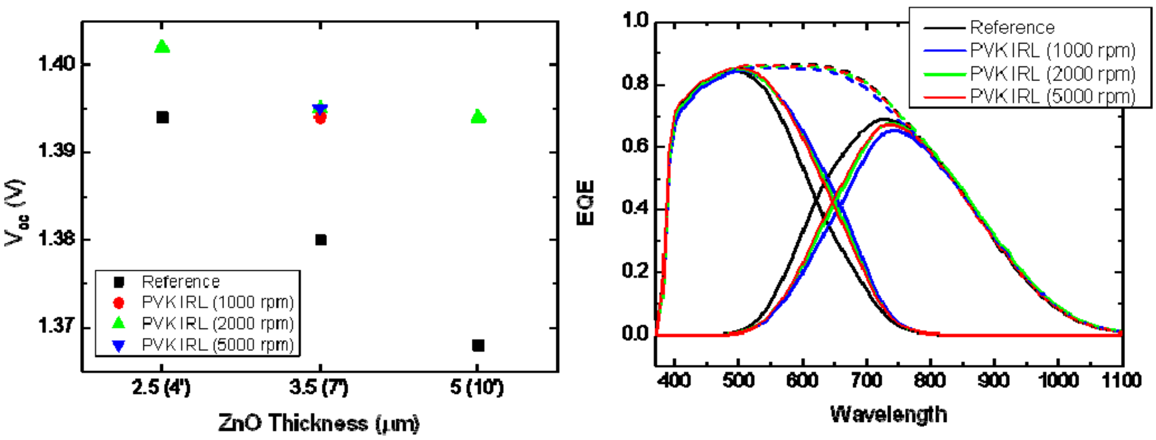


Figure 4.3.2, a) Voc values of p-i-n micromorph tandem cells without intermediate reflector (Reference), and with PVK intermediate reflectors deposited at several spin speeds, for several ZnO front electrodes. The numbers in brackets indicate the Ar plasma treatment time in minutes.
Figure 4.3.2, b) External quantum efficiency (EQE) of p-i-n micromorph tandem cells on 3.5 µm thick ZnO front substrates, treated with Ar plasma for 7 minutes.

The smoothening effect in combination with the redistribution of the photocurrent generation between the two sub-cells (i.e. the J_{top}-J_{bottom} mismatch) due to the PVK intermediate reflector lead to an efficiency enhancement from 11.2% up to 12.5% initial, compared the reference cell without intermediate reflector. It was found that a 3.5 µm thick front ZnO electrode represents a good candidate for further optimization, as we observed a significant Voc enhancement with the PVK smoothening layer, as well as high currents in the top cell due to efficient light scattering by the ZnO surface features and strong light reflection by the PVK layer.

Compared to the lacquer-based approach reported last year, this solution has the advantage not to need an extra “etch-stop“ layer, neither an etching step.

4.4 Triple and Quadruple cells in p-i-n configuration

Triple junction solar cells in p-i-n configuration (a-Si:H/µc-Si:H/µc-Si:H) with an initial efficiency of 13.7% and a stable efficiency of 12.8% have been fabricated on > 1 cm^2 with a total Si thickness of ~4.2 µm. Simple architecture and sub-cell combinations were used here, setting a good basis for further integration of advanced layers. In other devices, summed current densities over 30 mA/cm^2 have been demonstrated on two different superstrate configurations, i.e. standard LPCVD ZnO and In_2O_3:H on replicated nanotextured front structures, for only ~4.2 µm of µc-Si:H.

We also made first tests on quadruple junction thin film Si solar cells. We have been able to make properly working cells (without S-shape, shunts etc). We have also been able to measure the EQE of all different subcells, using appropriate bias light conditions. A very high V_{OC} of 2.6 V was obtained, albeit that the current densities of the different subcells have not been properly matched yet; the initial efficiency of this first device was therefore only 10.1%. The complexity of current matching for such devices and of processing make it hardly competitive for industrialization, yet it appears as a promising solution to break the 15% efficiency which would contribute to evidence the mid-term potential of thin-film silicon technology.

5. Reliability and Characterization

5.1 Encapsulation of small-area devices

Encapsulated and non-encapsulated micromorph cells incorporating a high-rate (1.5 nm/s) deposited bottom cell were compared in initial and after 200h LID to assess the part of degradation due to ambient air exposure. To insure fair comparison between the cells all parts (substrate, top cell, bottom cell and back contact) were produced in co-depositions. Then, one cell was encapsulated using white paint as back reflector and a silicone layer as back sheet, the other cell being left unencapsulated as usual. Measurements in initial states and after 200h LID were performed. Variable-spectrum measurements were performed since the encapsulation may modify the current mismatch—due to different reflector material—and thus the FF of the micromorph cell. It was observed that the FF of the encapsulated cell was slightly lower than the FF of the reference cell in hte initial state by 1% absolute. Yet, after 200h LID the FF loss of the cell with encapsulaiton was only 2% when the FF of the reference cell degraded by 5%. This tends to indicate that part of the degradation of micromorph devices using high-rate deposited bottom cells is due to exposure to ambient air. The difference between the two samples might however be partly due to the 5° difference in temperature seen by the two devices during light induced degradation due to their different design.

5.2 FF separation in micromorph devices

The results concerning the characterization of the influence of mismatch on the FF and efficiency of micromorph devices were presented in an extended presentation at the IEEE conference in Tampa Bay, and published in a journal paper [10]. By comparing simulated to experimental data, it was notably seen that the deposition rate of the bottom cell can impact the degradation of the top cell in micromorph devices.

5.3 Accelerated degradation with 3-sun illumination system

The 3-sun illumination system is now fully operational. Characterization of the spectrum indicated that the quality is better than class A. Temporal stability was measured to be well below +/- 2% for a 6h period (class AAA). The spatial homogeneity of light intensity was measured to be 2% on the full illumination area (16x16cm2). First experiments are ready to start as soon as the system is set in operation in the new building.

6. Infrastructure

6.1 High temperature LP-CVD systems

After the Large-area tool, the medium-size high-temperature LP-CVD ZnO system is now also running. Depositions at high temperatures could be made, with promising layer properties as was probed with SEM cross sections. Hardware adjustments are still to be made to make the system fully operational, in particular concerning the cleaning procedure.

6.2 Octopus II cluster

Octopus tool is now fully operational. Excellent layers for passivation of silicon heterojunction were already obtained. Complete cells with efficiencies exceeding 22%, using amorphous silicon layers deposited in the Octopus II were produced.

6.3 Sputtering system

The Clusterline 200 II tool from Oerlikon was installed and is now fully operational. It enables the deposition of metals and TCO by sputtering with a high throughput and a high reliability. Up to now, layers with excellent quality could be deposited for ZnO, ITO, Ag, SnO2, as well as mixed phase materials and multi-layer stacks. In particular, excellent heterojuntion devices could be made with ZnO / Ag back reflector (>20%), and a thorough study of the influence of the back reflector material could be made for thin-film silicon devices in a master thesis.

6.4 TMGa gas line to enable Ga doping of silicon layers

The TMGa line is now operational. Several layers could aready be deposited and the development is ongoing. A master student is presently working on this subject. Ga-doped layers with similar properties as B-doped layers were already deposited, but the integration in complete cells was not successful up to now.

6.5 Microcity

The laboratory is in the process of moving to the new building. First characterization tools are expected to be installed only beginning of November due to delay in the reception of furniture. Heavy equipement will move in December and January, for a fully operational lab expected for end of March 2014.

National and international collaborations

Regular academic contact/scientific and sample exchanges continued to be maintained throughout the project both with national and international entities (ETH Zürich, Zürich University of Applied Sciences, CSEM Neuchâtel, Forschungszentrum Jülich, Helmoltz Zentrum Berlin, Academy of Science Prague, University of Delft, Energy Research Center Netherlands, Berkeley University and National Laboratories, Caltech, National University of Singapore, AIST Japan…).

A new collaboration with the group of Ali Javey in Berkeley recently lead to a publication in Nano Letters, for the demonstration of a low-cost and highly efficient photocathode for solar hydrogen production. This amorphous Si based photocathode has achieved a "best in class" photovoltage and a 6.0% energy conversion efficiency, which represent a major step toward realizing spontaneous water splitting for fuel generation. By using an aSi cell from EPFL as light absorber, and ~80 nm TiO2 as protection layers and Pt or Ni-Mo as hydrogen evolution catalyst, a photovoltage as large as 0.93 V, a current density of 11.6 mA/cm2 were achieved, stable for over 12 hours under operation. For such devices, unlike commonly reported single crystalline photocathode, the low-temperature process (about 200°C) and the use of earth-abundant and ultrathin light absorber materials make this photocathode low-cost and economically scalable [11].

PV-Lab continued to be involved in several European projects (Fast Track, FlexOfab, Pepper, Pliant, 20plus) as well as national projects (Dursol, Axpo, Archinsolar, Velux in collaboration with CSEM) and benefits from the support of the National Science Foundation. This variety of interests in several aspects of the technology creates a strong synergy between all these projects and this running SFOE project. In addition, national and industrial collaborations with industrial partners are ongoing, either in the frame of CTI projects or through direct mandates, e.g. with TEL Solar, Roth & Rau Research AG, Meier Burger, Solneva, Indeotec, Air Liquid,...

Evaluation at the end of 2013 and perspectives for the future

As for previous years, PVlab was present in numerous international conferences with several presentations, in several cases of extended duration, confirming the status of PV-lab as leading laboratory in the thin-film silicon field. Following the obtaining of the Zeno Karl Schindler Price 2012 by Dr. Corsin Battaglia, two PhD thesis awards from EPFL were obtained in 2013, rewarding the excellent scientific work of Peter Cuony and Karin Söderström, through the "Dupont de Matériaux" and the "Chorafas Fundation" awards.

In the first 18-month period of this project, fundamental progress was made for amorphous silicon and microcrystalline silicon material improvement. For the first time in the community, a direct comparison of different types of i-layers was made in a unique reactor and for a unique device architecture. The data coming out of this study will enable to provide a clear strategy for each application of a-Si cells (single-junction, tandem, rough substrate, high operating voltage,…). For microcrystalline silicon, all the progress of the last years was put together in a record device that sets the basis for future improvements. Then, two axis were explored that are i) current improvement through the development of high crystallinity material by using SiF4 as a source gas, and ii) voltage improvement, for which the interfaces between the i-layer and doped layers were shown to be very critical.

Concerning device architecture, efficient cells with a metal back reflector were produced. By further improving the fabrication of such devices, record efficiencies are within reach. For multi-junction devices, ways of providing a smooth template for the silicon growth while preserving light trapping were developed both for opaque substrate and for glass superstrates. This resulted in high-efficiency triple-junction devices for opaque substrate, whereas further stability assessment is still required for smoothening layers in the superstrate case.

For all devices, world-class efficiencies—if not world record—have been reached recently, with little optimization. The numerous innovations that are still under development indicate that further improvement is still within prompt reach. In particular, the integration of metallic back reflectors and smoothening intermediate reflectors (not yet implemented in record devices) was seen as very promising. Combining this device architecture with advanced absorber materials with improved interfaces (buffer layers) and enhanced absorption (SiF4 gas precursor), efficiency improvement is possible with an industrially viable approach. Further improvement towards 15% efficiency devices will most probably require a triple junction configuration, for which baseline process have been assessed in PV-Lab.

Finally all the processes and knowledged developed in this project is also of high interest for crystalline silicon solar cells in the form of heterojunction. New material improvements should lead to efficiency increase for standard heterojunction as well as for other structures such as IBC-SHJ.

Acknowledgements

All the PV-Lab collaborators, who contributed to the results presented in this report, are warmly acknowledged. The support from the bachelor and master students, as well as from the civil service participants is also acknowledged.

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DEMONSTRATION OF HIGH PERFORMANCE PROCESSES AND EQUIPEMENTS FOR THIN FILM SILICON PV MODULES PRODUCED WITH LOWER ENVIRONMENTAL IMPACT AND REDUCED COST AND MATERIAL (PEPPER)

Annual Report 2013

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ABSTRACT

The 3-year FP7 EU PEPPER project aimed at achieving high efficiency (11%) thin-film tandem micromorph modules at low cost (CoO ≤ 0.5 €/Wp) while reducing the environmental impact of fabrication processes. The project thus included development of a new generation of Plasma Enhanced Chemical Vapor Deposition (PECVD) reactors for high rate deposition (up to 15 Å/s) of intrinsic *μ*c-Si:H thin films.

PV-Lab led the second work package (WP2), which aimed at improving the front transparent conductive oxide electrode properties. To do so, new low-pressure chemical vapour deposition (LPCVD) processes and regimes were investigated to produce more effective zinc oxide (ZnO) electrodes and test them in solar cells. The most interesting concepts were transferred to WP5 for up-scaling to the industrial-scale. The main results are:

- Conductivity/transparency trade-off conditions relaxed thanks to a multi-layer approach.
- The use of additives such as ethanol or different growth regimes involving changes in the precursor's total flow were shown to provide improved surface morphology for the growth of high-quality silicon films.
- All milestones achieved.

PV-Lab was also involved in the larger WP3 to assess the most favorable PECVD process parameters space for high-rate deposition of microcrystalline silicon (μc-Si:H) and also contributed to the development of a model linking layer quality to deposition parameters and plasma dynamics. The main results this year are:

- A comparison study of the plasma excitation frequency for the growth of the bottom cell at 0.7 nm/s.
- A device with 11.9% stable efficiency using a bottom cell i-layer grown at 0.7 nm/s.
- Devices with bottom cell deposited at 1.5 nm/s with very high initial efficiency of 13%.
- Simulations performed in collaboration with University of Patras highlighting the important roles of the different silane radicals contributing to the growth of high bulk quality and/or less porous μc-Si:H films.
- 13% high-efficiency solar cells prepared in collaboration with TEL Solar to validate their new reactor.

Most of the milestones were achieved, even though a reduction of the deposition rate from 1.5 is favorable for high efficiency. The global project results with narrow-gap reactor, as developed by TEL makes it possible to produce with fast enough tact times modules with over 11% efficiency total area.

Aims of the project

The global goal of the project is to demonstrate and partially implement cost-effective high efficiency processes to prove the feasibility of thin film micromorph (amorphous/microcrystalline silicon tandem) module production. Its objectives are to:

- Increase the module power to 157 Wp stabilized (corresponding to 11% conversion efficiency)
- Maintain low Cost of Ownership (CoO) for micromorph module fabrication at 0.5 €/Wp
- Reduce the environmental impact of the fabrication process with the target of 20% lower energy payback time

For the third and last year of the project, the specific deliverables for WP2 was

D 2.3: Solar cell deposition on the optimum LPCVD-ZnO layer, reaching efficiency >11.5% (M36)

It was achieved during the year with a 12.1% stabilized efficiency device (not CMM[1] corrected) with the microcrystalline silicon (µc-Si:H) bottom cell deposited at 0.7 nm/s.

Regarding WP3 the remaining specific deliverable was:

D 3.1c: Demonstration of stable cells 11.5% efficiency with i-layer deposited at > 1.5 nm/s (M36)

Strictly referring to the original goal, this deliverable was not achieved. However EPFL mostly focused on a deposition rate of 0.7 nm/s since the M24 project meeting: indeed, the main industrial partner, TEL Solar, clearly pointed out that given the present status of their production line development, a deposition rate as high as 1.5 nm/s was not anymore necessary for achieving the overall cost goal of the project. The goal was thus achieved at 0.7 nm/s with a stabilized efficiency of 11.9% (with CMM).

Description of the project

An optimized TCO front contact is a prerequisite to cost-effective and efficient micromorph modules. Two requirements should be fulfilled: first, the transparency has to be improved without sacrificing too much conductivity. During the first year, different deposition concepts and regimes have been evaluated in order to improve this transparency/conductivity tradeoff of the front zinc oxide (ZnO) layer. Then this front TCO electrode should be rough enough to enable good light scattering (high solar cell current) while, at the same time, still allowing high quality silicon growth. During the second year, different concepts have been tested in order to reduce the defect density in µc-Si:H cells in relation with the ZnO front contact morphology. This relies on the use of additional ethanol (EtOH) or growth regimes involving changes in the precursor’s total flow (high DEZ). During the last period, the EtOH ZnO and the high-DEZ ZnO growth were further investigated, but this time combined with a multilayer approach.

Regarding plasma processes and µc-Si:H high deposition-rate regimes development, the first year was focused on studying the impact of the inter-electrode distance of a KAI-M Plasma Enhanced Chemical Vapor Deposition (PECVD) reactor on the process parameter space for high rate deposition of µc-Si:H. The second year we further studied the impact of the inter-electrode distance (d_{gap}) on the process parameter space for µc-Si:H high rate deposition by further reducing d_{gap} from 12 mm to 9 mm in our medium-size PECVD KAI-M reactor. We could demonstrate that reduced d_{gap} combined with higher pressures led to improved bulk material quality of the deposited intrinsic µc-Si:H layers and enhanced solar cell performances at higher deposition rates (R_d) up to 1.5 nm/s. This last year was focused on improving the overall micromorph cell efficiency with a target R_d of 0.7 nm/s. New deposition regimes were investigated using the narrowest gap configuration available. Two different plasma excitation frequencies were compared and the p-SiOx layer was re-optimized for this configuration. Further collaboration with the University of Patras also helped developing a better understanding of the underlying physics of the µc-Si:H growth and how it relates to the actual plasma deposition conditions.

[1] CMM stands for Current Matching Machine which allows to correctly evaluate the FF of a tandem cell which depends on the current mismatch of the two subcells (more details in previous report and in [1]).

Work carried out and results achieved

TCO developments

During the first two years, single layers of EtOH ZnO were shown to crack if they were thicker than 200 nm, which was detrimental to the layer electrical conductivity. Regarding the high-DEZ ZnO, its preparation required the use of large quantity of DEZ leading to higher production costs. Thus, both kinds of ZnO were instead used as thin cap layers to smoothen the surface morphology of a standard rough ZnO [2]. The high-DEZ ZnO cap layer was chosen as most promising approach given promising improvement in solar cell efficiencies and was further optimized to reach the D2.3 of a stabilized micromorph solar cell with 12.1% stabilized efficiency. Finally, a global multilayer approach was demonstrated, with films having a heavily doped base layer, a lightly doped bulk layer, and a smoothened cap layer.

Comparison of EtOH ZnO and high-DEZ ZnO optimized cap layers

If both EtOH ZnO and high-DEZ ZnO cap layers lead to a smoothening of the surface morphology and improvement in the Si layer growth quality and cells performance, they however, do not lead to the same modification of the front rough ZnO texture.

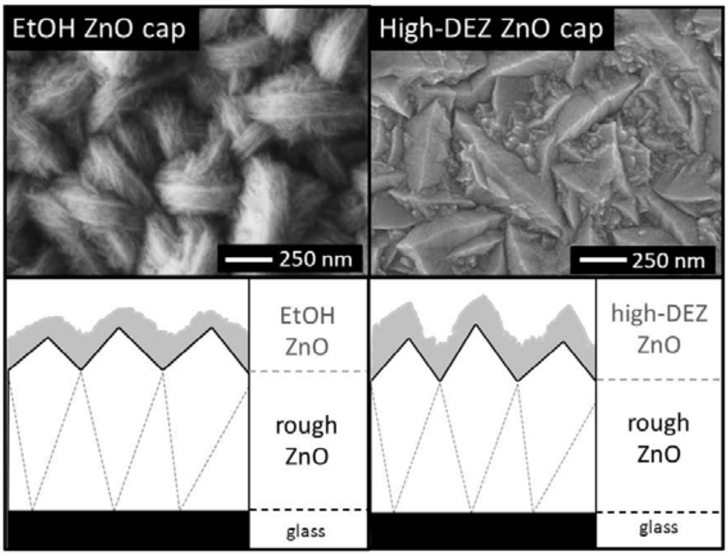

***Figure 1**: SEM pictures and schematics of multilayers with a 200-nm-thick EtOH ZnO cap and a 500-nm-thick high-DEZ ZnO cap layer.*

As illustrated in the schematics of figure 1, the small elongated grains of the EtOH ZnO cover the bottom of the valleys as well as the tips of the pyramidal features, whereas the high-DEZ ZnO fills the valleys, while it continues to grow following the sharp edges of the pyramids. Therefore, the use of EtOH ZnO caps give rise to more pronounced levelling of the rough standard ZnO morphology and to more important losses in light scattering properties than the use of high-DEZ ZnO caps. Thus, the EtOH ZnO cap solution might be more favorable to Si growth processes that are very sensitive to surface roughness. However, a careful optimization should be conducted in order not to reduce too much the current photogeneration while improving the VOC and FF of the solar cells. In the case of the silicon growth processes at EPFL which are tolerant to substrate roughness to some extent, the high-DEZ ZnO cap layer approach was preferred for its better preservation of the light scattering.

A 2.1-μm-thick ZnO base film capped with a 0.3-μm-thick high-DEZ film was used as front contact for micromorph devices with a bottom cell deposited at higher rate (220-nm-thick i-layer top cell, SiOx-based intermediate reflector and 1.3-μm-thick i-layer bottom cell deposited at 0.7 nm/s). The micromorph solar cell performances are summarized in table WP2.I, where it can be seen that an initial conversion efficiency of 13.0% was achieved. At 800h, a nano-imprinted antireflective coating was applied on the glass and contacts were soldered. At 1000h the cell performances had not further decreased, so that a final stabilized conversion efficiency of 12.1% was reached.

***Table I**: Summary of the initial and degraded micromorph cells performances on a front contact consisting of a 2.1 µm rough ZnO smoothed capped with a 0.3 µm high-DEZ layer.*

	Front ZnO	V_{oc} (V)	FF (%)	J_{sc}, top ($mAcm^{-2}$)	J_{sc}, bot ($mAcm^{-2}$)	Efficiency (%)
Initial	2.1+0.3µm	1.332	74.9	13.2	13.0	13.0
800 h light soaked	2.1+0.3µm	1.336	67.8	12.65	12.95	11.45
+ soldering + ARC	2.1+0.3µm	1.320	69.5	13.4	13.2	12.1
Stabilized	2.1+0.3µm	1.330	68.8	13.5	13.15	**12.1**

<u>Global multilayer approach: cap-layer smoothening of a rough film with a boron-enriched nucleation</u>

Finally, LPCVD ZnO films were prepared to combine together a rough bilayer grown with a high diborane doping in the nucleation (developed in the first period) with h a high-DEZ layer. The films were intentionally prepared thicker to exaggerate the surface roughness and enhance the smoothening effect of introducing a 0.3-µm-thick high-DEZ cap layer.

Both capped and non-capped ZnO bilayers were used as front contact for micromorph solar cells (220-nm-thick i-layer top cell, SiO_x-based intermediate reflector and 1.3-µm-thick i-layer low-rate 3Ås^{-1} bottom cell), soldered contacts and a nano-imprinted antireflective coating were also applied in initial state. The cell on the bilayer with a cap-layer showed a 20mV higher V_{OC} and a different current balance than on the non-capped bilayer (table II). Overall, the cell on the capped bilayer achieved 13.2% initial conversion efficiency, 0.5% higher than the non-capped bilayer. As for previous series, the initial VOC were probably underestimated, due to too high temperature during measurement, which explains that the values measured after 1000h light soaking were actually higher or similar than in the initial state. After degradation, the micromorph cell on the smoothed bilayer still exhibited a higher V_{OC} and efficiency than on as-grown rough bilayer.

***Table II**: Summary of the initial and partially degraded micromorph cells performances on a 2.8-µm thick rough ZnO bilayer (B-enriched nucleation), compared to a 2.5-µm-thick bilayer smoothed with a 0.3µm high-DEZ cap-layer.*

	Front ZnO	V_{oc} (V)	FF (%)	J_{sc}, top ($mAcm^{-2}$)	J_{sc}, bot ($mAcm^{-2}$)	Efficiency (%)
Initial	Bilayer 2.8 µm	1.335	76.2	14.3	12.5	12.7
	Bilayer 2.5+0.3 µm	1.355	75.6	13.65	12.9	13.2
Stabilized	Bilayer 2.8 µm	1.343	71.9	13.4	12.2	11.8
	Bilayer 2.5+0.3 µm	1.351	70.2	12.9	12.65	12.0

High-rate deposition of µc-Si:H

The main focus of PV-Lab was to develop µc-Si:H layers at high deposition rates from 0.7 to 1.2–1.5 nm/s. This study highlighted a fundamental aspect of µc-Si:H deposition on highly textured substrates: the contribution of two different phases of µc-Si:H material to overall solar cell efficiency, both of which can drive cell performance. First, the bulk phase of the material, whose quality is related to the defect-related absorption as measured with FTPS. Then a secondary detrimental nanoporous phase (previously called *cracks*), which is shown to be due to the deposition conditions and/or the substrate morphology. The presence of such nanoporous phase in the µc-Si:H film can affect the stability of the thin-film silicon solar cells, which is sometimes referred as dark degradation. Details can be found in [3].

Narrow inter-electrode gap for high pressure processing

During the whole project, EPFL analyzed in detail the influence of d_{gap} on the plasma conditions and the µc-Si:H quality. A reduction of d_{gap} was shown to be beneficial for higher growth rates: with powder formation in the plasma being reduced, the use of higher pressures becomes accessible, improving gas utilization efficiency and reducing ion bombardment energy. This results in improved material quality, as assessed by Fourier transform photocurrent spectroscopy (FTPS) measurements, and very high performances μc-Si:H solar cells. Figure 2a clearly shows that reducing d_{gap} (going from 22 mm, to 12 mm and 9 mm) and using higher pressures allow maintaining higher solar cells performance—as assessed here by V_{OC} × FF values—at larger growth rates. In Figure 2b, we demonstrate that this improvement is related to a decrease of the defect-related absorption of the μc-Si:H *i*-layers. Another benefit from the reduced d_{gap} is that the formation of nanoporous regions during the growth was also decreased, as suggested by the stability of non-encapsulated micromorphs under light-soaking conditions.

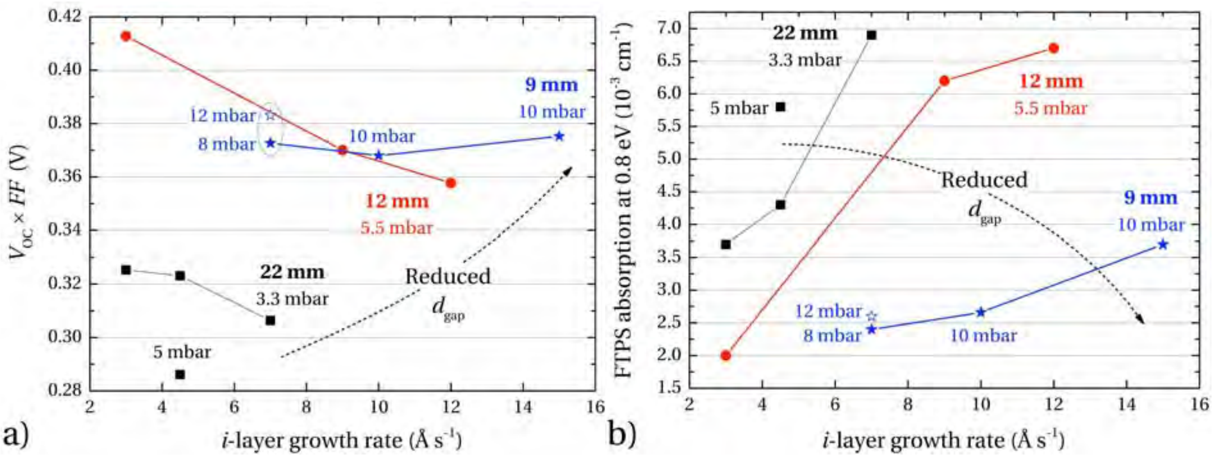

***Figure 2** : (a) Best Voc × FF values obtained for each d_{gap} using the best deposition pressure found for the highest target growth rate. (b) Associated defect-related absorption value at 0.8 eV as measured by FTPS.*

<u>Investigation of the pressure and excitation frequency at 0.7 nm/s with the narrow gap</u>

The use of a lower plasma excitation frequency of 13.56 MHz (RF)—instead of the typical TEL Solar KAI reactor of 40.68 MHz (VHF)—was also evaluated under the narrowest configuration of d_{gap}=9 mm and for a target deposition rate of R_d = 0.7 nm/s. We could show that RF led indeed to a more defective bulk phase, as very high power densities were required, hence limiting the solar cell efficiencies (Figure 3). The RF cells performances benefited much more from increased deposition pressures as compared to the VHF ones, as a result of a reduction of the ion bombardment.

Micromorph cells were also prepared at the same time on 2.5-μm-thick as-grown LP-CVD ZnO electrode, with much smaller and sharper pyramids is typically used as front electrode in micromorph tandems, to allow better light coupling in the top cell. It is however more difficult to grow dense μc-Si:H material at high rate on these types of substrates as shown in the previous periods of the project. This is most probably because of the defective nanoporous regions formation which is promoted. A similar trend was observed as for single-junction μc-Si:H solar cells: deposition at higher pressure leads to better cell performances. For the micromorph cells with bottom cell i-layers grown with VHF frequencies the trends is not as clear for pressure above 8 mbar but, contrary to the single-junction case, the 6 mbar regime clearly exhibits lower performances. Therefore a small trend of improved performances with higher pressure is also observed here in VHF.

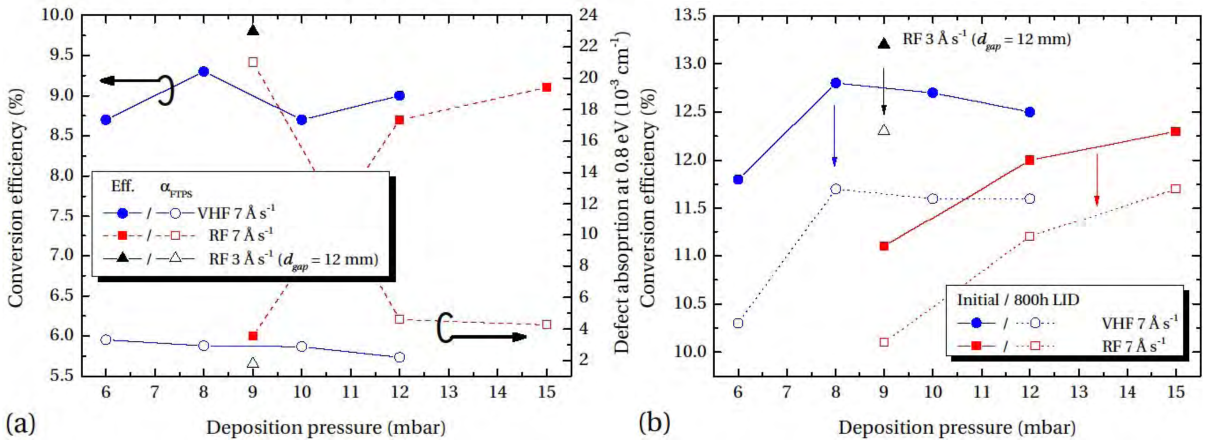

Figure 3 *: a) Efficiency and b) V_{oc}*FF values and defect-related absorption of 1.3-µm-thick µc-Si:H single junction solar cells with the i-layer deposited in different regimes (pressure, frequency) at R_d = 0.7 nm/s and d_{gap} = 9 mm.*

After 800h of light soaking the pressure trends stay the same and it is remarkable to note that the cells deposited at 0.7 nm/s does not appear to degrade more than the reference cell deposited at 0.3 nm/s. This suggests that this combination of lowered gap together with increased pressure leads to an i-layer which is not only less defective in the bulk of the material but also more compact (hence the stability vs dark degradation). Interestingly, the degradation of the micromorph cells with the bottom cell i-layer deposited at 0.7 nm/s in RF seems lower than with VHF. This might indicate the deposition of an even more compact material under these conditions but further studies are required to draw a firm conclusion in this regard.

Best micromorph cell with efficiency above 11.5% with a 0.7 nm/s i-layer bottom cell

Once the parameters space was studied in detail and the most promising conditions identified, dedicated optimization was undertaken directly in micromorph conditions. Table III presents the electrical parameters of the best stabilized micromorph efficiency obtained with the bottom cell i-layer deposited at 0.7 nm/s using the most promising conditions (VHF, 10 mbar). It was grown on a 220-nm-thick top cell made on a 2.5-µm-thick as-grown LP-CVD ZnO electrode, with an n–doped SiOx intermediate reflector.

Table III*: Summary of the best initial and degraded micromorph cell performances.*

	V_{oc} (V)	FF (%)	J_{sc},top (mAcm^{-2})	J_{sc},bot (mAcm^{-2})	Efficiency (%)
Initial	1.303	75	13.6	13.2	12.9
800 h light soaked	1.326	67	12.9	13.1	11.5
+ART+soldering	1.315	70	13.7	13.4	12.3
Stabilized	1.335	69	13.8	13.3	12.3
CMM corrected	1.335	67	13.8	13.3	11.9

The efficiency decreased from 12.9% to 11.5% after 800h of light soaking. At this point, a nanoimprinted antireflective texture (ART) was applied on the glass and the front contact was soldered. The ART resulted in an important increase in top cell current density, a moderate increase in the bottom cell current density and an increase in FF due to different matching conditions. The soldering of the front contact slightly helped to increase the FF as well. As a result, the efficiency was increased to 12.3% and after the last 200h of light soaking, the cell performances had not further decreased, so that a final stabilized conversion efficiency of 12.3% was reached. The J-V curve and EQE curve of this cell after degradation are, respectively, reported in Figures 4a and 4b. A stable cell efficiency of 11.9% was obtained which is a remarkable result for a bottom cell grown at this high rate (the FF was correctly measured in our lab thanks to our current-matching setup [2]).

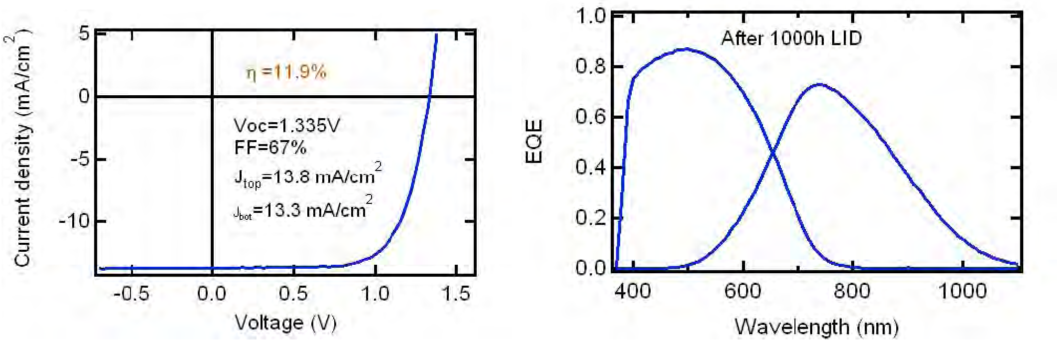

***Figure 4**: Performance of the best micromorph cell obtained after 1000h light soaking: a) J-V curve and b) EQE measurement.*

Latest development of processes at 1.5 nm/s

Even though the primary goal of a micromorph stabilized efficiency over 11.5% was achieved with 0.7 nm/s, EPFL combined all the knowledge gained to continue the development of micromorphs with the i-layer deposited at 1.5 nm/s. A promising initial efficiency of 13% with ART texture was reached (FF = 76%, V_{oc} = 1.33V and J_{sc} = 12.6 mA/cm$_2$) but the cell degraded much more under light soaking than the one presented earlier in this report. Figure 5 presents the J-V curves of this cell in the initial and after 300h of light soaking. Clearly, the high degradation of the FF which is observed is attributed to dark degradation associated with a more porous material as discussed above.

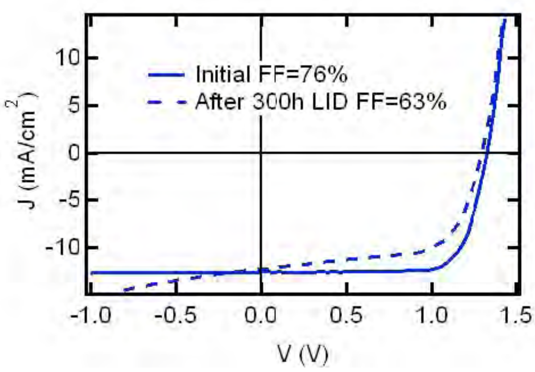

Figure WP3.5: J-V curves of a micromorph device with bottom cell i-layer deposited at a growth rate of 1.5 nm/s measured in initial state and after 300h of light soaking.

Significant effort was made in the beginning of this year to encapsulate our small lab-size cells to reduce the dark degradation issues. However, since this degradation was not visible anymore in devices with bottom cell deposited at 0.7 nm/s EPFL did not pursue these studies and, thus, did not focus on establishing a dedicated process for encapsulation which might help decreasing the impact of dark degradation.

National and international cooperation

Solar cells were prepared in collaboration with TEL Solar in Switzerland: substrates and silicon layers were prepared in both IMT and TEL Solar in order to fabricate complete solar cells, and fully characterize the materials. Multiple exchanges allowed for the validation of the new TEL short-gap reactor, allowing for the growth of a very good quality intrinsic µc-Si:H with low defect density on top of EPFL *p*-SiO$_x$ layer. Using this approach, high-efficiency micromorphs of 13% initial were reached with the *i*-layer deposited at 0.7 nm/s.

To better understand the physics of the µc-Si:H growth we also collaborated with the University of Patras in Greece. Many plasma deposition conditions and solar cell results were shared with them.

The simulations performed highlighted the important roles of the different silane radicals contributing to the growth of films with higher µc-Si:H quality. These results are promising for providing a better understanding of the plasma requirement to grow high-quality µc-Si:H films and this collaboration will extend after the end of the PEPPER project.

Evaluation 2013 and Outlook 2014

The EU FP7 PEPPER project ended up this year. Very interesting results were obtained and significant knowledge was gained both for the LPCVD ZnO development and the high-rate deposition of µc-Si:H in narrow gap reactors.

LPCVD ZnO development

Based on a better understanding of the effect of precursor flow and of addition of EtOH on LPCVD ZnO adatom mobility and film growth, it has been possible to control the pyramidal feature density on the surface until reaching ZnO surface with less than 20 nm roughness and a haze factor of zero. By stacking these "smooth" ZnO on standard rough ZnO films, the surface morphology could be adapted and decoupled from the electrical properties, without additional argon-based plasma treatment. A twosteps LPCVD growth with a high-DEZ ZnO cap approach was thus selected to fulfil the deliverable D2.3 with a micromorph cell stable efficiency of 12.1% efficiency.

These new understandings open a very interesting road for more flexibility in the development of LPCVD ZnO for solar, as well as other applications. In addition, it has been observed that such smooth ZnO films possess better intrinsic electrical properties than the standard rough ZnO.

High-rate deposition of µc-Si:H

Developments of processes suitable for obtaining high-quality micromorph devices with bottom cell i-layer deposited at a high growth rate of 0.7 nm/s were conducted. VHF as well as RF frequencies were investigated for different pressure regimes. When using RF frequency it is obvious that higher pressure regimes leads to better µc-Si:H material quality and cell performances. In PV-Lab studies, only a minor trend for better material quality with increased pressure using VHF was visible but TEL Solar, who was able to study a larger range of deposition pressure using shorter inter-electrode gap distance, could confirm the trend in VHF as well [4]. The further reduction of the inter-electrode gap distance as followed by TEL Solar seems the promising approach to reach higher material quality by benefiting from higher deposition pressure with low powder formation.

With the current inter-electrode distance of 9 mm at PV-Lab we were able to produce a micromorph device with a stable efficiency of 11.9% using a bottom cell with i-layer deposited at 0.7 nm/s. These results are excellent when compared to the baseline for which the best results are in the range of 12.0%-12.4%. Note that the current certified world record efficiency is of 12.3% fully measured with JV measurements while PV-Lab extract the J_{sc} through EQE measurements and the FF is corrected with CMM measurement. It is also extremely encouraging that with deposition rates of 0.7 nm/s the devices do not degrade more than the reference cell which means that the amount of defective nanoporous regions in these deposition conditions is limited. At 1.5 nm/s such dark degradation is still observed suggesting that narrower gap and increased pressure would appear necessary.

TEL Solar industrial partner

The main industrial partner TEL Solar in Switzerland could benefit as well from the project and the knowledge gained. At the end of the PEPPER project a stabilized module performance of 151W in the TBB pilot line was reached using their newly developed narrow gap reactor. Using an anti-reflection coating and the latest cell design, an initial performance of 172.5W was obtained, which, assuming a 10% relative degradation would lead to a 155W record module. More gains can still be expected and certified results for modules with over 11% total area efficiency are expected.

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FASTTRACK

ACCELERATED DEVELOPMENT AND PROTOTYPING OF NANO-TECHNOLOGY BASED HIGH EFFICIENCY THIN FILM SILICON SOLAR MODULES

Annual Report 2013

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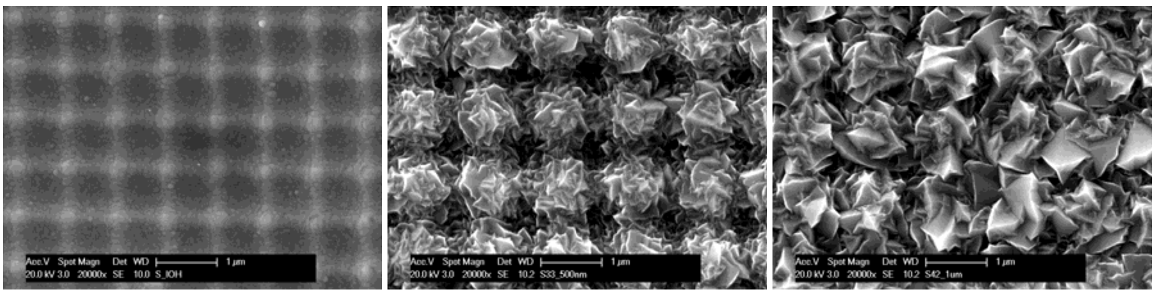
Project- / Contract Number	283501
Duration of the Project (from – to)	1.03.2012 – 28.02.2015
Date	2.12.2013

ABSTRACT

Thin film silicon solar cells require light scattering surface textures in order to enhance light absorption in the device. This project is devoted to the development and to the industrialisation of novel textures and light management schemes. Since interface textures also have an influence on the growth of the active layers, two work packages led by EPFL are devoted to light management (WP1) and the growth of material with high electronic quality (WP2). One approach is to design double structures with controlled transition from regular to random textures.



The industrial partners within the consortium ensure that the chosen approaches are nevertheless scalable from lab-oriented research to manufacturing.

Project goals

The project FastTrack is part of the theme “Energy” within the 7th Framework programme of the European Union. The main project goals are the development of innovative photovoltaic cell processes and their up-scaling to the level of pilot lines. These goals should be reached in terms of a stable device efficiency higher than 14% and a prototype module with stable efficiency higher than 12%.

International collaboration

The project consortium consists of 19 partners, among these are 6 universities, 4 research institutes and 7 companies. The work is organized in 9 work packages devoted to novel material, solar cell processing, processes for high deposition rates, and characterization. The remaining work packages address industrial aspects like up-scaling, module integration, cost analysis, and dissemination.

Work in reporting period

EPFL’s contribution is devoted to the development of novel nano-textured substrates, engineering of advanced materials, and to the integration into high efficiency tandem devices.

WORK PACKAGE 1: NOVEL SUBSTRATE TEXTURES

Tandem cells require a careful design of the underlying substrate texture since the current density produced in the top- and the bottom-cells should match. In a series of different substrate morphologies like the one shown in ***Figure 1***, light scattering does not always vary uniformly for short and long wavelengths. In order to assess the performance of a given substrate, it would therefore be necessary to find the appropriate cell thicknesses that yield the desired current matching.

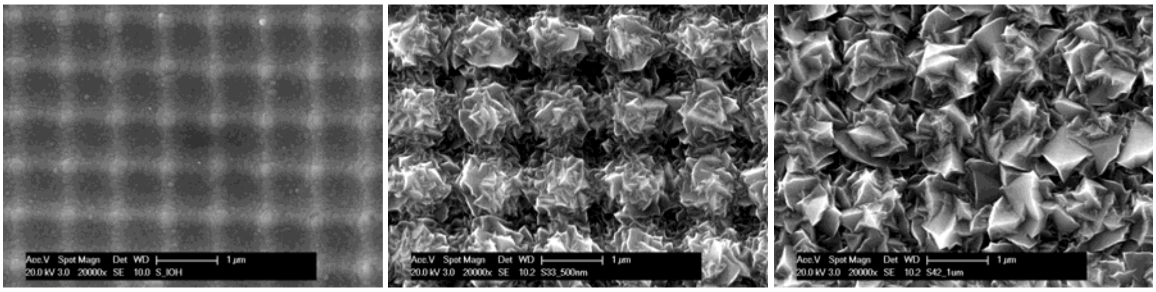


FIGURE 1: STARTING FROM A REGULAR TEXTURE (LEFT), COATING WITH THICKNESSES OF 0.5 AND 1 MICROMETER OF LP-CVD ZINC OXIDE YIELD A GRADUAL TRANSITION TO A FULLY RANDOM TEXTURE (RIGHT).

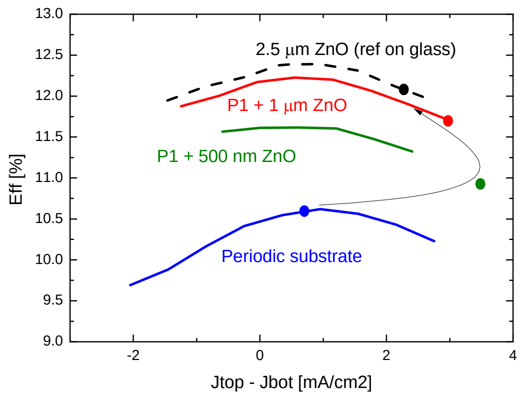


FIGURE 2: CURRENT MATCHING EXPERIMENT OF TANDEM CELLS ON THE SUBSTRATES SHOWN IN FIGURE 1. THE DOTS ILLUSTRATE CONDITIONS OF AM1.5 ILLUMINATION OF THE SUN.

In order to speed up this process, a characterization tool with varying illumination spectrum has been developed. ***Figure 2*** shows the variation of the efficiencies of a tandem cell as the illumination spectrum is swept from red-rich (left) to blue-rich (right). The periodic substrate yields a matched cell, but with moderate performance around 10.5%. Adding 500 nm of ZnO, efficiencies around 11.5% are achievable, but the resulting cell is strongly mismatched because the additional current density is produced only in the top cell. Adding 1 µm of ZnO, the efficiency is further improved to levels around 12% and matching is slightly improved. For any of the combinations, it now easy to predict the required thicknesses of the component cells that yield the desired matching.

We also note that the combination of the periodic structure and 1 µm of ZnO yields a substrate that is very similar to the reference cell denoted by the dashed line.

This experiment shows that the performance of the standard 2.5 µm thick ZnO reference texture can be achieved by a combination of a periodic texture and a much thinner ZnO film. Compared to the ZnO film that is grown by a vacuum process, the periodic structure is manufactured by UV imprinting and does not require vacuum. The combination offers thus a significant acceleration of the process.

WORK PACKAGE 2: NOVEL MATERIALS

Since the first description of amorphous silicon solar cells and the report on its light induced degradation, a variety of alternate deposition regimes has been studied in different labs around the world. Overall, the different reports agree that the material should ideally be deposited by plasma-enhanced chemical vapour deposition (PE-CVD), but the details of the ideal deposition conditions are controversial between the different labs.

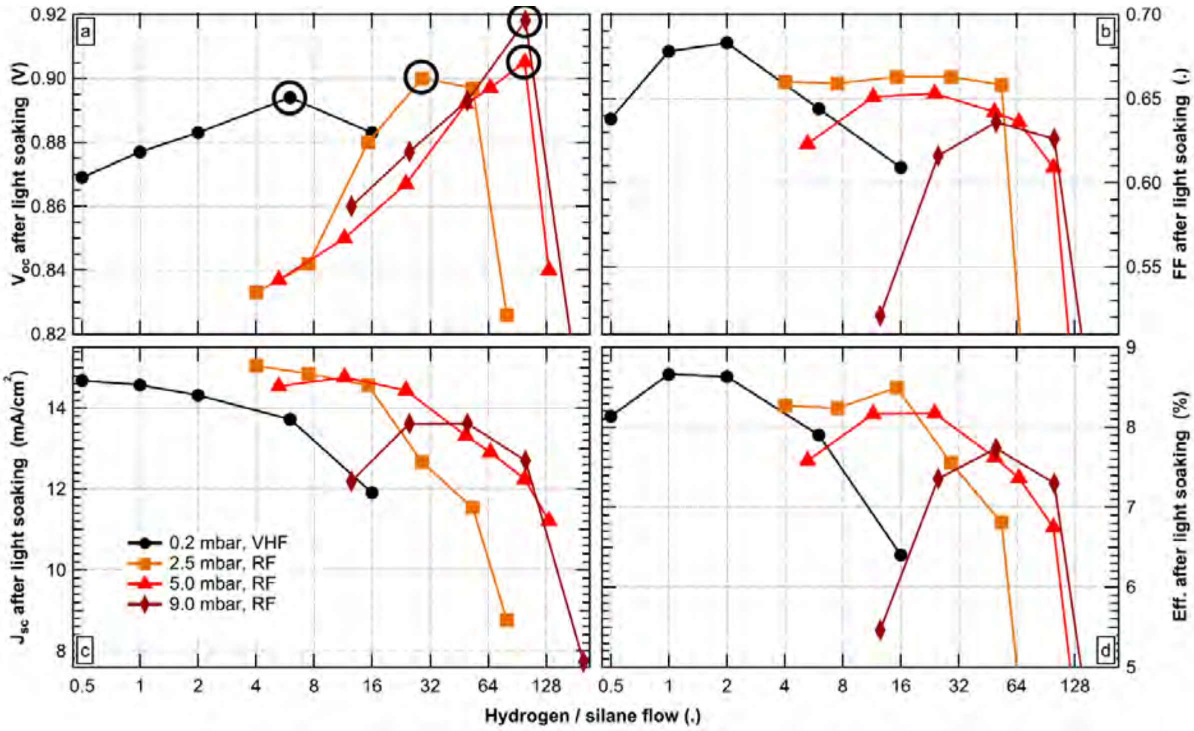


FIGURE 3: STABILIZED PARAMETERS OF AMORPHOUS SILICON SOLAR CELLS DEPOSITED OVER A WIDE RANGE OF DEPOSITION PARAMETERS, COVERING LOW PRESSURE AND HIGH FREQUENCY AS WELL AS HIGH PRESSURES AND STANDARD RF EXCITATION.

We used a versatile cluster deposition system that has been custom-designed to cover a sufficient range of temperatures, pressures, gas fluxes, and excitation frequencies. ***Figure 3*** shows the main results of a consistent screening across most of the reported deposition regimes. We use the hydrogen content in the precursor gas-mix as primary parameter to plotted are the performance parameters after light soaking for 1000 hours at 50°C. It is thus observed that the highest efficiencies are obtained for cells deposited at low pressure and high frequency excitation. Compared to high-pressure regimes that reach only slightly lower efficiencies, the low-pressure regime has the additional advantage of a broad process window of hydrogen addition.

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INTERFACE TEXTURING FOR LIGHT TRAPPING IN SOLAR CELLS

Annual Report 2013

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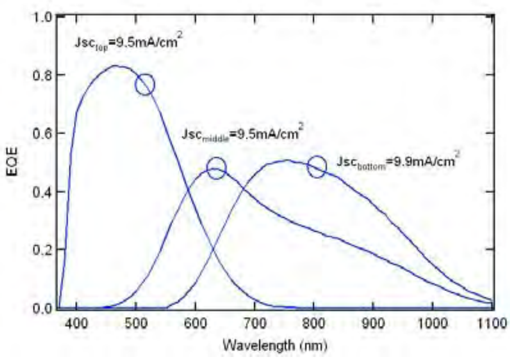
Project- / Contract Number	SNF200021_125177-01 / SNF200020_137700-01
Duration of the Project (from – to)	Oct 1st, 2009 – Nov 30th, 2013 (2 + 2 years)
Date	Dec. 2nd, 2013

ABSTRACT

This project combines experimental and theoretical work on novel surface textures for light confinement in thin film solar cells. Using a novel substrate configuration in combination with an anti-reflection texture, a triple junction solar cell with stabilized efficiency of 13.0% has been demonstrated.



Theoretical work concentrated on finding out whether plasmonic effects with their extraordinary confinement of the electromagnetic field are useful for absorption enhancement. Therefore model systems consisting of an a-Si film deposited periodically textured silver reflectors were studied.

SNF project "Interface texturing"

The project funded by the Swiss National Science Foundation is a collaboration between the PV-Lab and the group of Advanced Optics. The project aims at the development of optical simulation tools and experimental analysis of interface textures.

Work performed in the reporting period 2013

EXPERIMENTAL WORK

Based on work from the previous reporting period, work on the flattened reflectors shown in Figure 1 was continued. Using the high reflection of a flat silver film, a ZnO film is added as light scattering texture. In order to avoid growth of defective material on the texture, first a dummy material with high refractive index is deposited and subsequently polished. On this flat interface, microcrystalline material can be grown with high quality.

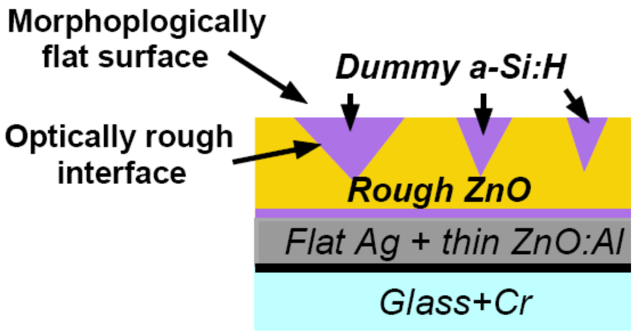


FIGURE 1: SCHEMATIC DESIGN OF THE FLATTENED BACK REFLECTOR.

Figure 2 shows the external quantum efficiencies of triple junction cells on the flattened reflector. Starting from a cell with initial efficiency of 13.7%, the cell stabilizes at 12.5% after exposure to 1000 h of continuous illumination. Finally, application of an anti-reflecting texture on the front, cells from this experiment yield an efficiency of 13.0%.

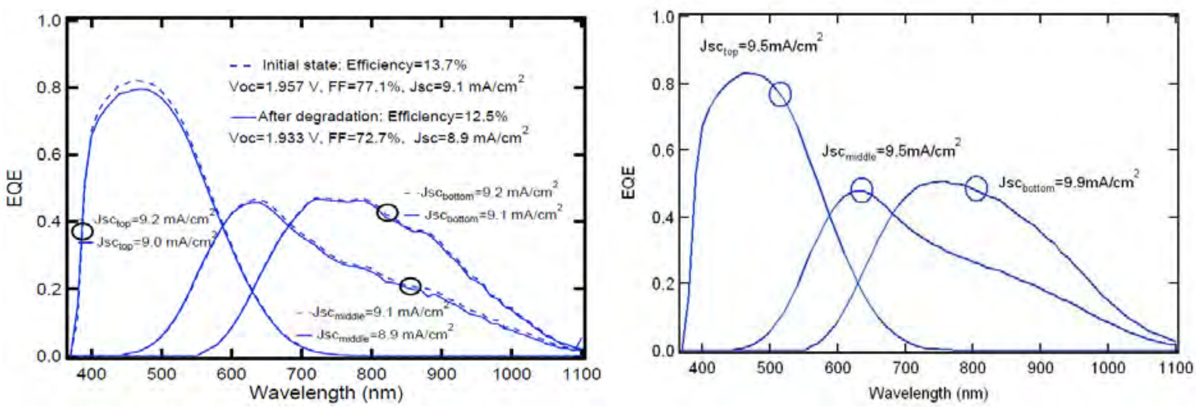


FIGURE 2: EXTERNAL QUANTUM EFFICIENCY (EQE) OF A TRIPLE JUNCTION SOLAR CELL ON THE FLATTENED SUBSTRATE. DASHED AND FULL LINES DENOTE THE INITIAL AND THE STABILIZED STATE, RESPECTIVELY. THE RIGHT PANEL SHOWS THE EQE AFTER APPLICATION OF AN ANTI-REFLECTION TEXTURE.

THEORETICAL WORK

The stack of a solar cell can be regarded as a kind of waveguide. Different from most waveguides in telecommunication, however, the solar cell is a planar guide. A second difference is related to the high refractive index and the absorption of silicon which makes a multi-mode guide with attenuation. Coupling, i.e. getting external radiation into the guide is essentially achieved by the same mechanisms.

We investigated model systems that consist either of a single film of amorphous silicon on a silver back reflector of complete stacks including the transparent front electrode. Next, we chose a sinusoidal texture as coupling element.

Figure 3 illustrates the dispersion relations of the modes that can propagate in the “silicon waveguide” in TE and TM polarization. Their characteristics are located between the straight lines denoted “air” and “a-Si” with the exception of the lowest-order TM mode which crosses the a-Si line. The former behaviour is typical for guided modes, the latte distinguishes a surface plasmon polariton (SPP). Common to all modes is the fact that they are to the right of the air-line.

Incident light is denoted by the symbols overlaid to linear characteristics; each of the straight lines corresponds thus to a reflection spectrum out of a series of angle resolved measurements. Perpendicular incidence of 0° yields the vertical characteristic along the energy axis, incidence of 50° yields the most oblique of the lines.

The coupling mediated by a periodicity is illustrated by the Brillouin zones (BZ). The waveguide modes are plotted in extend scheme, i.e. covering several BZs, and after reduction to the first BZ. Absorption enhancement by grating-coupling is clearly located at positions where characteristics of the incident light and guided modes intersect.

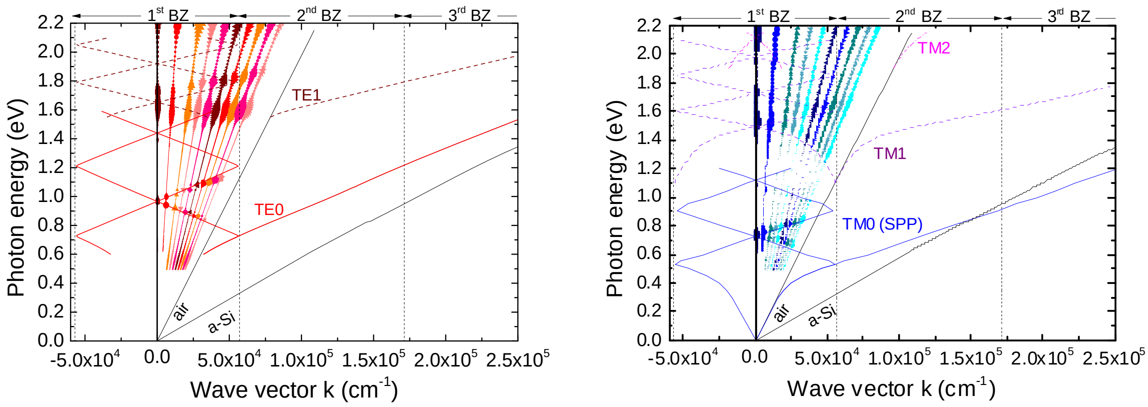


FIGURE 3: DISPERSION DIAGRAMS OF A FILM OF AMORPHOUS SILICON ON SILVER FOR TE- (LEFT) AND TM-POLARIZATION (RIGHT). THE SYMBOL SIZE REPRESENTS THE AMOUNT OF ABSORPTION.

The absorption enhancement of the SPP mode is clearly seen in the right diagram of Figure 3 at energies between 0.6 and 0.9 eV, clearly at energies below the relevant region of amorphous silicon. Coupling into first order modes starts above 1.6 eV is therefore more relevant for absorption enhancement. Maps of the electromagnetic field intensity are shown in Figure 4.

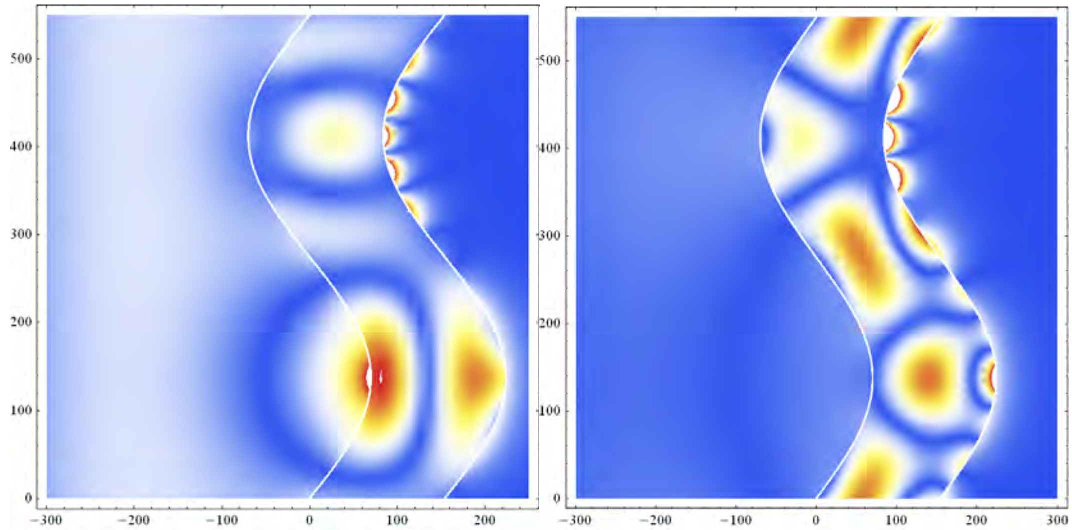


FIGURE 4: ELECTROMAGNETIC FIELD INTENSITIES OF THE TE1 (LEFT) AND TM1 MODES (RIGHT) FOR RESONANCE CONDITIONS AT 1.75 eV (710 nm) AND 1.65 eV (750 nm), RESPECTIVELY. IMAGE SIZE IS 550X550 nm, FROM LEFT TO RIGHT IS AIR, SILICON, AND SILVER.

If we would like to exploit coupling to the fundamental TE1 and TM1 modes in the region relevant for absorption enhancement of amorphous solar cells, i.e. between 1.8 and 2.0 eV, we should try to find conditions where the first crossing of the reduced characteristics occurs in that energy range. This would require a larger BZ which translates to a smaller grating period.

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HIGH RATE DEPOSITION OF MICRO-CRYSTALLINE SILICON

FOR SOLAR CELL APPLICATIONS BY MEANS OF A RESONANT NETWORK RF ANTENNA

Annual Report 2013

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Project- / Contract Number	KTI 15082.1
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Date	2.12.2013

ABSTRACT

To change from the traditional capacitively coupled plasma reactor to inductively coupled devices might reduce the cost and increase the efficiency of thin film solar cells. In the present project, a plasma box reactor equipped with a resonant network RF antenna will be constructed and, as a main topic, PV related material will be aimed for under these conditions. Additional equipment of the plasma reactor with a biasing electrode will allow the ion bombardment of the substrate to optimize the material properties. The project will lead to a concept and design of a novel PECVD production reactor. The antenna parameters have been determined and reactor construction has begun.

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

Annual Report 2013

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Project- / Contract Number	20plµs / 256695
Duration of the Project (from – to)	01.10.2010 – 01.10.2013
Date	09.12.2013

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 silicon solar cells. The guiding principle of this project is to develop new and innovative process steps for wafer, solar cell, and module fabrication on wafers less than 100 µm thick, taking into consideration 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 are being studied and compared. Our laboratory is focusing on amorphous silicon (a-Si:H) / crystalline silicon (c-Si) heterojunction (HJ) solar cells processed at low temperatures. In this project, our efforts are shifted to understanding and improving optical and electrical losses in devices, as well as light trapping in thin wafers. Our final target is to demonstrate ultra-high efficiency (up to 23%) a-Si:H/c-Si heterojunction solar cells on thin wafers.

EPFL 'PV-Lab' at IMT Neuchâtel has extensive experience for fabrication of high quality amorphous and microcrystalline silicon layers, as required for perfect low temperature passivation of c-Si wafers and a-Si/c-Si heterojunction. In the last year EPFL could successfully fabricate devices with high V_{OC} (above 727 mV) and FF (78%), taking full benefits of the intrinsic a-Si:H layer. Cells on textured wafers with a front transparent conductive oxide (TCO) layer leading to 22.1% efficiency (4 cm^2) were fabricated with screen-printed contacts.

In this report we show the final advances that have been obtained during the final year of this project. We report on the development of amorphous silicon passivation layers that are both highly transparent and enable high open-circuit voltages (V_{OC}) on thin wafers. A detailed optical loss analysis of the device has been addressed to define the internal reflection requirements to maximize the short-circuit current density (J_{SC}). A nanostructured rear side has been implemented on solar cells to improve the J_{SC}. Finally, record cell efficiency results are presented.

Introduction

The reduction of cost per Watt-peak (W_p) for silicon solar cells is most efficiently achieved by reducing silicon material cost using thin wafers *and* by enhancing efficiency to above 20%. However today´s industrial standard cell structures are not suited to reach this goal. Additionally, the mechanical yield of the solar cell and module production has to be high enough to reach cost effectiveness, which tends to be in contradiction with wafer thickness reduction. The 20plµs project aims to resolve this contradiction for a solar cell thickness of 100 µm at a solar cell conversion efficiency of above 20%.

Goals of the project

The overall objective of the 20plµs project is the development of a 20% efficient silicon solar cell with a thickness 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 thin solar cells of a thickness of 100 µm with an area of 156 x 156 mm^2. Thus, the project addresses both, the development of future generation cell structures and the issues related to industrial production as yield, throughput, etc.

PV-Lab is concentrating on reaching this objective using the silicon heterojunction (HJ) solar cell design. Within the project, PV-Lab's goals for 2013 included the development of amorphous silicon (a-Si:H) window layers allowing for very low surface recombination velocities, emitters for cells with very high open-circuit voltages (V_{OC}) on thin wafers, as well as the demonstration of solar cells with improved short-circuit current density (J_{SC}). The ultimate goal we had during the last period of the project was the fabrication of devices featuring 23% efficiency on a 100 µm thick wafer and 22% efficiency on a 70 µm thick wafer.

Brief description of the project (2010-2013)

The guiding principle of this project is to develop new and innovative process steps for wafer fabrication, solar cell and module manufacturing, taking into consideration the transfer of the processes into a pilot production line. The needs of the industrial solar cell and module producing companies to find a solution for the next steps in further reducing the wafer thickness in their production lines have been addressed, and therefore the transfer of a solar cell process to the pilot production line has already considered at midterm of the project.

20plµs deals with the full process flow, giving attention to the following topics which are particularly crucial for solar cells on thin wafers, in more detail: wafering, surface passivation, light trapping, solar cell and module processing and handling of the thin wafers.

PV-Lab is a principal contributor to the work packages related to emitter formation, passivation, light trapping, metallization, and prototype cell fabrication. Consequently, we have been developing new scientific understanding and fabrication processes for each of these topics as they relate to silicon heterojunction solar cells, focusing on achieving more than 20% efficient cells on wafers less than 100 µm thick.

Work performed and results achieved in 2013

During 2013 major efforts were put on the development of new and better high quality passivation layers, well adapted to thin wafers, giving high carrier lifetimes already in the as-deposited state. Besides, the optimisation of the a-Si:H film thicknesses and TCO has been a key aspect to limit light absorption and thus increase $J_{SC.}$ Moreover, a detailed theoretical and experimental analysis of internal reflection in heterojunction devices has been carried out to determine the route towards high performing devices. The use of all our knowledge and advances has allowed us to fabricate record devices on very thin c-Si substrates, as it will be presented in the following paragraphs.

1. Assessment of different materials and materials stacks

A strong effort was put on the development of high-quality passivation layers, giving high carrier lifetimes already in the as-deposited state and with minimal thicknesses. With the aid of different in-situ plasma diagnostics used during the PECVD process, it has been shown that good a-Si:H passivation layers are obtained in regimes close to the microcrystalline transition [1]. To go even further this transition without risking epitaxial growth (which is very detrimental to passivation), H2 plasma treatments during a-Si:H deposition can greatly help to improve the passivation level [2].

With these optimizations, very high minority carrier lifetimes were obtained on solar cell precursors (textured wafers passivated with *in* and *ip* a-Si:H stacks), for various wafer thicknesses. All this work led to impressive implied open-circuit voltages, as high as 767 mV on 70 µm-thick wafer (see Figure 1, black plots). The V_{OC} on finished devices ranged from 737 mV to 747 mV (same figure, red plots). We remarked that to obtain these results, a well-controlled wafer texture process and surface cleaning is extremely important.

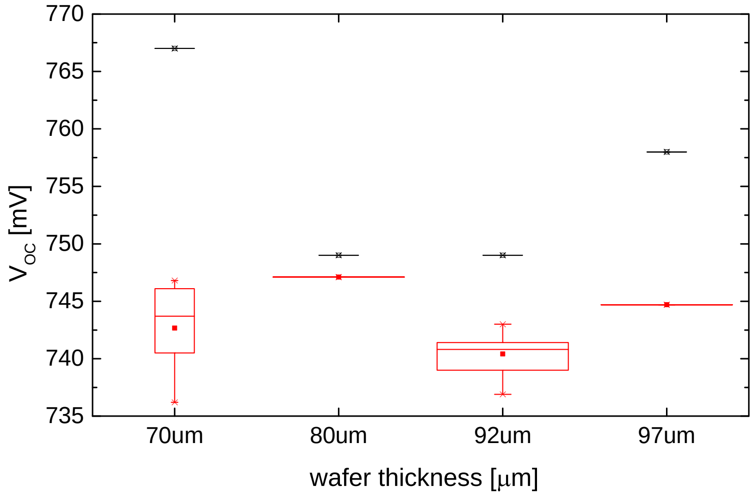

Figure 1. V_{OC} (red plots) and implied V_{OC} (black plots) of HJ devices of different wafer thicknesses.

Much of the work done on this topic has also focused on the development and assessment of rear reflector materials stack with superior optical performance, since it is a significant source of parasitic absorption. Related to this, the transparent conductive oxide requirements that must be met to achieve active area short-circuit current density, J_{SC}*,active* > 40 mA/cm^2 in 100-µm-thick HJ cells were listed and a description on how to push J_{SC}*,active* over 41 mA/cm^2, focusing on the role of internal reflection of IR light was given. Starting with the external quantum efficiency (*EQE*) and reflectance (*R*) spectra we measured on our best 100-µm-thick HJ cell, we showed several ways in which these spectra may be modified to boost J_{SC}*,active* to 41 mA/cm^2. The three possible routes to improvement are decreased UV parasitic absorption, improved internal reflection, and improved light trapping. We showed that the first route is the most effective and that extending the path length of IR light is not the only way to high currents. This report is also publically available as the following reference [3].

Throughout the research done, the optimal TCO (or dielectric) and metal layers to maximize internal reflectance in thin HJ solar cells have been defined. We have achieved near-optimal layers experimentally, so that additional improvements of internal reflection will result in a maximum addition 0.4 mA/cm^2. To reach J_{SC}*,active* > 41 mA/cm^2, one must consider define the internal reflection requirements in relation to the other optical losses in the device. For example, with our current best devices, perfecting internal reflection while keeping everything else constant is insufficient. However, if very transparent front a-Si:H-like layers are developed, we can reach nearly 42 mA/cm2 with our present internal reflection. Thus, though there are numerous paths to 41 mA/cm^2, the most likely route will combine new materials to reduce UV and IR parasitic absorption, improved anti-reflection coatings to reduce primary reflectance, and new textures to trap light.

In addition, new materials such as amorphous silicon oxide layers for the front of heterojunction solar cells have been developed, since these cells include parasitically absorbing materials that light “sees” before the active absorber layer (the wafer).

2. Light trapping schemes

J_{SC} losses due to parasitic absorption in the front a-Si:H, transparent conductive oxide, and rear metal electrode layers are a persistent problem in silicon heterojunction solar cells that become increasingly important as the wafer thickness is reduced.

Figure 2 shows the measured external quantum efficiency (EQE) and total absorbance (1-reflectance) of a 96-µm-thick, 20.8%-efficient silicon heterojunction solar cell fabricated in our laboratory. The figure has been divided into several regions according to loss mechanism to illustrate the relative importance of each mechanism and to motivate this study. Shadowing from the front screen-printed silver grid accounts for the largest loss, but parasitic absorption at wavelengths greater than 900 nm is nearly as significant. Interestingly, escape reflection due to imperfect light trapping is the least important loss, even in this 96-µm-thick cell, because the random-pyramid texture is excellent at confining light to the wafer.

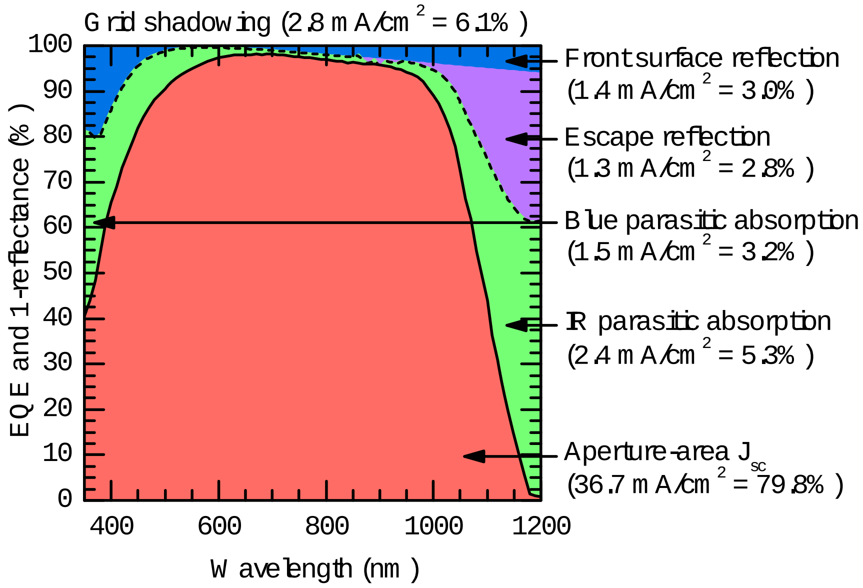

Figure 2. External quantum efficiency (solid) and total absorbance (dashed) of a 20.8%-efficient silicon heterojunction solar cell on a 96-µm-thick wafer.

We reported that IR parasitic absorption in silicon heterojunction solar cells arises from free-carrier absorption in both the front and rear TCO layers, as well as plasmonic absorption in the rear metal electrode. The plasmonic loss occurs only for *p*-polarized light that is incident on the rear TCO above the critical angle, and only if the metal electrode is within the penetration depth of the resulting evanescent wave. Consequently, one method to mitigate the loss in the metal electrode is to require the rear TCO layer to play an optical as well as electrical role by making it thick and very transparent. An alternative approach is to make the rear TCO very thin so that it serves only an electrical contact function (or dispose of it altogether if a suitable doped a-Si:H/metal junction can be formed), and to add another layer specifically to suppress plasmon excitation in the metal electrode.

Then rear reflectors with low-refractive-index were fabricated exhibiting magnesium fluoride (MgF_2) as the dielectric, and with local electrical contacts through the MgF_2 layer. These MgF_2/metal reflectors were introduced into solar cells in place of the usual transparent conductive oxide/metal reflector. An MgF_2/Ag reflector yields an average rear internal reflectance of greater than 99.5% and an infrared internal quantum efficiency that exceeds that of the world-record UNSW PERL cell. As it has been demonstrated, an MgF_2/Al reflector performs nearly as well, enabling an efficiency of 21.3% and a short-circuit current density of nearly 38 mA/cm^2 in a silicon heterojunction solar cell without silver or indium tin oxide at the rear.

The design of this reflector can be seen in Figure 3. This design has been used, employing MgF_2 as rear dielectric, and either ZnO or ITO as rear transparent conductive oxide and either Cu or Ag as full coverage rear metallization. In Figure 4, we show the spectral responses of the different devices fabricated. We show in the same figure the responses of the published record devices of Panasonic, and also of the UNSW PERL world record cell. Quite interestingly, one sees that our combination of ZnO as transparent conductive oxide layer at the rear and Ag as full coverage metal back contact, even has a better red response than the UNSW record cell! The latter cell has a certified efficiency of 25 % (designated area), and a reported short circuit current density of 42.7 mA/cm^2. As our structure has even a better response, arguably with this structure an active area short circuit current density > 42 mA/cm^2 is indeed feasible.

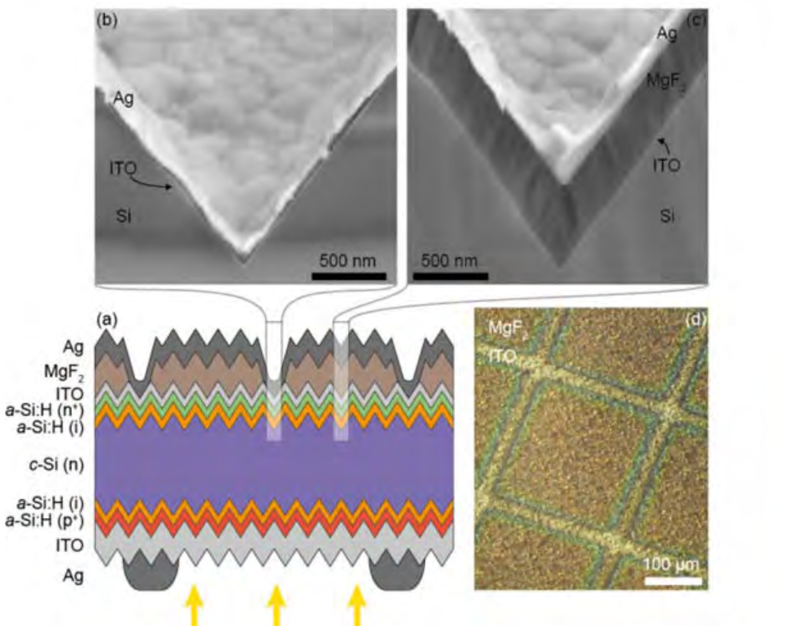

Figure 3. New rear reflector for heterojunction solar cells.

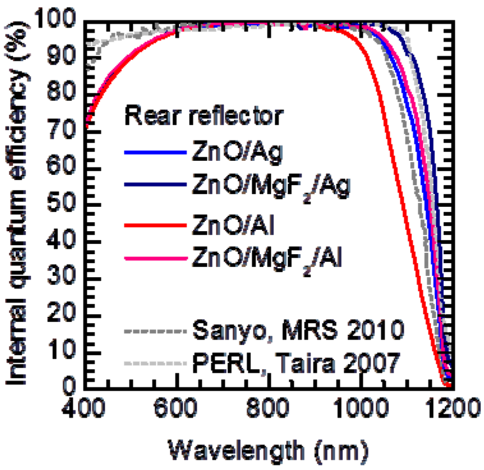

Figure 4. Internal Quantum Efficiency of the different heterojunction rear stacks fabricated.

As shown in Figure 3, local contacts through the insulating MgF_2 layer are necessary to collect electrons at the rear of the cell. The contact design requirements are relaxed compared to those for PERL-like solar cells because these local contacts are through an optical—not passivation—layer. In particular, a relatively large contact fraction can be tolerated since only internal reflectance will suffer in the contacted areas, and thus current crowding and the associated increase in series resistance are not a concern.

In this study, we demonstrated an MgF_2/Ag reflector that gives exceptional rear internal reflectance and, when implemented in a silicon heterojunction solar cell with a high-mobility front TCO, excellent IR *IQE*. An MgF_2/Al reflector performs nearly as well, and in this case the boost in performance provided by the MgF_2 layer may warrant the additional processing step. The reflector concept introduced here, in which local contacts through a low-refractive-index insulating layer are made for an optical rather than passivation gain, may be transferred to other cell structures. For example, an MgF_2/metal reflector is expected to be particularly advantageous in thin-film silicon solar cells grown on metal foils, though the contact pitch will need to be reduced to compensate for the high lateral resistivity of the absorber. This report is also publically available as the following reference [4].

3. Final device performance

The goal here was to evaluate the impact on device performance of the new materials and light trapping schemes developed throughout the project. Here, n-type 5 inch Cz wafers were thinned from 56 to 96 µm by means of alkaline texturing. Intrinsic a-Si:H layers were deposited at temperatures below 250ºC on both sides of the wafers using plasma-enhanced chemical vapor deposition (PECVD) in a reactor operated at very high frequency (VHF, 40.68 MHz). These layers have been optimized on thick wafers to yield minority carrier effective lifetimes as large as 11 ms. *p*- and *n*-type a-Si:H layers were deposited on the front and back of the cell, respectively, to form the emitter and back surface field. The p-layer thickness was kept below 5 nm to minimize blue and UV parasitic absorption, while the n-layers were somewhat thicker. Hydrogenated indium oxide/indium tin oxide (IO:H/ITO) bilayers—high-mobility, low contact resistance TCO layers—were sputtered on the front side of the device and a double stack ITO layer was deposited at the rear of the wafer. The cells were finished with a sputtered silver reflector and a screen-printed silver front electrode grid.

Table I compares the previous results obtained on 4 cm^2 size cells and the recent advances obtained during the last year of the 20plµs project. As inferred from Table I, the quality of the material has been changed from FZ to Cz which responds to the fact that the initial thickness of Cz as-cut wafers was much closer to the target thin thickness and thus the saw damage removal step was shortened. By doing this, a fine texturing was obtained which contributed to such high results on Cz material.

	FZ 230 µm 4 cm^2	Cz 160 µm 4 cm^2	FZ 96 µm 4 cm^2	Cz 70 µm 4 cm^2	Cz 85 µm 4 cm^2
V_{OC} [mV]	727	731	735	747	740
J_{SC} [mA/cm^2]	38.9	36.9	36.7	36.9	37.5
FF [%]	78.4	77.1	77.3	77.9	77.6
Efficiency [%]	22.1*	20.8	20.8	**21.5**	**21.5**

Table I. Solar cell characteristics of 4 cm^2 solar cells fabricated throughout the project. Latest results are highlighted in red.

Integrating all best industrially compatible process (texturing, cleaning, a-Si:H and TCO deposition, printing) allowed us to enhance our previous results. Efficiencies up to 21.5% and open circuit voltages as high as 747 mV have been achieved on 70 µm thick wafers. Applying the additional MgF_2 double antireflective coating layer deposited on top of the cell by thermal evaporation, short circuit current density and efficiency have been boosted for these thin wafers. As it can be seen in Figure 5 active-area efficiency reaches 21.7%.

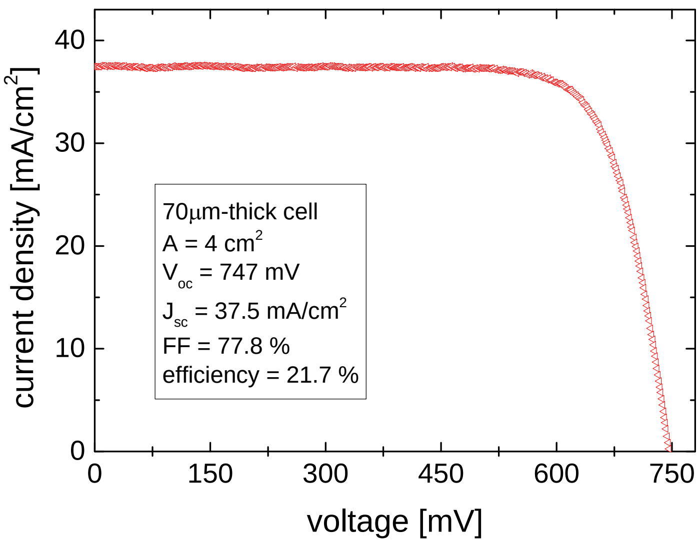

Figure 5. I-V curve of the best 4 cm^2 nlt cell on a 70-µm-thick wafer. Electrical parameters of the cell are given.

Analogous advances have been done on 100 cm^2 size devices, as presented in Table II. Using Cz substrates, efficiencies not only have been maintained but also enhanced as well as open-circuit voltages. We have measured 21.1% efficiency 100 cm^2 cell on an 80 µm-thick wafer. Electrical parameters of 92 µm-thick cell are slightly lower mainly due to the lower V_{OC}.

	FZ 160 µm 100 cm^2	Cz 160 µm 100 cm^2	FZ 96 µm 100 cm^2	Cz 92 µm 100 cm^2	Cz 80 µm 100 cm^2
V_{OC} [mV]	727	730	728	738	747
J_{SC} [mA/cm2]	36.5	36.5	36.5	37.1	36.8
FF [%]	78.9	77.7	76.5	76.6	76.8
Efficiency [%]	20.95	20.71	20.32	**21.0**	**21.1**

Table II. Solar cell characteristics of 100 cm^2 solar cells fabricated throughout the project. Latest results are highlighted in red.

Although the excellent results already obtained we believe that further developments are needed to still improve the performance of our devices. Combining the highest V_{OC} we have ever measured (747 mV) together with straightforward optimization of the front side metal grid with a Nickel/Copper plating, aiding also improvement of the FF value, will enable even higher conversion efficiencies. However, adapting the process flow to thin wafers is currently still a major concern, since the breaking risk is significantly high.

National and international collaborations

Due to the nature of this European Project, PV-Lab is in collaboration with many of 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 (now part of Hanwha), and PSE AG from Germany; New and Renewable Energy Centre Limited (Narec) from the United Kingdom; Eni S.p.A. from Italy; and Mechatronics Systemtechnik GmbH from Austria. Moreover, in Neuchâtel, PV-Lab also has an ambitious collaboration with Roth & Rau on the development of production technology for silicon heterojunction solar cells.

Evaluation of 2013 and perspectives

2013 has been the final year of this project. PV-Lab has met all deliverables, milestones and internal goals, and a better understanding leading to the fabrication of improved solar devices has been achieved.

We fabricated our first solar cells on Cz wafers with thicknesses as low as 70 µm and record efficiencies were achieved. Both small area (4 cm^2), as well as large area (100 cm^2) devices were fabricated showing excellent results. Although 2013 has been the final year of the 20plµs project, PV-Lab will continue working on thin wafers as a way to reduce manufacturing costs and assess key aspects on light management to maintain and even increase J_{SC} on heterojunction solar cells.

Acknowledgements

All the PV-Lab collaborators, who contributed to the results presented in this report, are warmly acknowledged. Besides, part of these results has been obtained in projects financed by Roth and Rau Switzerland and the Axpo Naturstrom fonds, for which we gratefully thank them.

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DEVELOPMENT OF THIN HIGH-EFFICIENCY LARGE-AREA INTERDIGITATED BACK-CONTACTED SILICON HETEROJUNCTION SOLAR CELLS FOR MASS PRODUCTION (HET-IBC)

Annual Report 2013

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Date	06.12.2013

ABSTRACT

This “HET-IBC” project is a CTI project between the PV-lab of the École polytechnique fédérale de Lausanne (EPFL) and Roth & Rau Research AG. It aims at developing innovative silicon heterojunction solar cells featuring efficiencies over 21 % on thin, large-area wafers, with the potential to reach 25 % efficiency on the long-term.

The guiding principle of this project is to develop a novel cell architecture, called “interdigitated back-contact” silicon heterojunction solar cell (IBC-SHJ), where all contacts are defined at the rear-side of the device. Thus, the front side features reduced parasitic absorption, and can hence be purposely tuned tu maximise the sunlight absorption. IBC-SHJ devices have then strong assets to reach efficiencies as high as 25 %.

However, the actual processing of IBC-SHJ devices faces numerous issues, especially concerning the patterning of the amorphous silicon, TCO and metal layers. Moreover, new insights into the IBC-SHJ device physics are needed to minimize the electrical losses within the cell. The “HET-IBC” project thus aims at tackling these issues to demonstrate a process flow suitable for producing IBC-SHJ cells with efficiencies over 21 % on 125 x 125 mm^2 wafers.

In this report we present the results of the first year of the project. We firstly describe the process flow that we set up to fabricate IBC-SHJ devices. It is based on direct in-situ hard-masking to pattern the amorphous silicon layers, and on wet-etching to pattern the TCO/metal stack. With this process flow we then obtained a champion cell featuring an efficiency of 20.9 %, which is the european record achieved so far on IBC-SHJ cells. In the second part of the report, we introduce an analytical model that allows us to calculate the resistive losses within our IBC-SHJ devices. According to this model, our devices are currently limited by a too high contact resistance between the a-Si:H layers and the TCO. In the third part of the report, we present the developments of transparent anti-reflective layers, as well as passivation stacks.

Finally, we report on the perspectives for 2014. Further work will be focused towards further improvement of the IBC-SHJ devices efficiency. To meet this goal, we will especially work on the a-Si:H patterning technique itself (plasma conditions) and on the a-Si:H/TCO interface (reduction of the contact resistance). The IBC-SHJ cells process flow will also be scaled-up to bigger devices (125 x 125 mm^2) in 2014.

Introduction

Crystalline silicon heterojunction solar cells (SHJ) are promising candidates to achieve high conversion efficiencies at low cost. Owing to the outstanding passivation level of the c-Si interface obtained using hydrogenated amorphous silicon (a-Si:H) layers, SHJ cells feature open-circuit voltages (V_{oc}) as high as 750 mV and efficiencies up to 24.7 %, as recently demonstrated by Panasonic, Japan [1].

Nevertheless, planar SHJ architectures, either in front- or rear-emitter configuration, are eventually limited by their front-grid shading and the parasitic absorption of light [2].

One straightforward enhanced architecture suitable for getting rid off of those parasitic losses is the interdigitated back-contacted heterojunction cell (IBC-SHJ) scheme. In IBC-SHJ cells, the emitter, the BSF, and their respective contacts are defined at the rear-side of the device. The front-side can thus be purposely tuned to maximise sunlight absorption. Sharp, Japan, recently demonstrated a short-circuit current density (J_{sc}) above 41 mA/cm^2 on an IBC-SHJ device [3], highlighting the strong assets of such devices to reach efficiencies over 25 %.

However, there remain numerous issues to be solved for efficient processing of IBC-SHJ cells. Especially, a well-controlled patterning of the emitter and BSF a-Si:H stripes is essential. Several techniques have been proposed to date, such as (i) photolithography combined with wet-etching [4], (ii) laser ablation [5] and (iii) hard-masking [6,7]. Moreover, most of the IBC-SHJ devices proposed to date appear to be limited by their low fill-factor (FF) value [4]. Though several possible causes have been mentioned [8], the processing of IBC-SHJ cells featuring high FF remains challenging.

Project goals

The HET-IBC projects aims at the development of an industrial process for the manufacturing of high-efficiency large-area interdigitated back-contacted silicon heterojunction solar cells on thin silicon wafers. Efficiencies over 21 % on 125 x 125 mm^2 devices are targeted as final project goal. The aim for our industrial partner Roth & Rau Research, now part of the Meyer Burger group, is to deliver the equipments for wafer sawing and for cells manufacturing with the related processes.

Short project descrption (2012 – 2014)

The technological goal of the project is the realization of thin high-efficiency large-area IBC-SHJ solar cells with efficiencies over 21 %, produced with industry-compatible low-cost processing steps. In the long term, IBC-SHJ devices have the potential to reach efficiencies over 25 %.

More specifically, the project goals involve:

- Simulation and optimization of IBC-SHJ solar cell design (backside geometry, front and back passivation layers, requirements for the front window layer, wafer properties and thickness);
- Evaluation of different patterning processes for the back side, both for a-Si:H layers patterning and for TCO/metal stack patterning (mechanical masking, photo-lithography, inkjet-printing, screen-printing);
- Implementation of the IBC-SHJ concept into real devices, with the demonstration of a 125 x 125 mm^2 solar cell prototype with > 21 % efficiency at the end of the project, together with a clear roadmap to 25 % efficiency.

For 2013, the major tasks have been to:

- Understand the physics of the IBC-SHJ device, especially the transport mechanisms and the electrical losses, in order to design a suitable back-side geometry (emitter and BSF width, pitch);
- Develop an IBC-SHJ cells process flow, firstly suited for small devices (30 x 30 mm^2): this especially requires the development of a suitable patterning scheme for both a-Si:H layers and TCO/metal stack;
- Develop specific anti-reflection coatings and passivation schemes to maximise the sunlight absorption at the front stack while reducing the parasitic losses.

Work performed and results achieved in 2013

1. Processing of IBC-SHJ devices

The IBC-SHJ cell process flow we developed within the framework of this project is depicted in Fig. 1. It starts with the blanket deposition of an intrinsic a-Si:H layer on the back of cell, whereas a stack consisting of an intrinsic and a n-doped a-Si:H layers is deposited on the front. The emitter and BSF stripes are then deposited in step #2, using in-situ patterning with mechanical masks. In step #3, the TCO/metal stack is deposited on the rear-side of the cell. An anti-reflection coating (ARC) is then deposited on the cell front-side (step #4). Finally, in step #5, the TCO/metal stack is patterned using a combination of masking resist and wet-etching chemicals.

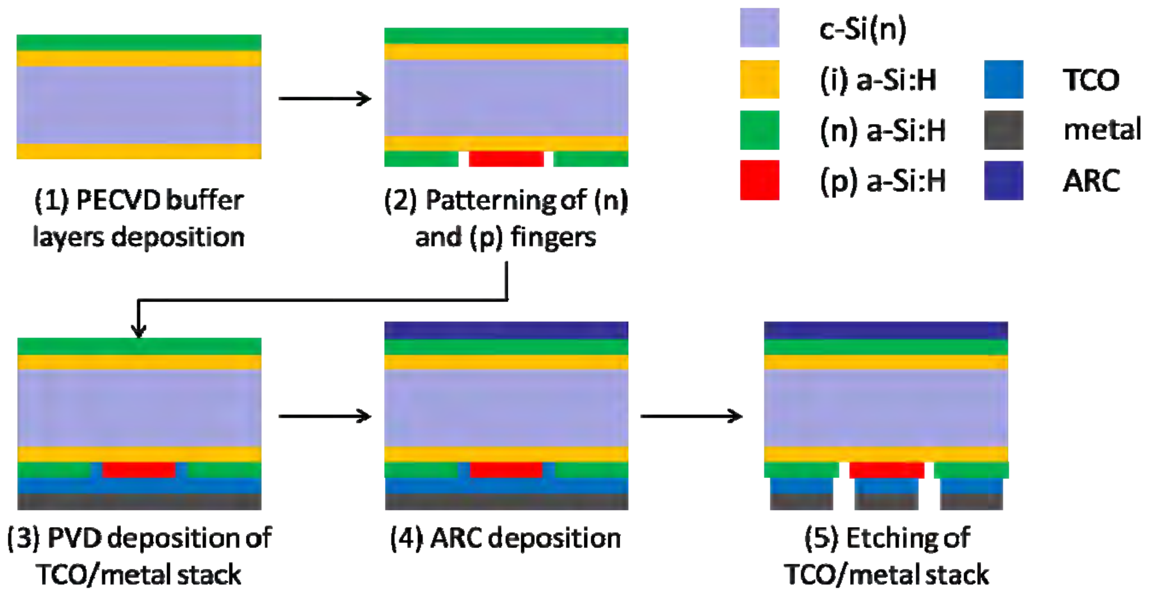

Fig. 1: IBC-SHJ cell process flow developed within the framework of the CTI 13348.1 project.

With this process flow we produced a champion cell with an efficiency of 20.9 %, which is the European record reported to date for IBC-SHJ devices. Our champion cell features a short-circuit current density (J_{sc}) of 39.5 mA/cm2, an open-circuit voltage (V_{oc}) of 726 mV and a fill-factor (FF) of 73 %. A picture of the device is given is Fig. 2, and its illuminated-IV curve is plotted in Fig. 3.

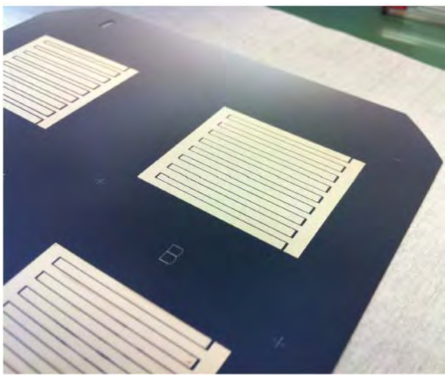

Fig. 2: arrangement of 30 x 30 mm^2 IBC-SHJ cells on a 125 PSQ wafer.

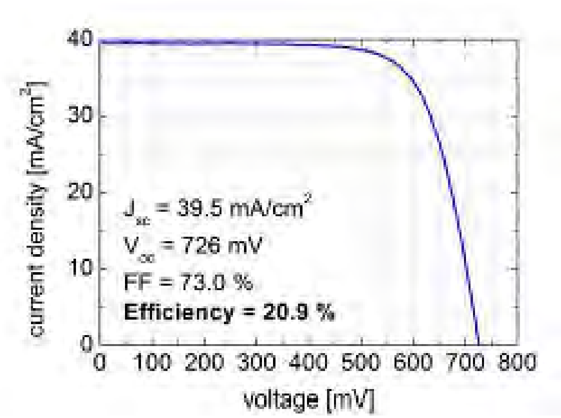

Fig. 3: illuminated-IV curve of our champion IBC-SHJ device featuring 20.9 % efficiency.

As can be seen from the IV results, our IBC-SHJ device is now mainly limited by its poor FF value, but it also suffers from a rather low J_{sc} value.

On the FF side, a two-diode fit of the IV curve yields a series-resistance (R_{series}) value that is much higher than on standard HIT devices, while the shunt resistance (R_{shunt}) is high enough not to induce FF losses (see Table I). Reaching higher FF thus requires to shrink down the R_{series} component of our IBC-SHJ devices.

Table I: resistive losses value for the IBC-SHJ champion cell compared to a "standard" front-junction HIT cell (results taken from PV-lab baseline process).

	IBC-SHJ cell (this work)	"standard" HIT cell (PV-lab)
R_{series} [$\Omega\cdot cm^2$]	2.1	1.3
R_{shunt} [$\Omega\cdot cm^2$]	48 x 10^3	18 x 10^3

On the J_{sc} side, further gain could be obtained by reducing the parasitic absorption of the (i) a Si:H/(n) a-Si:H front stack.

In the next sections, we will thus review the actions we took to tackle these issues.

2. IBC-SHJ devices modeling

We developed an analytical model to calculate the breakdown of the series resistance losses in our IBC-SHJ devices. The total series resistance of the IBC-SHJ cell consists in:

- The contribution of the base of the device (R_{base});
- The contact resistance of the TCO on the emitter stripes ($R_{contact}^{TCO/emitter}$), as well as on the BSF stripes ($R_{contact}^{TCO/BSF}$);
- The resistive losses within the metal grid and the busbars, for both the emitter ($R_{grid}^{emitter}$, $R_{BB}^{emitter}$) and the BSF (R_{grid}^{BSF}, R_{BB}^{BSF}).

The model uses both experimental and literature data as input parameters. The results are displayed in Fig. 4.

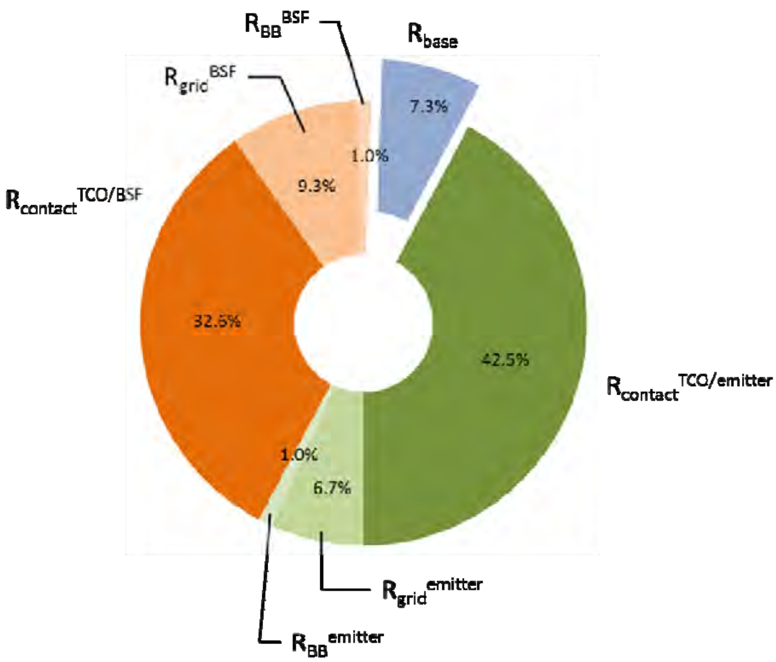

Fig. 4: breakdown of the series-resistance losses of an IBC-SHJ cell.

According to our model, the contact resistance of both the emitter and the BSF are the major contributors to the total series-resistance losses (≈ 75 % of the total R_{series}). On the other hand, the losses within the metal grids and busbars, and the wafer base, are minor contributors. These results show that reducing the contact resistance between the TCO and the emitter (resp. BSF) should be the best way to decrease R_{series}, and thus to enhance the FF.

3. Front-surface passivation and anti-reflective coatings

In order to reach high J_{sc} values, two issues have to be adressed:

- Development of a transparent ARC layer compatible with the IBC-SHJ process flow: especially, this ARC layer must be deposited at temperatures of 200°C or less;
- Reduction of the parasitic losses within the front-side passivating a-Si:H layers (stack or single-layer): the issue here is to reduce the thickness without mitigating the passivation.

In the framework of this project, we thus developed a higly-transparent silicon nitride (SiN_x) layer deposited by plasma-enhanced chemical vapor deposition at 200°C. Fig. 5 shows the absorption spectra of a standard ITO layer (used as ARC is front-junction HIT cell), and two recently-developed SiN_x layers, with and without H_2 gas during the deposition. As can be seen, the absorption is strongly reduced over a wide wavelengths range for the SiN_x layer without H_2. This leads to a 1 $\%_{abs}$ reduction of the effective absorption when compared to the standard ITO layer. The absorption could be further reduced by using dielectrics stacks, consisting e. g. of SiN_x stacked with silicon oxide (SiO_x). These kinds of stacks are currently under development.

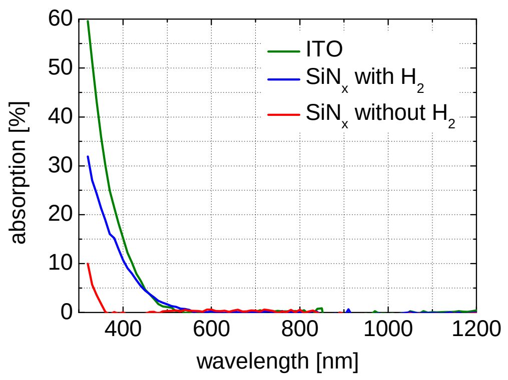

Fig. 5: absorption spectra of ITO and SiN_x anti-reflective layers.

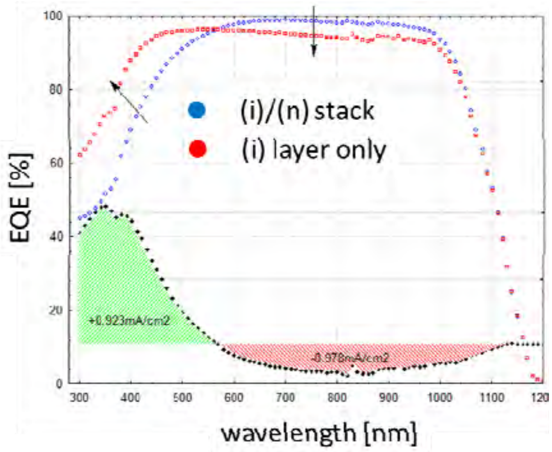

Fig. 6: external quantum efficiency curves of IBC-SHJ cells featuring either a (i)/(n) stack or a single (i) layer on the front.

Concerning the front-side passivating stack, we compared the (i) a-Si:H/(n) a-Si:H stack (currently used in the IBC-SHJ cell process flow, see Fig. 1) with a single (i) a-Si:H layer. Their respective external quantum efficiency (EQE) curves are plotted in Fig. 6. The single (i) a-Si:H layer features an important EQE gain in the UV region: this is the sign of a reduced absorption, owing to the smaller thickness of the single (i) a-Si:H layer compared to the (i)/(n) stack. Nevertheless, this gain is balanced by a reduced EQE signal at higher wavelengths for the single (i) layer, which demonstrates a reduced collection for this layer. Further experiments are needed to understand which layer or stack is the best suited to reduce the absorption without mitigating the collection.

Evaluation of 2013 and perspectives for 2014

In 2013 we set up an efficient process flow for IBC-SHJ solar cells within the framework of this CTI project. With thorough optimizations we reached the European efficiency record for an IBC-SHJ device, with a champion cell featuring an efficiency of 20.9 %. All milestones, deliverables and internal goals were also fulfilled in due dates. We also developed an analytical model that allows us to understand the parameters that are limiting the current efficiency of our devices.

2014 will be focused on the further improvement of the IBC-SHJ devices efficiency. To meet this goal, we will especially work on the a-Si:H patterning technique itself (plasma conditions) and on the a-Si:H/TCO interface (reduction of the contact resistance). The IBC-SHJ cells process flow will also be scaled-up to bigger devices (125 x 125 mm^2) in 2014.

Acknowledgements

All the PV-Lab collaborators, who contributed to the results presented in this report, are warmly acknowledged. In particular we acknowledge the contributions of J. Seif, J. Geissbühler and B. Demaurex. We also thank our colleagues from Roth & Rau Research for their support in processing IBC-SHJ cells.

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CIGS MULTISTAGE IN-LINE PILOT MACHINE DEMONSTRATION

Annual Report 2013

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ABSTRACT

The goal of the project is to demonstrate a roll-to-roll CIGS deposition system where the innovative multi-stage co-evaporation process developed in the Laboratory for Thin Films and Photovoltaics at Empa for small area substrates can be scaled up for coating on in-line moving large area substrates. Demonstration of such a pilot scale deposition system plays a pivotal role in industrialisation of CIGS deposition technology for high efficiency solar cells and modules in future.

Introduction/Aims of the project

CIGS is recognized as an important thin film PV technology for cost effective manufacturing because of high efficiency potentials shown by the solar cells developed in research laboratory. However, there is a lack of CIGS production equipment supplies with proven process for high efficiency solar cell manufacturing on industrial scale.

There is no company providing CIGS evaporation systems with a process of multi-stage evaporation known to provide the highest efficiency devices. This is severely hindering the growth of CIGS PV industries since new companies with interest in CIGS production do not have possibilities of acquiring such systems. The proposed demonstration system would prove the industrial capability of the process and help in industrialisation of the technology and strengthen the position of Switzerland internationally in the field of photovoltaics.

Goal of the proposal

The goal of the pilot project is to develop and demonstrate a CIGS deposition system where the innovative processes developed in the laboratory for very high solar cell efficiencies can be scaled up towards industrial applications. Demonstration of such a system plays a pivotal role in industrialisation of highly efficient PV technology for large volume production.

The overall objectives of the pilot project are therefore:

- to develop an in-line vacuum deposition system for the demonstration that the multi-stage CIGS co-evaporation technology can be scaled up for large size moving substrates
- to demonstrate a pilot level deposition system proof of concept based on a proprietary design and process know-how
- to attract industries as potential end users for subsequent scale-up for production

Description of the project

Innovative multi-stage evaporation processes for the CIGS absorber layer were developed at Empa for obtaining an optimum chemical composition grading which proved to be highly reliable and reproducible and therefore suitable for industrial scale up. The developed processes are, however, stationary, i.e. the substrate is not moving relative to the evaporation sources. In this P&D project Empa wants to demonstrate that the multistage co-evaporation process can be transferred to industrially relevant in-line equipment.

Key issue of the development of the demonstration machine is the design of appropriate vacuum deposition system with evaporation sources having appropriate sequences and vapor flux profiles which allow the same composition grading of the CIGS for a moving substrate. A schematic of such source sequence is shown in figure 1.

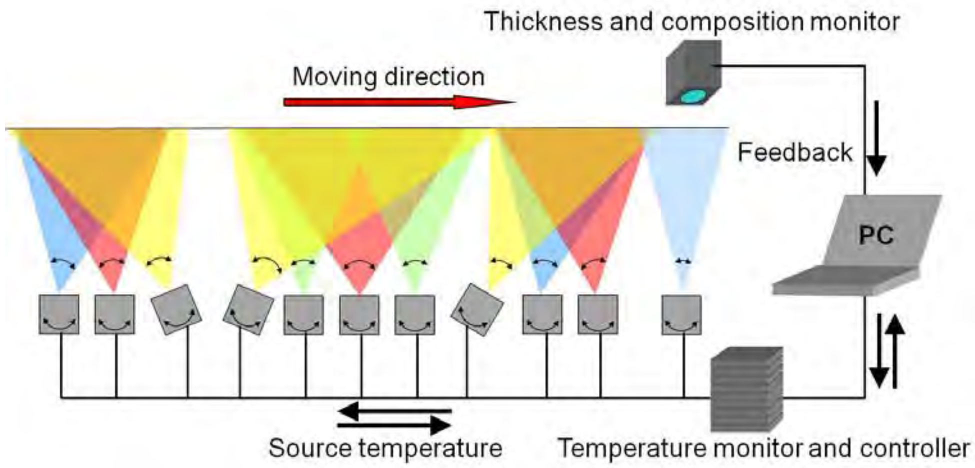

Figure 1: Simplified schematic of the pilot system for multistage evaporation of CIGS based on the Empa process which yields world record efficiencies flexible solar cells on polymer and metal foils. The processes are applicable also for high efficiency cells on glass.

The features of the in-line multi-stage CIGS deposition machine are the following:

- Proprietary low-temperature CIGS process allowing various substrate materials including flexible polymer film and metal foil
- continuous deposition for extended coating runs on long substrate rolls
- Multiple evaporation zones representing the different stages in the multi-stage process
- Evaporation sequences designed for reaching the same optimized composition grading in the CIGS layer as obtained from the laboratory scale process, for this optimization process the machine will be equipped with variable beam shapers and aligners for the evaporation sources
- Process control for chemical composition including feedback loop

Foreseen is an in-line CIGS coating platform for flexible substrates of a width of maximum 50 cm. This is the standard substrate width where Partners can provide the necessary molybdenum coated substrate material with its existing sputtering equipment.
Within a pre-study of various possible chamber geometries, the rectangular shape has shown most advantages as the long, preferably horizontal, deposition zone could best be accommodated. Several of the side plates can be considered as modular to allow testing of various concepts within the same frame. Figure 2 shows a draft proposal with a large modular side and bottom plate. The side plate would be used to fix the winding and substrate heating hardware, whereas the bottom plate will mainly contain the evaporation sources and controls.

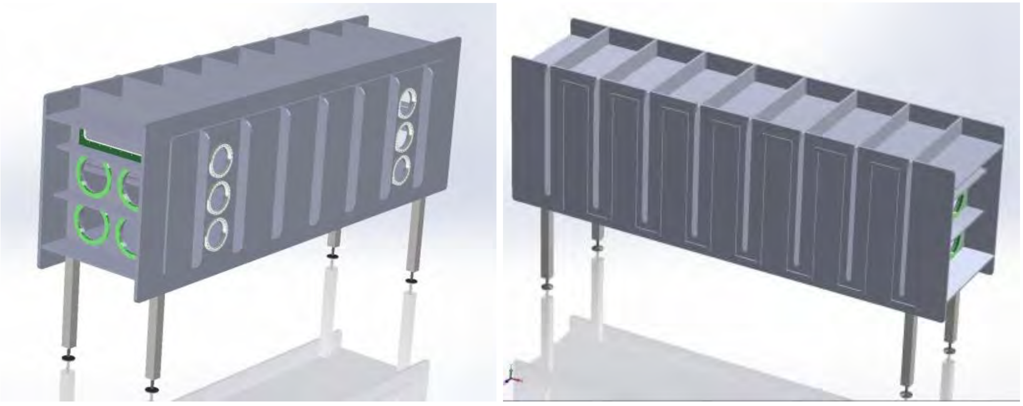

Figure 2: Preliminary chamber concept preview

Outgassing of incorporated water and gases in the large amount of polyimide material in the vacuum chamber is a crucial step to allow good deposition conditions. The planned system allows outgassing and layer deposition at the same time.

A special focus is set on integrating maximum process and tool diagnostics. Due to the flexible and modular concept it is easily possible to do upgrades or amendments:

- By placing additional flange for later buffer layer coatings that can be directly integrated without breaking the vacuum process.
- Adjustable number of heater circuits and position
- Fully adjustable crucible type, number, position
- Additional flanges for supplies, measurements etc.

The following table summarizes the planned machine performance at the beginning of the reporting period.

No	Target description	Target values
1	Process pressure	1.5E-5mbar
2	Max web coating speed	0.2m/min
3	Max web speed	2m/min
4	Max web size	514mm
5	Min. deposition zone length	2m
6	Min. preheating zone length	2m
7	Max. substrate process temperature	600°C
8	Telescoping adjustment, automatable	+/-20mm
9	CE compliance	Possible
10	Max. roll length [@ 50um web thickness]	500m

The uniqueness of this pre-industrial pilot machine is the high level of degrees of freedom in the evaporation geometry which will allow the 1to1 transfer of the sophisticated multistage co-evaporation process.

The project is divided into the following phases:

- Design phase I (2 months): During the design phase the overall and detailed concept is elaborated, mechanical details are discussed, the plans of the chamber and electrical supplies are finalized and orders for core components are placed.
- Design phase II (3 months): While the Chamber is being constructed, the component designs are finalized and ordered and the electrical racks are prepared and programming of the system is started.
- Construction and Assembly phase (4 months): Chamber and components are assembled and connected to the control system and electrical supplies attached. Various testing procedures and debugging is started. First layers will be coated and evaluated.
- Debugging and Ramp-up (3 months): CIGS processes are being implemented and the control mechanisms (XRF, evaporator control) fine-tuned. Empa scientists are instructed to the usage of the tool.
- Joint testing and observation phase (6 months): The operation of the tool is still closely monitored and robustness of functionality improved. Scientists of Empa test coatings and determine operation parameters
- Continuous phase: Empa uses equipment with partners for conducting R&D activities.

Subsequent to the joint testing and observation phase, i.e. 18 month onwards process optimization will continue to achieve (in 24 months, not shown in the above table) the cell and module efficiency targets: targeting cell efficiency >17% and module efficiency >14% both on flexible foil.

Work carried out and results achieved

The design phase I is completed and the overall and detailed concept is defined in the blueprint document of equipment specification in detail approved by the project partners.

Design of the roll-to-roll CIGS deposition equipment:

In order to allow high degree of freedom for the pre-industrial coating equipment a fully modular concept was elaborated. The vacuum chamber will be equipped with large number of spare flanges with only three flange sizes to ensure reuse of component on different locations of the machine. The evaporation sources are installed on a bottom plate to facilitate simple and quick readjustment of evaporation sequences and profiles. The deposition has a length of more than 2 meters including a post-deposition treatment and the total web treatment length is more than 4 meters including pre-treatment (degasing, cleaning), cool-down and in-situ characterization.

The final location of the equipment at Empa is identified and the room has been converted into a laboratory space. A clean room is installed in order to guarantee the required working environment. Separate cooling water supply for the cooling the machine is installed. A mechanical crane is included into the room concept. Different crane concepts were evaluated and the most appropriate one was selected. Foundation for the deposition machine enforced and track lines are installed in the floor for moving the door of the deposition machine.

The suitability of the vacuum chamber for the specified base and working pressures has been confirmed by an external engineering company in the first instance. For further optimization investment went into a professional construction and simulation software to simulate the stiffness and torsion of the vacuum chamber by finite element analysis.

The detailed drawings with optimized stiffness were released to the manufacture of the vacuum chamber after evaluation of three different vacuum chamber manufacturers in Europe. After pre-acceptance test at manufacturer's site the vacuum chamber was delivered on October 15th 2013 with 1.5 months delay.

The two stage pumping system is defined with pre-vacuum pump, external exhaust filter system and in total more than 6 turbo pumps which are equipped to the vacuum chamber. The control system architecture is specified based on a state of the art PLC system. The PLC, Motors and drives are assembled and the electrical cabinets are specified and delivered. The order was placed after four different manufacturers for the electrical cabinet were evaluated. The development of the control software is in the final stage.

The construction of the first generation evaporation sources is finalized. The feed through for electrical power of the sources and the thermo couple are mounted and supporting frame for the sources is in place. It is envisaged that the evaporation sources are installed onto a main cooling plate in order to dissipate excess heat from the sources.

The detailed concept of the web winding system is finalized and all components have been delivered. The water cooled bearing is mounted to the vacuum chamber. Final assembly of the web handling including the substrate heating is ongoing.

National and international cooperation

Part of the presented work is (co)-financed by a FP7 project "R2R-CIGS". The European consortium consists of 4 research institutes (TNO, Netherlands; Empa, Switzerland; ZSW, Germany; CPI, UK) and 6 companies (Manz CIGS GmbH, Germany; Flisom, Switzerland; Isovoltaic, Austria; Beneq, Finland; Solaytec, Netherlands; Mondragon Assembly; Spain).

Evaluation 2013 and Outlook 2014

The total delay of the construction and Assembly phase is 3.5 months. Taking the upcoming holiday season into account this sums up to total delay of 4 months. Therefore, the assembly phase has to be extended into January 2014. Since debugging and ramp up of several components can already start before the final assembly is completed, an overlap of the two phases is possible and foreseen. Even though there is a substantial delay of 4 month in the construction and assembly phase the timely achievement of the final milestones is still feasible.

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NOVA-CIGS: NON-VACUUM PROCESSES FOR DEPOSITION OF CIGS ACTIVE LAYER IN PV CELLS (EU FP7 PROJECT)

Annual Report 2013

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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 utilization of 30-70%. The EU project NOVA-CIGS 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 last 6 months of the project, the research was directed on increasing the performance and reproducibility of obtained solar cells by further improving the material properties of the printed absorber layer, i.e. compositional gradients, homogeneity, grain size, and morphology. The employment of individual inks of monometallic nanoparticle dispersions was found to be a useful tool to adjust and tailor stoichiometry of the absorber layer. Process development for the conversion step by means of rapid thermal processing (RTP) and reducing atmosphere resulted in vast improvements in respect of absorber morphology and solar cell conversion efficiencies. Without the application of an anti-reflection coating, solar cells exhibited efficiencies up to 8.4% for $Cu(In,Ga)Se_2$ and 8.0% for $CuInSe_2$ absorbers, which exhibits the highest efficiency of a CIS solar cell obtained by a liquid coating process without the use of highly toxic hydrazine solvent or H_2Se gas.

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, and it is also comparatively energy intensive to manufacture and results in rigid and heavy devices. As conversion efficiencies for c-Si cells have not been improved since 2004, a radically different step-change concept is required to become competitive with fossil-based energy [1].

With 100 times thinner absorbers than conventional c-Si wafers, 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 (CIGS) 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 1-1.5 $/Wp.

However, TF PV has significant cost reduction potential. Thin layers can be applied by non-vacuum 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 the companies ISET and Nanosolar that reported CIGS solar cells with 13.6% and 17.1% efficiency, respectively by printing pastes containing oxide nanoparticles [2]. Kaelin et al. reported 6.7% efficient cells in 2005 [4] by selenization of metal salt solution pastes, which has been recently improved to 7.7% by Uhl et al. [5]. Todorov et al. utilized hydrazine as a solvent reaching an efficiency of 15.2% [6], 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 feedback to the project partners engaged in precursor materials and ink formulation, and preparing background for large area solar cells and industrial implementation. The three specific work packages at Empa are:

1. Layer deposition
2. Layer activation
3. Solar cell processing and characterization

The layer deposition is 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 takes 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, 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 selenization 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.

Methodology

The non-vacuum deposition of CIGS absorbers can be divided into four steps (see Figure 1). A suitable precursor paste is formulated from nanoparticle dispersions. The paste is then transferred on a molybdenum coated substrate by means of a non-vacuum technique. Dispersions were applied on molybdenum coated soda-lime glass (SLG) by knife blading technique or ink-jet printing. Various coating defects were observed for dried precursor films, and respective measures were taken in order to obtain homogeneous, pin-hole free layers. 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. Standard selenization was carried out in a two temperature zone tubular furnace. The precursors are thereby exposed to reactive Se vapors that are carried onto the substrate by a N_2 gas flow. 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.

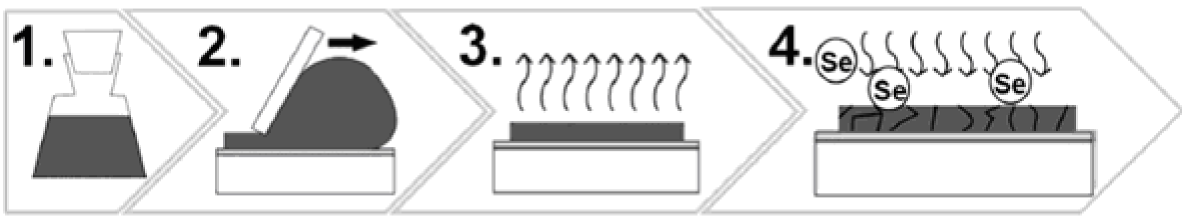

Figure 1: *CIGS formation steps: 1) precursor formulation, 2) non-vacuum deposition, 3) drying in ambient atmosphere to remove solvents, 4) selenization step to convert precursor into absorber layer.*

The morphology, phase and elemental composition of both precursor and selenized layers were evaluated using in-situ and ex-situ X-ray diffraction (XRD), secondary ion mass spectrometry (SIMS), scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDX), as well as X-ray fluorescence (XRF). Ink characterization was additionally carried out by transmission electron microscopy (TEM) and dynamic light scattering (DLS) method.

Performed work and results

Compositional control of absorber layers

Individual monometallic hydroxide particles were developed with a typical particle mass-median diameter below 100 nm. An organic stabilizer was used to disperse the particles in a non-toxic organic solvent. The choice of solvent and stabilizer was found to be critical as it determines the amount of residual carbon in the final absorber layer. Besides others, EDX measurements of the precursor films after conversion with elemental selenium could confirm the oxygen and carbon-free nature of the obtained absorbers [7].

Further characterization by TEM and DLS measurements was used to confirm the particle size distribution and shape of the used precursors (see Figure 2). Aggregation of particles < 500 nm can be observed while larger clusters are prevented to ensure a dense packing density of the dried precursor particles and upmost compositional homogeneity of the precursor film.

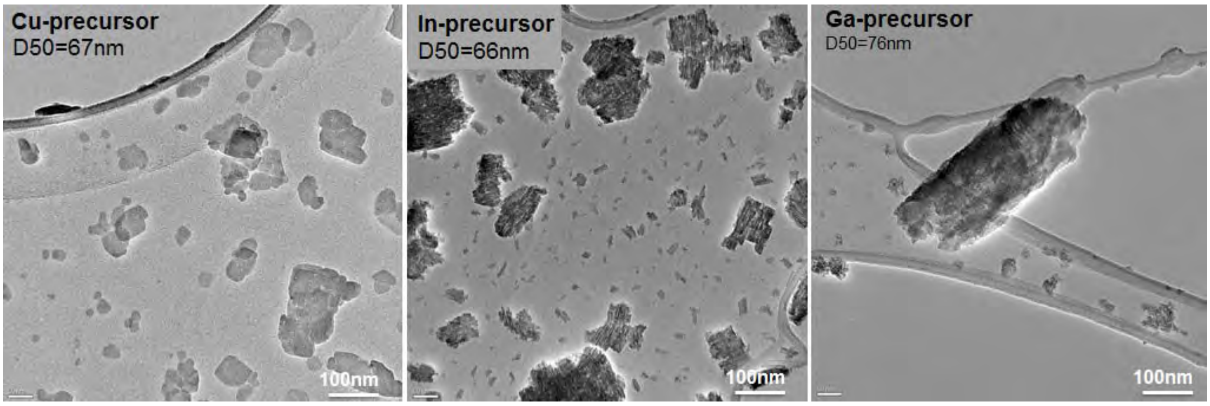

Figure 2: *Transmission electron micrographs of dried, stabilized Cu-, In-, and Ga-hydroxide particles. The D50 particle mass-median diameter as measured by DLS is indicated. Large aggregation up to 400 nm size can be seen for the gallium particles [9].*

The use of individual monometallic nanoparticle dispersions allows for the adequate mixing and compositional adjustment of the precursor film. By varying the mixing ratios of the respective inks, Cu/(In+Ga) as well as Ga/(In+Ga) ratios can be tailored conveniently. Repeated coatings of inks with varying composition, moreover, allow to adjust compositional gradients within the absorber layer and thus open up the road for sophisticated band gap engineering.

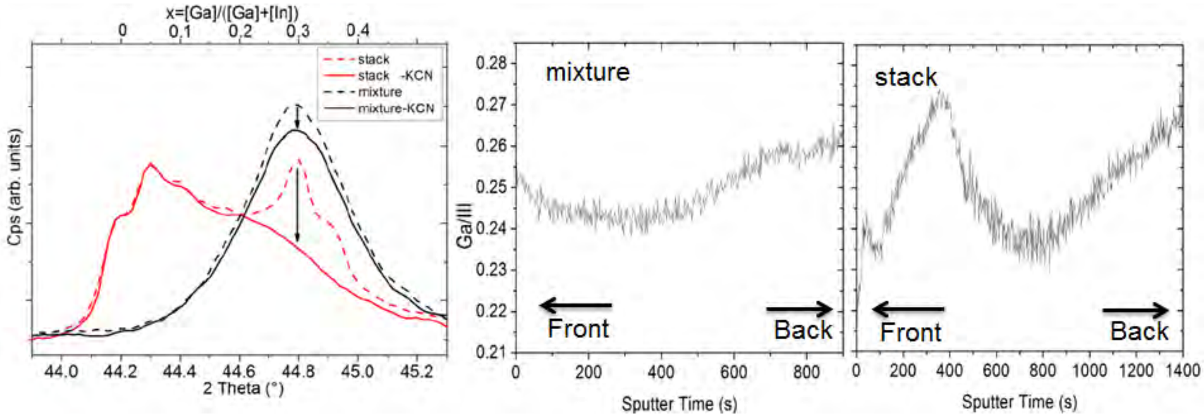

Figure 3: *Comparison of compositional Ga/III gradients as obtained from mixed (Cu+In+Ga) and stacked (In+Ga/Cu/In+Ga) precursors after selenization. The stacking approach results in a wide compositional spread and a Ga-double gradient, which is typically used for highest efficiency co-evaporated CIGS absorbers [8].*

The beneficial influence of compositionally graded absorbers is also commonly used in the co-evaporation process for CIGS, that results in highest efficiency solar cells [9],[10]. The Cu-rich growth phase in the so called "three-stage process" facilitates a large grained morphology and leads to a double gallium gradient towards the front- and back contact. The influence of the Cu-rich growth phase was investigated by employing a stacking approach for the precursor layer deposition. A first layer of In and Ga was followed by a layer of Cu, and finally covered by a In and Ga layer. With this approach, a locally Cu-rich stoichiometry could be facilitated while leaving the over-all composition Cu-poor. Solar cells from this process exhibited a significantly higher shunt resistance stemming from the improved particle sintering. However, in this configuration a higher mobility of the Cu phases was observed resulting in higher surface segregation and a the formation of high porosity at the position of the Cu-precursor. The solar cell efficiency could be improved to 5.8% as compared to 4.8% for a similar conversion process of a mixed particle configuration. Compositional analysis by means of XRD and SIMS confirmed that, similar to absorbers from a three-stage co-evaporation process, absorbers exhibited a wider compositional spread and higher amounts of incorporated gallium towards the front and back contact (see Figure 3). This result opens a wide area of research and proofs that band gap engineering is possible also for printed absorber layers.

Conversion methods

Depending on the employed precursor system, the conversion procedure and setup had to be chosen and optimized. Typically, precursor films were activated in a two-zone tube furnace conversion process where evaporated selenium is transported by a N_2 carrier gas towards the sample. While the latter constitutes a robust and reproducible process, further development towards faster processing and scale-up is desired by industry. In this respect, the process development was extended to rapid thermal annealing (RTP). Schematic drawings to compare the two conversion setups can be seen in Figure 4. Characteristic of the tube furnace conversion is an open reactor design, independent heating zones, and resistive heating, while the RTP setup typically comprises a closed system and radiative heating, which enables heating rates up to 40 K/s.

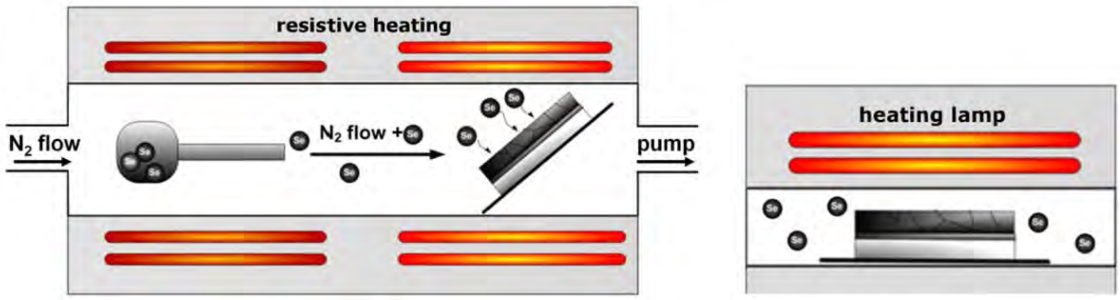

Figure 4: *Schematic drawing of a conventional two-temperature zone tube furnace (left) and single-temperature zone rapid thermal processing setup (RTP) (right). Both setups were used in the framework of this project for the conversion of dried precursor layers.*

Influence of reducing atmosphere

The beneficial effects of the highly reactive gas H_2 is well known for the reduction of precursor layers [2]. However, the high explosiveness can be a concern when it comes to industrial implementation of the process. Based on these considerations, Empa has focused on a process in which a reduced amount of 5% H_2 in a mixture with Ar is used for the reduction. This low concentration is well below the explosion limit even at elevated temperatures. Reducing atmospheres were found to be especially suitable for the hydroxide precursors, where a mild reduction can avoid or reduce the formation of metal oxides that can cause compositional variations of the chalcogenide phase and/or resistive losses in the finished solar cell. Figure 5 shows the morphology of an absorber layer from an optimized conversion process utilizing mild H_2 reduction. The absorber morphology appears two-layered with a top- and bottom layer of different morphology. While the bottom layer is small grained, a close to 1 µm thick, densely sintered top-crust can be obtained. Solar cells from that conversion route exhibited up to 8.4% efficiency, which is the highest value obtained within the project. The reduction of the porous bottom layer, leading to increased series resistances as well as the implementation of an anti-reflective coating are expected to further increase the device performance.

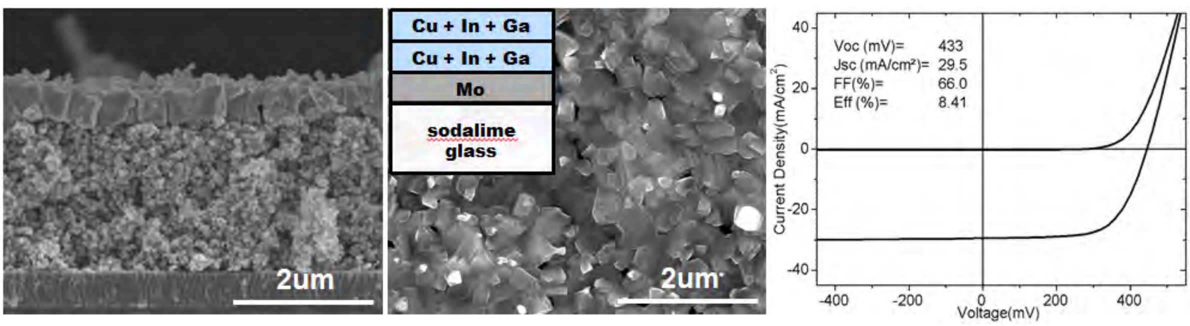

Figure 5: *Up to 8.4% efficient solar cells could be obtained with hydroxide particles utilizing a process with mild reduction with diluted H_2 gas. While the surface appears well crystallized, cross-sections reveal a still porous morphology under the dense top crust.*

Rapid Thermal Processing (RTP)

Rapid thermal processing was investigated in the framework of the project for the activation of the dried precursor layer. Inherent advantages of the method include, low thermal budget, fast processing speed, and high temperature homogeneity of the substrate. Moreover, the process is desired by industry due to the ease in scale-up. Empa developed a novel conversion method that employed a fluxing medium to improve the densification and grain growth. Figure 6 shows the top-view and cross section SEM micrographs of a selenized precursor layer on a Mo-covered glass substrate. Remarkable lateral grain sizes up to 4 µm can be seen for 1 µm thick absorber layers from this process. The gallium-free absorber layers from Cu- and In-hydroxide particles exhibit reduced band gaps and consequently lower V_{OC} as Ga-containing solar cells. The high density of the material, however, excels in high shunt resistance and high fill-factors, which yielded solar cells up to 8.0% efficiency.

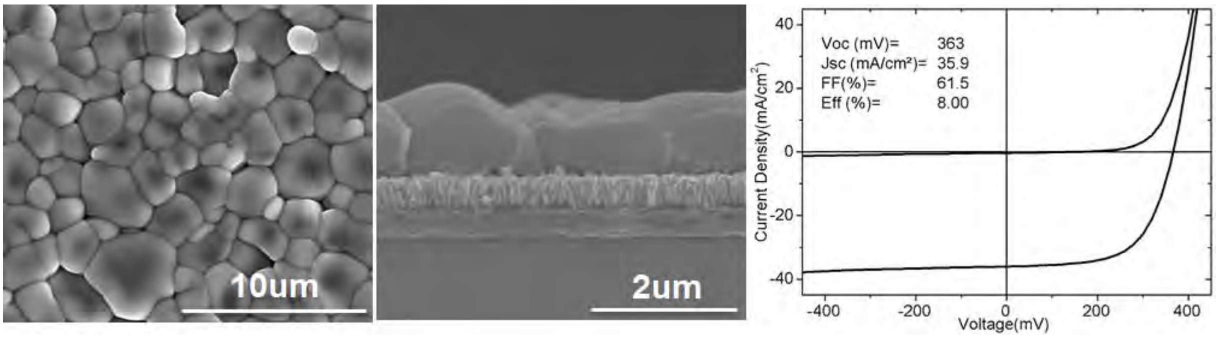

Figure 6: *Top view and cross-section pictures of a $CuInSe_2$ layer on Mo as obtained by RTP processing. The corresponding efficiency of the cell was 8.0%, which exhibits the highest efficiency of a CIS solar cell obtained by a liquid coating process without the use of highly toxic hydrazine solvent or H_2Se gas [1].*

The good reproducibility of the RTP conversion process is exemplified in Figure 7. Multiple samples with solar cell efficiency values between 7 - 8% were obtained with a champion efficiency of 8.0%. A high reproducibility of the process is indispensable when considering further process optimization, scale-up and industrialization.

sample	Voc (mV):	Jsc (mA/cm^2):	FF (%):	Eff. (%):
A	361	35.0	60.6	7.65
B	359	34.8	59.5	7.42
C	370	33.6	59.9	7.44
D	360	34.3	58.2	7.21
E	363	33.3	60.2	7.27
F	363	35.9	61.5	8.00

Figure 7: *Efficiency table of CIS solar cells obtained from RTP process at Empa. The low efficiency spread exemplifies the good reproducibility of the process.*

National and international collaboration

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

* Umicore S. A., Brussels, Belgium (coordination)
* Swiss Federal Laboratories for Materials Science and Technology (Empa), Dübendorf, Switzerland
* FLISOM AG, Dübendorf, Switzerland
* Zentrum für Sonnenenergie und Wasserstoffforschung (ZSW), Stuttgart, Germany
* Manz AG, Reutlingen, Germany
* VTT Technical Research Center of Finland
* Technische Universität Chemnitz, Germany
* Xennia Technology Ltd., Letchworth, UK

In the framework of this FP7 project, Empa was 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 2013 and Outlook

- Hydroxide-type particles were found as a suitable precursor family to obtain oxygen and carbon-free absorber layers from a process without toxic and explosive solvents and/or gases.
- Monometallic precursor inks allow for excellent control of the absorber composition. Multilayer deposition with adjusted ink stoichiometry is a means to tailor chemical gradients throughout the absorber thickness and increase the device performance.
- Reduction with highly diluted H_2 gas can aid the CIGS formation process and grain growth. Solar cell efficiencies up to 8.4% could be obtained from this route.
- RTP processing resulted in large grained absorber layers that yielded solar cell efficiencies up to 8.0% for pure $CuInSe_2$ absorbers. This presents the highest value for CIS solar cells from a non-vacuum, liquid-coating process without the use of toxic H_2Se or hydrazine.

While multiple conference contributions and publications could be presented for this work - highlighting the novelty of the obtained results - the efficiency target of the project of 14% could not be achieved within the timeframe of this project. The steep learning curves for the developed processes, however, exemplify the high potential for future optimization and efficiency improvements.

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Bundesamt für Energie BFE

ROLL-TO-ROLL MANUFACTURING OF HIGH EFFICIENCY AND LOW COST FLEXIBLE CIGS SOLAR MODULES (EU-FP7 R2R-CIGS)

Annual Report 2013

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Project- / Contract Number	EU Project R2R-CIGS / 283974
Duration of the Project (from – to)	Apr. 2012 – Sep. 2015
Date	09.12.2013

ABSTRACT

Thin film solar cells with $Cu(In,Ga)Se_2$ (CIGS) compound semiconductor as absorber material show excellent efficiency and with proper encapsulation long term performance stability. CIGS solar module technology on rigid glass substrate is already mature and industrial companies are producing hundreds of MWp each year. Bringing flexible CIGS solar modules to industrial maturity will yield the next breakthrough for further cost reduction by taking into account the inherent advantages of thin film technology, e.g. high throughput and large scale coating with less energy and material consumption. Within this project efficiencies above 19% have been achieved for lab-scale flexible CIGS solar cells on polymer substrate with front and back interface properties of the CIGS controlled on nanoscopic range. The project R2R-CIGS will contribute to industrial large scale production of flexible high efficiency CIGS solar cell devices based on processes for roll-to-roll manufacturing. The aim is to develop efficient solar modules by implementing innovative cost-effective processes such that production costs below 0.5 €/Wp can be achieved in large volume factories with annual capacity of 500MWp in future.

Introduction and project goals

The project R2R-CIGS will contribute to industrial large scale production of flexible high efficiency CIGS solar cell devices based on processes for roll-to-roll manufacturing. The aim is to develop efficient solar modules by implementing innovative cost-effective processes such that production costs below 0.5 €/Wp can be achieved in large volume factories with annual capacity of 500MWp in future. This ambiguous target will be achievable when the efficiencies of flexible solar cells are comparable to those based on glass substrates and high throughput process with less energy and material consumption are implemented.

An important objective for meeting this target is to achieve 20% cell efficiency and to develop 16% module efficiency on flexible substrate in order to demonstrate the technical potential and to reach comparable performance to CIGS technology on glass. On large area solar module level the roll-to-roll (R2R) manufacturability of monolithically interconnected cells has to be demonstrated for achieving high efficiency modules with long term performance stability.

For cost-effective manufacturing some of the bottleneck problems have to be solved including but not limited to: Chemical bath deposition (CBD) of CdS should be substituted by a deposition method for Cd-free buffer layer which is more compatible to R2R production. Moisture barrier coatings for efficient and low-cost encapsulation should be developed to overcome the problems of efficiency degradation due to corrosion of electrical contacts. Improvements in the current state-of-the-art will be achieved by implementing the concepts of nanotechnology in terms of modification in the structural, chemical, and electrical characteristics on nano-scale range for improving the CIGS absorber, buffer layer, TCO and encapsulation. Control of properties of surfaces and interfaces on nano-scale will be the most important aspect for achieving high efficiencies and stable performance of solar cells. These concepts, especially of buffer-, barrier-, and TCO- layers have already shown encouraging results for technologies based on rigid glass, however, some of them need further development for roll-to-roll manufacturing.

A key advantage of thin film solar cells is the monolithical interconnection, successfully implemented on glass but still a challenging task for flexible substrates. Although preliminary results are shown, further development is needed for improving the patterning technique and reducing the losses due to laser-material interactions.

The knowledge gained in this project, based on some innovative concepts that have shown promising results, will be transferred to pilot line scale and for industrial production.

The main objectives of Empa in this project are:

- Flexible solar cells on polymer film with 20% efficiency and mini-module with 16% efficiency by control of composition gradient, surface, and interface properties on nano-scale
- Transfer of innovative buffer layer process for roll-to-roll manufacturing and replacing problematic CBD-CdS by higher yield processes such as ultrasonic spray
- Scale-up of static multi-stage CIGS deposition process from laboratory scale towards inline R2R compatible processes
- Implementation of the up-scaled multi-stage CIGS deposition process into pilot lines yielding flexible CIGS modules with 14% efficiency from R2R manufacturing

The consortium of this project includes 4 European research institutes and 6 European industries and SMEs:

1. TNO (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek), Netherlands
2. Empa (Swiss Federal Institute for Materials Science and Technology), Switzerland
3. Manz CIGS GmbH, Germany
4. Flisom AG, Switzerland
5. ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg), Germany
6. CPI (Centre for Process Innovation), UK
7. Isovoltaic GmbH, Austria
8. Beneq Oy, Finland
9. SoLayTec, Netherlands
10. Mondragon Assembly Coop., Spain

Work and results

DC and pulsed DC sputtering of doped ZnO from rotatable targets

Intrinsic ZnO layer were sputtered from a slighty doped (0.05% Al2O3) target and optimized with respect to the oxygen content in the sputtering gas. Optimum buffer layers show resistivities higher than 200 kΩ and low average adsorption, below 1.2%. First optimization of DC sputtering of AZO was done from a ceramic target with a pulse frequency range from 0 to 150 kHz for temperatures lower than 110°C. However, the resistivity using this temperature range are above 12 µΩm and do not meet the requirements. For DC sputtered AZO (without pulsing) on 5x5 cm^2 soda lime glass, a detailed optimization was done by changing the sputtering power (0.2-1.4 kW), total gas pressure (0.25-0.85 Pa), reactive O_2 partial pressure (0-6 mPa) and the substrate temperature (30-200°C). Optimum conditions were depositions at 150°C, 1 kW DC, 0.85 Pa total pressure and 3 mPa O_2 partial pressure, which yields a resistivity of 10.59 µΩm and an average absorption of 8.5 % (400-1100nm).

An optical sensor and all the necessary hardware for plasma emission spectroscopy (PES) were installed. Control software of BAS450 PM was extended for using PES as an active feedback for plasma emission monitoring (PEM).

In-line homogeneity

The homogeneity of the in-line deposition of AZO films was investigated on polyimide foil with an area of 270x130 mm^2 and, as a reference, on soda lime glass [SLG]. The AZO films were sputtered from a metallic Zn:Al target by PEM control at 150°C yielding films with resistivity of ~2x10^{-3} Ωcm and optical Transmittance >85% (optical properties measured on reference SLG).

The electrical properties were measured on 10x10 mm^2 samples and for each in-line position an average of 5 samples from different y positions was taken (y direction perpendicular to the in-line movement). The resistivity of 1.3 x 10^{-3} Ωcm shows along the in-line movement only a deviation of ±10% on reference SLG, which proves the stability of the PEM control (blue line in Figure 1). On polyimide foil, the resistivity has an average of 1.3 to 3.5 x 10^{-3} Ωcm.

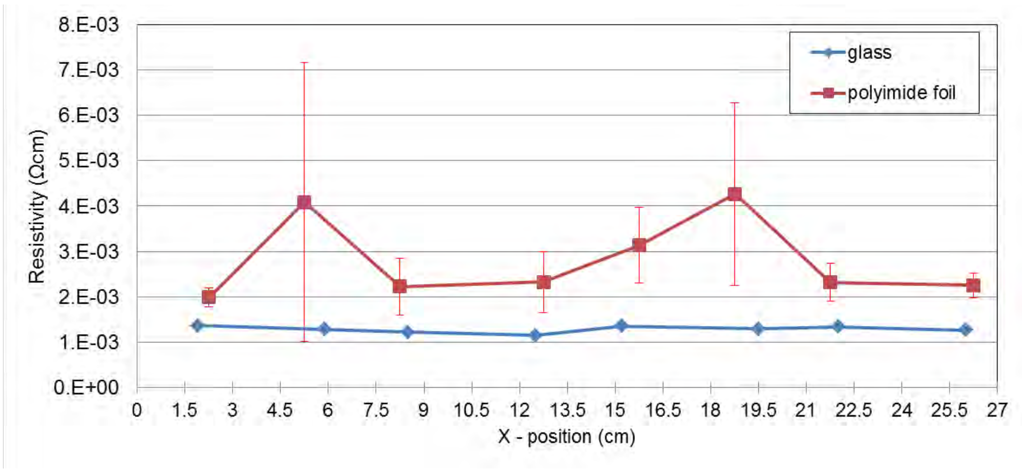

Figure 1: Electrical resistivity of AZO on glass (blue) and on polyimide foil (red) as a function of the in-line position x. The average resistivity and corresponding standard deviation of 5 samples along different positions of the y axis is shown for deposition on polyimide foil.

Hall measurements show that the carrier density of 4.5 x10^{20} cm^{-3} is equal on both substrates (figure 2), but mobility is reduced from 11 cm^2/Vs on SLG to 4-8 cm^2/Vs on polyimide foil (figure 3). The polyimide foil was under stress after film deposition and coiled up as soon as it was detached from the substrate holder. Most probably this led to cracks in the film resulting in low mobility and therefore high local resistivity. The assumption of cracks in the film is confirmed by the fact that the carrier density is not affected, but only the mobility. Further damage of the film could be caused while cutting the foil to 10x10 mm^2 samples for the Hall measurements.

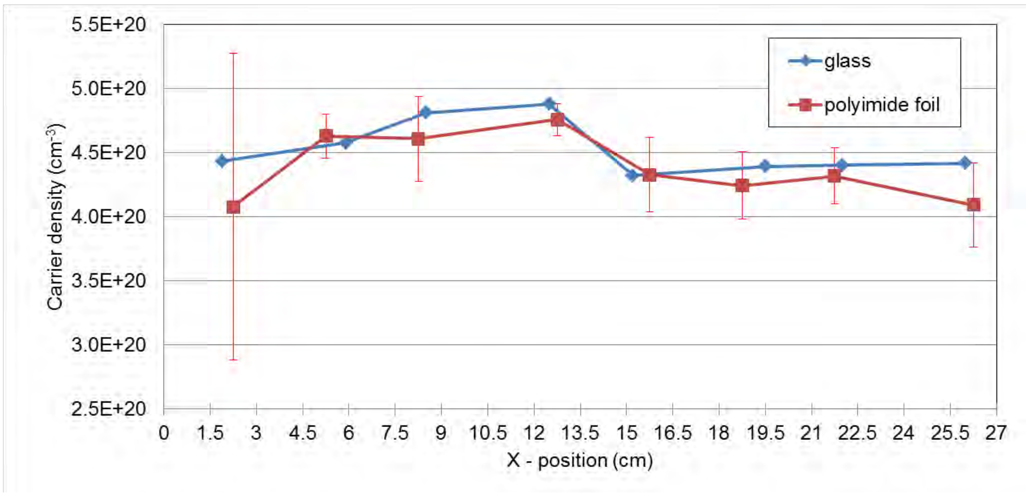

Figure 2: Carrier density N from Hall measurements of AZO on glass (blue) and on polyimide foil (red) as a function of the in-line position x. The average N and corresponding standard deviation of 5 samples along different positions of the y axis is shown for depositions on polyimide foil.

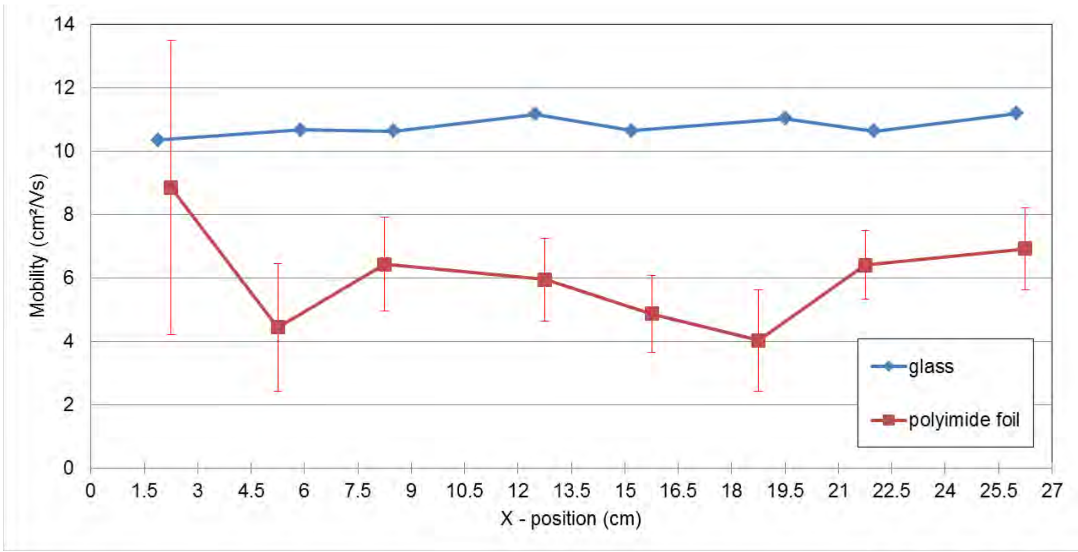

Figure 3: Hall mobility μ of AZO on glass (blue) and on polyimide foil (red) as a function of the in-line position x. The average μ and corresponding standard deviation of 5 samples along different positions of the y axis is shown for depositions on polyimide foil.

The average visible transmittance and the reflectance of AZO on reference SLG are shown in figure 4. The optical properties are homogeneous along the in-line movement axis on a length of ~26 cm with an average transmittance > 85% in the visible range.

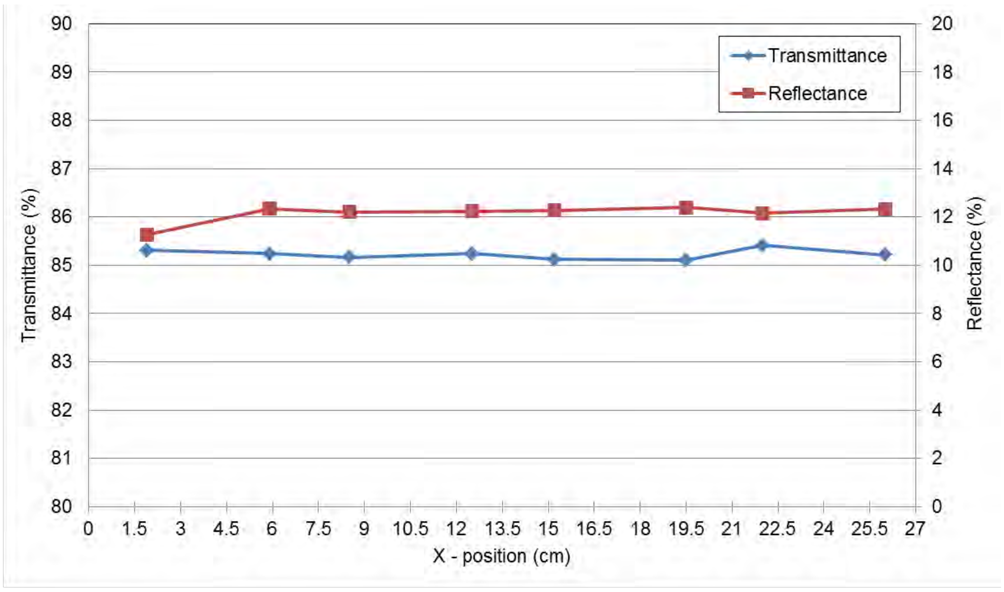

Figure 4: Average visible transmittance and reflectance of AZO on reference SLG as a function of the in-line position x.

Implementation in CIGS solar cells

DC sputtered AZO films were deposited on a stack of (i-ZnO/CdS/CIGS/Mo/SLG) to test the implementation as a window layer in a solar cell. A reference solar cell was produced with equal stacking but with a window layer deposited by RF sputtering from a ceramic target. The DC sputter deposition was performed at 150°C with a total pressure of $3x10^{-3}$ mbar. The JV-curves of the best cells on the array are shown in Figure 5. The performance parameters of the best cells and the average from all cells are shown in Table 1 for both window layers, i.e. for DC sputtered AZO (PEM AZO) and for the reference RF sputtered AZO film.

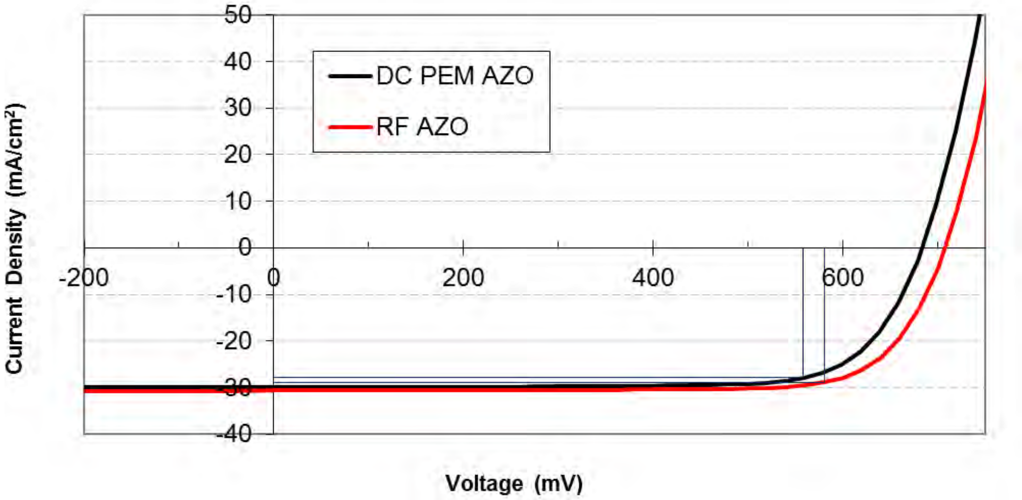

Figure 5: JV-curves of the best cells with PEM controlled, DC sputtered AZO and reference RF sputtered AZO film as window layer.

A DC sputtered AZO window layer was implemented to produce a working CIGS solar cells with an efficieny of 14.9%. As the quantum efficiency (data not shown here) has a similar characteristics for both window layers, DC and RF sputtered AZO, the decrease in efficiency must be attributed to the sputter process conditions, e.g. the elevated temperature of 150°C or a higher target voltage leading to increased O^- ion bombardment into the growing film.

Table 1: Comparison of the solar cells with PEM controlled AZO front contact and RF sputtered reference AZO front contact.

	DC, PEM AZO		**RF AZO**	
	best cell	Average	best cell	average
V_{OC} (mV)	**683**	674±6.6	707	705±3.0
J_{SC} (mA/cm^2)	**29.9**	29.7±0.4	30.6	30.0±0.2
FF (%)	**76.1**	74.4±1.8	77.3	76.0±0.7
η (%)	**15.5**	14.9±0.5	16.7	16.1±0.3

Flexible CIGS solar cell with nano-scaled compositional grading

Further investigations of relevant parameters for the process window and process robustness have been investigated in more details. An externally certified efficiency of 19.6% was achieved based partially on the implementation of the knowledge gained on the nano-scaled compositional grading during this project, but also with a new process step (KF post-deposition treatment) which was developed as sideground and can be included in activities of the R2R-CIGS project. These aspects are discussed in more details below.

Potassium post-deposition treatment[1]

In order to reach the target of 19% efficiency for a small laboratory scale solar cell, a potassium post-deposition treatment developed at EMPA was used in order to reduce optical losses due to CdS absorption and improve the quality of the junction. The evaporation of KF onto the finished absorber modifies the surface properties of the CIGS layer in such a way that it allows a reduction of the CdS deposition time, therefore CdS thickness, without the commonly observed losses of the PV parameters (for more details on the effects of the KF post-deposition treatment, see Chirilă, A. et al., Nature Materials, 12, 1107-1111 (2013)). The reduced optical losses due to reduced CdS thickness and improved junction quality are evidenced in external quantum efficiency measurements when comparing the normalized external quantum efficiency and P-V parameters of the new 19.6% certified efficiency cell with our previous highest efficiency device reported earlier (Chirilă, A. et al., Nature Materials 10, 857-861 (2011)). Significant increase in open circuit voltage and fill factor is observed for the sample subjected to the KF PDT. The gain in current density due to reduced absorption losses in CdS is however balanced by a poorer spectral response at higher wavelengths, which can be explained by a different Ga nano-scaled compositional grading. Further improvements in overall device performance can be expected with a Ga compositional grading optimized for cells with absorbers subjected to the new KF PDT.

Nano-scaled compositional grading

Control of the nano-scaled compositional grading has been found in earlier studies to be of crucial importance to achieve high efficiency, especially when growing the CIGS absorber at lower temperature. A too pronounced Ga double grading should be avoided, because it leads to increased recombination of minority charge carriers. The optimum shape of the Ga profile is however still unclear. The [Ga]/([Ga]+[In]) ratio of 4 different absorbers has been measured by SIMS depth profiles and corrected using XRF average Ga content. All cells made with these absorbers showed high efficiencies above 18%, even though their nano-scaled compositional grading shows significant variations of the notch shape and depth. This is a good indication for the robustness of the multistage deposition process and shows that high efficiency can be achieved with different Ga gradings. This information is very important for the transfer of the multistage process towards inline pilot-production line, broadening the process window for the adjustment of the Ga grading.

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[1] sideground brought-in to R2R-CIGS

Appraisal 2013 and Outlook 2014

Milestone MS2 (Demonstration of <10 Ohm sq and >85% relative transparency for (pulsed) DC-AZO (10 x 10 cm^2) reference RF-AZO) was achieved. DC magnetron sputtering from a planar, metallic Zn:Al target is feasible with a PEM control. Implementation of DC sputtered AZO in a CIGS solar cell was realized.

CIGS solar cells, with an absorber layer deposited by a low-temperature multi-stage deposition process and a post deposition Na treatment, using process automation, yield efficiencies above 18%.

A certified small area cell efficiency of 19.6% on a flexible substrate using low-temperature deposition process is reported (Deliverable 5.1 achieved).

A broader process window for the control of the Ga grading (especially the shape of the notch) has been found.

In 2014 the following tasks are planned: Test of rotatable ceramic AZO target, Optimization of sputtering parameters for rotatable ceramic AZO target, Further implementation of DC sputtered AZO in module to achieve efficiency >12%, Evaluation of using metallic ZnAl target for rotatable cathode, proceed with process transfer for uniform deposition of In_2S_3 and Zn(O,S) layers by USP method, A closer investigation of the shape of the nanoscaled compositional grading (especially shape of the notch) will be undertaken and a study on how it should be adjusted in combination with the newly introduced KF PDT will be conducted, in order to increase efficiency even further. A new tool allowing precise measurement of the Se evaporation flux directly on the Se source will be tested. Development of R2R inline multi-state CIGS deposition process will start.

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FLEXIBLE PHOTOVOLTAIC CELLS OPTIMIZED FOR HIGH CONVERSION EFFICIENCY FROM INDOOR TO OUTDOOR ILLUMINATION CONDITIONS, USED IN NEW WRISTWATCH PRODUCTS

Annual Report 2013

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Project- / Contract Number	KTI 15166.1
Duration of the Project (from – to)	01.10.2013 - 30.09.2015
Date	09.12.2013

ABSTRACT

The goal of the project is to develop flexible CIGS photovoltaic (PV) cells optimized to yield high conversion efficiencies under low (indoor) to high (outdoor) illumination intensities, tailored for new generations of innovative wristwatch products. Device processing will be optimized to meet the stringent requirements of high performance under low illumination conditions.

Introduction/Aims of the project

Thin film solar cells based on $Cu(In,Ga)Se_2$ (CIGS) absorber layers yield excellent device performance under approximately 1 sun illumination intensity. Highest record efficiency of 20.4% on flexible polyimide substrate has been demonstrated under AM1.5G standard test conditions. However, the solar cell efficiency is known to depend on illumination conditions, e.g. under an illumination intensity that is 100 to 1,000 times less intense than the standard 1 sun, most of the standard CIGS solar cells exhibit disproportionately lower conversion efficiency. For several applications, especially under indoor or low illumination conditions, high conversion efficiency, exceeding 10%, is highly desired, which in general is not the case with thin film solar cells. The goal of the project is to improve the device efficiency at low light illumination intensity by applying innovative device modification at the CIGS/CdS/ZnO interfaces.

Description of the project

Reduce the leakage current in the CIGS photovoltaic cells

Depending on the processing conditions and substrates thin film CIGS photovoltaic cells have shown efficiencies in the range of 17% to 20 % under 1 sun illumination, and preliminary measurement results performed at the Empa show that these solar cells perform better, in terms of absolute PV power values, than amorphous silicon photovoltaic cells which are currently state-of-the-art for low illumination conditions.

This project includes an optimization of the behavior of these CIGS photovoltaic cells under low illumination, where a substantial amount of energy is harvested, down to 150 lx for indoor or shadowed wrist conditions, as well as at high outdoor illumination, up to 100 klx, where high power peaks may be stored in appropriate devices. This optimization aims at reducing the leakage current which is the cause for efficiency deterioration at low illumination (the open circuit voltage Voc is proportional to the log of the illumination intensity when the leakage current can be neglected), by improving the CIGS absorber deposition and overall fabrication process for the formation of the heterojunction with the buffer layer and transparent oxide layers.

Develop and validate encapsulation techniques

Even if the solar cells will be enclosed in a waterproof watch assembly, it has to be noted that a watch is not completely humidity proof since in contact with sweat and atmospheric conditions including emersion in water. Specific additional encapsulation layers (humidity barriers to reduce water permeation toward the CIGS PV structure) will be introduced and standard test procedures for indoor and outdoor products will be applied. New test procedures will also be developed to address specific items.

Develop and validate indoor illumination testing techniques

Sunlight or light from tungsten filament lamps have a wide power spectral content that advantageously covers the spectral response of silicon or CIGS photovoltaic cells. The fast growth of high efficiency light sources such as LEDs and OLEDs represents, however, a disadvantage in terms of indoor optical energy harvesting, because most of their power spectral content is designed to fill the narrower eye response which is centred around 550 nm with about 100 nm FWHM. Not only the efficiency of the photovoltaic cells is reduced at this wavelength, but the cells lack a good part of illumination in the red to near-infrared spectrum emitted by the sunlight or light from a tungsten filament lamp. A solar cell exposed to 500 lx indoor illumination with a tungsten filament lamp or a high efficiency LED lamp will definitely yield different output power values because of spectral difference of emitted light. These considerations underline the importance of device optimization for specific illumination conditions as observed under practical conditions.

National and international cooperation

This is a collaborative project between the Laboratory for Thin Films and Photovoltaics at Empa, Asulab and ETA at Swatch Group and Flisom company.

Evaluation 2013 and Outlook 2014

The project has started recently and most of the activities are in a very early phase of development. During the course of the first year of the project it is expected that significant contributions on how to reduce the leakage current across the junction in the CIGS device as well as on the how to interconnect and encapsulate the devices can be realized.

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Bundesamt für Energie BFE

PERFORMANCE STABILITY OF FLEXIBLE CIGS SOLAR MODULES

Annual Report 2013

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Project- / Contract Number	CTI 12800.3
Duration of the Project (from – to)	01.07.2013-30.06.2015
Date	09.12.2013

ABSTRACT

Development of flexible CIGS solar modules for high performance and low cost are essential for diverse applications. Long term performance evaluation of encapsulated solar modules through accelerated tests and analyses of degradation and failure mechanisms on microscopic and macroscopic levels are necessary for proving improved long term performance stability and enabling market entry readiness. Long term performance evaluation of encapsulated solar modules through accelerated tests and analysis of degradation and failure mechanisms on microscopic and macroscopic levels are conducted in this project. Analytical methods and tools to optimize CIGS solar module designs for specifically targeted applications are developed. The final project goal is to certify the modules of Flisom according to the IEC standards 61646:2008 and 61730:2004 and fulfill even stricter extended test conditions which will be defined during this project. Up to now already more than 100 modules were produced by the project partners and exposed to various stress conditions.

Introduction/Aims of the project

Main objectives of this project are the development of flexible solar modules ready for certification, analysis and minimization of failure and degradation mechanisms as well as the formulation of a degradation model.

The project is structured in 3 work packages (WP). The chosen strategy to reach the project targets is an iterative approach as illustrated in Figure 1. A close interaction between the modelling efforts, numerical simulations, the experimental characterization and the product design should lead to a rapid, target-oriented product development cycle.

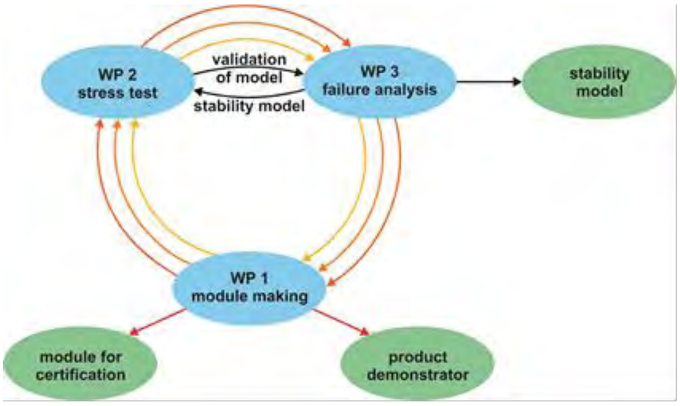

***Figure 1**: Illustration of interdependency of WPs in the iterative product development strategy. Also shown are the main deliverables of the project: (i) Product demonstrators which proof the marketability for targeted applications, (ii) Product development ready for module certification and (iii) validated performance stability model for life time prediction.*

Description of the project

Thin film solar cells have emerged as one of the most promising options for highly-efficient and cost-effective solar electricity generation with a potential of reaching grid parity on short term also in central Europe. Compared to rigid solar cells on wafers or glass substrates high performance flexible and lightweight CIGS solar modules offer even better potential for the reduction of production costs as well as overall system costs for enabling economical solar electricity.

Thin film solar cells with CIGS compound semiconductor as absorber material show excellent efficiency and with proper encapsulation long term performance stability as proven on glass substrate. CIGS solar module technology on rigid glass substrate is already mature and industrial companies are producing hundreds of MWp each year. However, the field of flexible CIGS solar cells is an emerging field of immense potential and importance, the field is still in early stage of R&D as well as in industrialization.

In the scope of this project the design of the flexible solar modules will be optimized for long term performance stability. This includes the single cell and module geometry for reducing resistive losses, the interconnection principle for adjusting output current and voltage, and the electric circuit design for reducing cell failure and shading losses. The optimization of the design of the flexible solar modules will yield improved initial device performance, however, for maximum energy harvesting the performance stability over time is of great importance. For power generation in the field a performance stability of >20 years is desired[1].

In consumable electronics performance stability over 2-5 years is sufficient in most cases.

Prototype samples of different sizes intended for diverse applications are developed and performance stability tests of monolithically interconnected and encapsulated solar modules are measured and analysed. Comparison of small size mini-modules of Empa (with characteristics of high performance processed on research lab type machines) and Flisom (with characteristics of devices processed under industrial conditions) provide valuable information on the impact of processing condition differ-

[1] The PV performance of a solar module is called stable if the output power is greater than 90% of the initial value after twenty years of operation in the field.

ences and potentials of the technologies for various applications. Components of the solar module including the layers, substrates, interconnects, encapsulation can cause performance stability degradation when the solar module is exposed to solar light and various environmental conditions of temperature and humidity cycles.

The developed models based on the separated external conditions are cross-checked under combined tests as well as real outdoor conditions.

PV module certification according to the IEC standards 61646:2008 and 61730:2004 is mandatory for placing flexible solar modules on the international market. Within this project the first very important steps and proofs are planned towards long term performance stability and identifying the encapsulation materials and procedures. Measurements of such mini-modules and modules as well as models for long term performance stability and failure analyses are developed.

The overall goals of the project can be summarized as follows:

1. Availability of methods and tools to optimize CIGS solar modules structure grown on flexible substrate for long time performance stability (>20 years).
2. Better understanding of CIGS solar module aging and failure mechanisms through measurements and models in order to match solar module designs to requirements for cost-efficiency and reliability.
3. Proven design and performance data on different prototype solar module samples and demonstrators.

The mechanisms which cause degradation of the PV performance are related to corrosion of electrical contacts due to moisture penetration on the one hand and to elemental diffusion as well as phase and structure alteration in the active layers induced by illumination and/or heating of the device on the other hand. Furthermore, different structure and microstructure of cells and layers can exhibit different degradation characteristics. The impact of the external factors moisture, illumination and heat on the performance are investigated by using two different test setups, a climatic chamber with controllable relative humidity and temperature as well as a light soaking chamber with controllable illumination, temperature and gas mixture. The influence of the internal factors (microstructure, layers and interfaces) are analysed by using well defined cell structures from Empa-TFPV laboratory as reference samples.

Selected equipment of EMPA and Flisom

The equipment used in this project includes chambers to test the solar cell under damp heat conditions and under the influence of illumination combined with heat. Such chambers are shown in figure 1a) and figure 2. Further special equipment dedicated for this project has been set up including a tool to measure electro luminescence emission from solar modules for failure analysis. This instrument is shown in figure 1b.

1a

1b

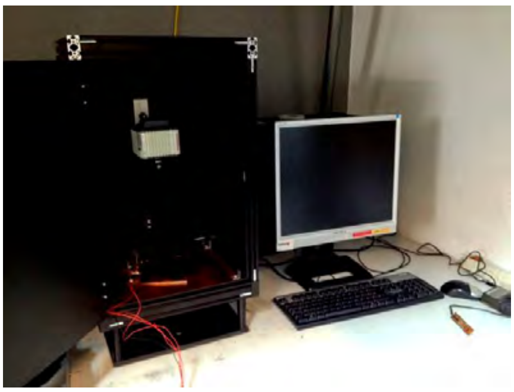

Figure 2: *Picture of Empa equipment for illumination stresstest a) and electro luminescence failure analysis b).*

Figure 3: *This picture shows the three climate chambers hosted at the Empa Electronics Laboratory which are used inside the project. Thermal cycling is running in the left chamber, humidity-freeze in the middle chamber and damp heat in the chamber to the right.*

Work carried out and results achieved

In the first work package, mini-modules at Empa and modules at Flisom are produced. Empa uses small scale deposition reactors to coat the thin light absorbing layers, resulting in about 5x5 cm mini-modules. The advantage of the small scale reactors is the possibility to work with state-of-the-art highly efficient CIGS absorbers deposited by multi-stage co-evaporation of the elements.

Flisom instead uses large roll-to-roll tools to coat rolls of more than 100 m length in one step. Single modules are then cut from these long rolls for further testing. In Figure 4, a submodule and a large area module from Flisom are depicted, both encapsulated and ready for the climate tests. Figure 5 shows a new tool which is used to align submodules to build large area modules.

For the first iterations more than 100 submodules from Flisom have been encapsulated by using different encapsulation materials and afterwards have been prepared for the different tests in work package 2 (stress tests). Also, large area modules have been produced. As the production process for these large area modules is still in development, these modules are not yet used for the stress tests.

The electroluminescence analysis tool shown in figure 1b, which Empa setup for this project, is in operation. With different optics, the setup is capable of imaging large area (20cm* 20cm) up to details (1mm*1mm image size). It will be used to locate failures in combination with an existing infrared imaging system.

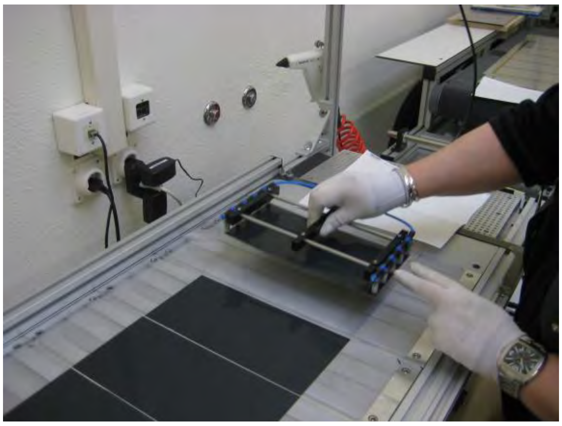

Figure 5: *Tool with vacuum gripper to align several submodules for the production of large area modules.*

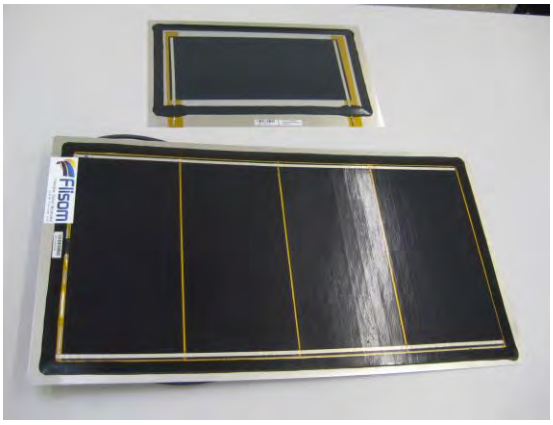

Figure 4: *Picture of an encapsulated submodule (back) and a large area module (front).*

In the reporting period mini-modules were fabricated in collaboration between the Laboratory for Thin Films and Photovoltaics at Empa and the company Flisom. In first iterative steps the minimodules were exposed to climate tests and illumination stress tests as well as hot spot analysis. Imaging techniques such as electroluminescence and thermography were used in order to monitor the overall performance and to identify local defects. First detailed failure analysis were performed at the localized defects in the Laboratory for Electronics/Metrology/Reliability at Empa.

In work package 2 (WP 2), the modules produced in WP 1 are exposed to different stress. Three main groups are distinguished for the tests: climate tests, illumination stress tests and hot spots / shading.

Climate tests are a very important part of the IEC standards to demonstrate that the modules can withstand the different climates existing on earth. So far, four different climate tests have been performed during WP 2. The most critical one for CIGS modules is generally said to be the damp heat test. The modules are exposed to a temperature of 85°C and a relative humidity of 85% for 1000 hours. So far, the encapsulated modules did show a good stability under these harsh conditions. In Figure 6 submodules in the damp heat chamber are shown. Several modules are always exposed to test conditions simultaneously in order to acquire statistically relevant test data. The modules show very good stability with performance above 95% of initial value after 700h of exposure; the tests are still ongoing to reach 1000 hours. It is also planned to further increase the testing time and optimize module stability and encapsulation to minimize any losses.

Figure 6: *Submodules stacked inside the damp heat chamber. After 700 hours exposure to 85°C and 85% relative humidity, the modules still have more than 97% of their initial performance.*

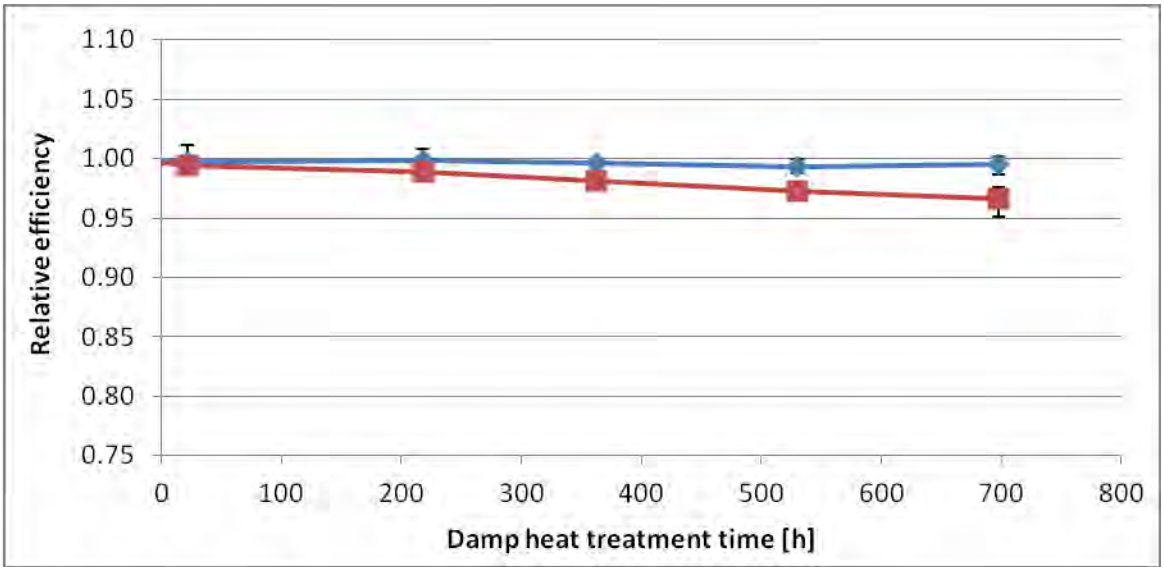

Figure 7: *Performance behavior of several submodules in the damp heat climate test. The two lines correspond to two groups with different encapsulation materials. There is nearly no degradation visible and the values are still far above the limits given by the international test standard.*

A second climate test is the thermal cycling, where the temperature in the chamber cycles between -40°C and 85°C, whereas the humidity is not controlled. This test is especially harsh for the encapsulation build-up as the different materials have different thermal expansions and the cycles can lead to mechanical stress and finally to delamination of the different layers. Normally, 200 temperature cycles are conducted. This test is still ongoing and results can be presented in the next progress report.

The third test, called humidity freeze, is combined with the thermal cycling. After undergoing 50 temperature cycles, the modules stay in damp heat conditions at 85°C and 85% relative humidity for 20 hours and then are cooled down rather fast to -40°C to stay there for about 1h. This cycle is repeated ten times. If any water has accumulated inside the encapsulation, it would freeze and lead to bursting of the package. None of the encapsulated modules from the first iterations showed any defects after the needed number of cycles, but the test is still ongoing to increase the severeness.

A last test, which is not part of the IEC standards, is the dry heat test. The modules stay in an oven at 85°C. This test is mainly to compare with the damp heat test. When modules fail in damp heat and dry heat, the failure must be more related with temperature than with the diffusion of water inside the package as there is almost no water present in the dry heat test. Encapsulated submodules did not show any defects after 700 hours.

National and international cooperation

This is a collaborative project between Flisom Company and the Laboratory for Thin Films and Photovoltaics at Empa and the Laboratory for Electronics/Metrology/Reliability at Empa.

Evaluation 2013 and Outlook 2014

The project is now in the middle of the first Project year. More than 100 mini modules and mid-size modules were produced by the project partners and exposed to damp heat and illumination stress test conditions. It could be shown that electroluminescence imaging and infrared imaging are suitable methods to localize stunts and other failure mechanisms also in fully encapsulated modules. Failure mechanisms induced by damp heat, mechanical stress and other factors could be detected. The work is currently focused on the development of a degradation model to reliably assure the module lifetime. The progress of the project well aligned with the project plan and the project partners are confident to achieve all the set project goals in 2014.

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Confédération suisse
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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

ALL LASER SCRIBING OF CIGS PHOTO-VOLTAIC PANELS ON RIGID SUBSTRATES

Annual Report 2013

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Project- / Contract Number	CTI13252.1 – PFFLE-NM
Duration of the Project (from – to)	01.01.2012 – 31.03.2013
Date	December 2013

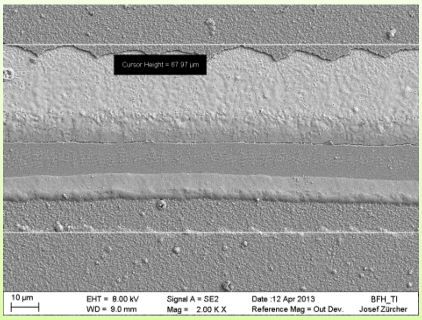
ABSTRACT

In this project all laser scribing of highly efficient Cu(In,Ga)Se2 (CIGS) thin film solar modules using a picosecond all-in-fiber laser has been optimized and brought to near-commercial maturity.

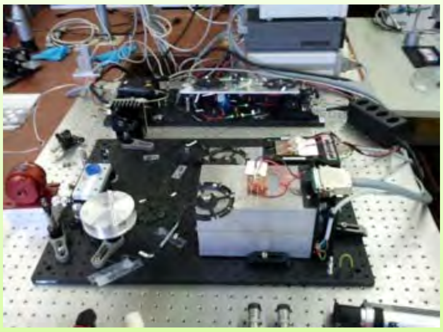
Description of the project

In this project all laser scribing of highly efficient Cu(In,Ga)Se2 (CIGS) thin film solar modules using a picosecond all-in-fiber laser has been optimized and brought to ***near-commercial maturity.***

With ultrashort laser pulses we have been able to reduce the overall width of the ***cell to cell interconnects from 300µm (state of the art for mixed mechanical and laser scribing when we started the project) to 70µm***.



CIGS scribing:
< 70µm linewidth for all three scribes
(mech: 300 µm)
Efficiency: 16.7%
(WR Solibro: 17.4%)



Fiber lasers for micro-processing :
35ps, >10µJ, 1MHz: achieved.
Scaling to higher rep-rates planned.

Even more: the ***process was significantly improved***: it is now ***more robust*** with respect to focal spot position, more tolerant to pulse energy variations and ***tolerates a broad variation in film properties***, a prerequisite for the processing of films from different manufacturers.

It has a higher ***reproducibility*** and yields cells with ***higher short circuit currents*** and ***higher open circuit voltages***. The visually smoother and cleaner ablation edges lead to better conditions for the deposition of the following layer (TCO).

The fiber laser system used for scribing was conceived in such a way that the bulky massive parts are ***separated from a lightweight laser head***; and the energy transmission to the head, where frequency doubling and beam focussing take place, is done by ***fiber delivery***.

This allows to mount the laser head directly on a fast moving axis which ***significantly simplifies the optical set-up and the alignment.***

To demonstrate the effectiveness of the system mini-modules (8 CIGS solar cells connected in series) were developed on 50x50x1 mm^3 soda lime glass. With a best case of ***16.7% the efficiencies obtained were well above the planned 15% and are very close to the World Record*** of 17.4% obtained by Solibro.

For laser scribing, a 50 ps Katana HP laser from Onefive GmbH was used. The P1 structuring of the Molybdenum back contact was performed at 532 nm for all presented mini-modules. Different scribing processes at 532 and 1064 nm wavelength were used for the P2 and P3 patterning. The CIGS layer was grown with a low-temperature co-evaporation process (<475°C). The deposition processes for all layers in the device are ***compatible with a variety of substrate materials including flexible polyimide substrates***.

The scribing equipment that we set up for these experiments has been bought by the Berne University of Applied Sciences with help of the extraordinary strong Swiss Franc measures and ***will stay as a fixed thin film processing station in the Applied Fiber Technology Lab in Burgdorf***.

This fact as well the exceptionally good efficiency results obtained in the project has yielded the participation of all project partners (with the exception of Solneva) ***in a big European project (Appolo).***

TRAINING FOR SUSTAINABLE LOW COST PV TECHNOLOGIES: DEVELOPMENT OF KESTERITE BASED EFFICIENT SOLAR CELLS

EU-FP7 KESTCELLS

Annual Report 2013

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Project- / Contract Number	KESTCELLS - 316488
Duration of the Project (from – to)	01.09.2012 – 31.08.2016
Date	09.12.2013

ABSTRACT

The overall objective of this project is the creation of an ITN network for the structured interdisciplinary training of researchers in advanced thin film photovoltaic (PV) technologies. The project proposes the development of new technologies compatible with the cost, efficiency, sustainability and mass production requirements that are needed to become a reliable and future alternative to conventional non renewable energy sources. With this objective in mind, the project will focus on the development of kesterite based solar cells. Kesterites $Cu_2ZnSn(S,Se)_4$ are quaternary compounds with a crystalline structure similar to that of Chalcopyrite $Cu(In,Ga)(S,Se)_2$ but they are composed of cheap and earth-abundant elements.

In cooperation with IREC (Spain), Univ. Northumbria, HZB, Univ. Luxembourg, Uni Uppsala, NEXCIS, Free Univ. Berlin, Autonomous Univ. Madrid and Univ. d'Aix-Marseille, the Laboratory for Thin Films and Photovoltaics at Empa engaged one motivated PhD student, Mr. Stefan Haass, to perform from 1 August 2013 research activities on the synthesis of photovoltaic grade CZTS(Se) by chemical and PVD routes, develop alternative back contacts and buffer layers (CdS and Cd-free buffers) for optimal heterojunctions with CZTS/Se absorbers, and to prepare kesterite-based solar cells. The research program is complimented with numerous exchange visits and training occasions for the young researcher.

Introduction and project goals

The overall objective of this project is the creation of a Marie Curie Initial Training Network (ITN) for the structured interdisciplinary training of researchers in advanced thin film photovoltaic (PV) technologies. Lack of professionals with these competences has been already identified as one of the main risks for the future development and consolidation of a competitive PV European industrial strategic sector. The project proposes the development of PV technologies based on new kesterite type materials and processes compatible with the cost, efficiency, sustainability and mass production requirements that are needed in order to become a reliable and future alternative to conventional non renewable energy sources. Kesterites are quaternary compounds with general composition Cu_2ZnSnS_4 (CZTS) and $Cu_2ZnSnSe_4$, (CZTSe) and their crystalline structure is very similar to that of chalcopyrites as $Cu(In,Ga)(S,Se)_2$ (CIGS), but in contrast to CIGS, kesterites are formed by earth abundant or cheap elements [1]. The specific scientific objectives of KESTCELLS are:

a) To achieve a much deeper understanding of the fundamental properties of kesterites

b) To identify and understand the role of secondary phases

c) To improve the knowledge on the main doping mechanisms

d) To apply this knowledge for the design and development of kesterite based solar cells

e) To optimise and demonstrate these processes for the achievement of cells with an efficiency $\eta >$ 10% without the involvement of toxic or hazardous reagents

Subproject at Empa has the following objectives:

- Synthesis of photovoltaic grade CZTS(Se) by chemical and PVD routes
- Development of alternative back contacts and buffer layers (CdS and Cd-free buffers) for optimal heterojunctions with CZTS/Se absorbers. Study of interfaces.
- Preparation of solar cells and their optoelectronic characterization, extension to flexible substrates

Work and results

Development of optimal CZTSSe based heterojunctions

The fabrication of the CZTSSe based heterojunctions is achieved by using a solution approach of metal-salts and thiourea dissolved in dimethylsylfoxide (DMSO) [2]. The solution is spin-coated in several steps onto a Mo-coated sodalime-glass including an annealing step on a hotplate after each layer as shown in Fig. 1.

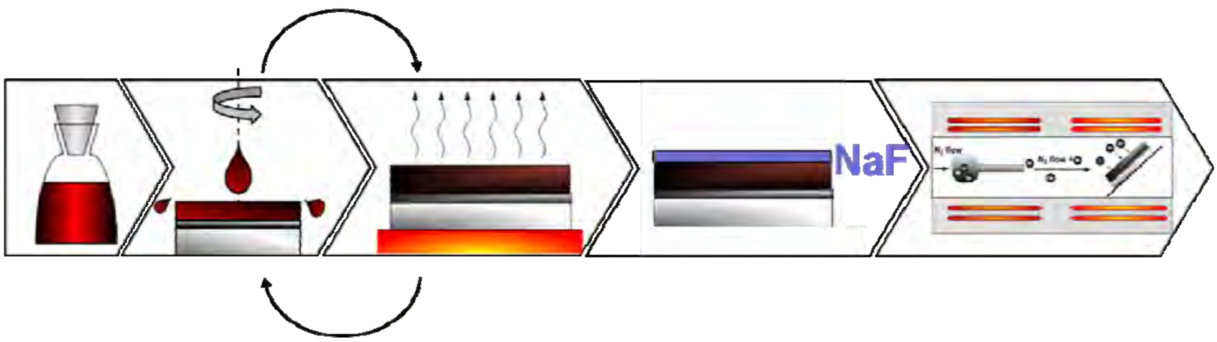

Fig. 1: Fabrication steps of the CZTSSe absorber layer

In order to improve the grain growth and the incorporation of Selenium in the final annealing step a layer of NaF is evaporated on top of the precursor [3]. Finally, the precursor is annealed to 550°C in a Se-atmosphere inside a 2-zone-furnace. Hereby the temperature of the Se-source is controlled independently from the sample temperature and the Selenium vapour is transported by a flux of Nitrogen to the sample. Hereafter an etching step with KCN-solution is used to remove Copper-rich secondary phases from the surface. With a standard CBD process a layer of CdS is deposited and forms the p-n-junction with the CZTSSe absorber layer. Finally, i-ZnO / Al:ZnO window layer is deposited by rf-sputtering, followed by EBPVD of the top grid. The fabricated devices with a total cell area of 0.3 cm^2

are characterized by IV-measurements under illumination, EQE, SEM. The composition as well as relevant properties of the absorber layer are measured by XRF, XRD, Raman spectroscopy, SEM and EDX.

Properties of solar cells based on solution deposited CZTSSe absorbers

The solar cells produced with the above described approach show efficiencies up to 5% and a good homogeneity over the whole sample area of 5x5 cm^2 as shown in Fig. 2. IV-measurements were performed in a steady-state sun-simulator under standard test conditions (1000 Wm^{-2}, 25°C, AM 1.5G illumination) and result in a J_{SC} of 29.6 mA/cm^2 and a V_{OC} of 332 mV (Fig. 3). Furthermore XRD patterns show strong peaks for the Kesterite phase and no secondary phases that are detectable by this technique (Fig. 4).

4	4.3	4.6	4.7	4.8
3	4.8	4.7	5.0	4.3
2	4.8	4.7	**4.8**	4.8
1	5.0	4.8	4.9	
SH6	A	B	C	D

Fig. 2: Efficiencies of 0.3 cm^2 solar cells on a 5x5 cm^2 sample

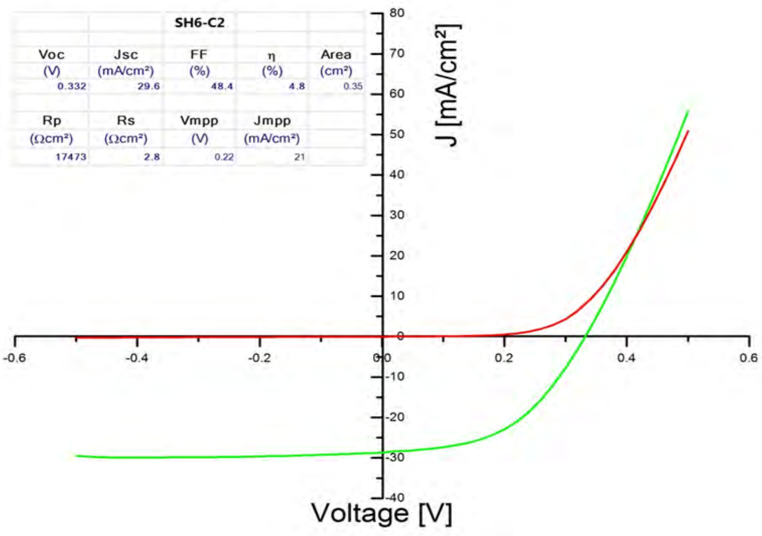

Fig. 3: Illuminated (green) and dark (red) IV-curve of cell SH6-C2 with 4.8% efficiency.

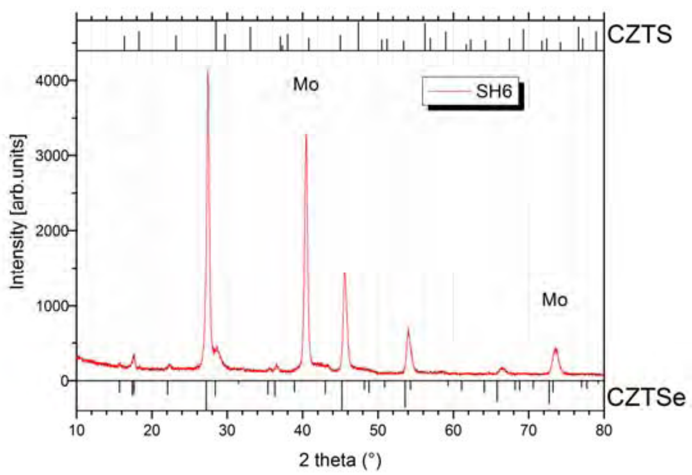

Fig. 4: XRD pattern of the 5x5 cm^2 sample. Strong peaks for Kesterite phase at 27.18°, 45.2° and 53.6°. The peaks are shifted towards higher angles because of incorporation of Sulfur in the lattice.

SEM image of the cross-section (Fig. 5) reveals a 2 µm thick absorber layer with bigger grains on top and smaller ones closer to the Molybdenum back contact.

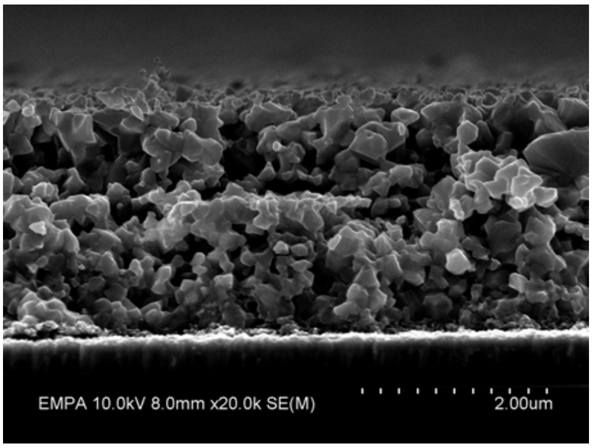

Fig. 5: SEM cross-section of the selenized absorber layer. Larger grains on top and smaller ones closer to the Mo-back contact.

National / international cooperation

The project foresees a close collaboration between all project partners:

IREC: Fundació Institut de Recerca de l'Energia de Catalunya, Spain

UL: University of Luxembourg

HZB: Helmholtz Zentrum für Materialien und Energie GmbH, Germany

EMPA: Swiss Federal Laboratories for Materials Science and Technology

NU: Northumbria University, UK

AMU: Aix-Marseille University, France

FUB: Freie Universitaet Berlin, Germany

UAM: Universidad Autónoma de Madrid, Spain

UU- ASC: Uppsala University, Ångström Solar Centre

ASNT: Abengoa Solar New Technologies S.A, Spain

NEXCIS, Rousset, France

The project involves a comprehensive training program with a well balanced structure including local training elements (doctorate programs, internal seminars) and network wide activities (thematic workshops intensive courses, network workshops) with the active participation of all the members of the network. All partners of the network will be hosting 1-2 researchers during a short-term visit.

Conclusions 2013 and Outlook

The project activities at Empa started on 1.08.2013 and a reproducible baseline process was established yielding solar cell efficiencies in the range of 4.5-5.0%. During next year the activities will focus on improved sintering strategies to obtain the phase-pure material, identify factors limiting the cell efficiency, and realize alternative buffer and contact layers.

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SCALENANO PROJECT

Development and scale-up of nanostructured based materials and processes for low cost high efficiency chalcogenide based photovoltaics

Annual Report 2013

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Project- / Contract Number	NMP4-LA-2011-284486
Duration of the Project (from – to)	01.02.2012 – 31.07.2015
Date	09.12.2013

ABSTRACT

SCALENANO aims at contributing to a further reduction of manufacturing costs of PV solar modules, in line with the 20/20/20 target established by the European Commission and the European Strategic Energy Technology Plan (SET-Plan). Cu(In,Ga)(S,Se)2 PV technologies, have already entered the stage of mass production. However, current production methods typically rely on costly, difficult to control over large surfaces, vacuum-based deposition processes which are known for lower material utilization of 30-50%. This compromises the potential reduction of material costs inherent to thin film technologies. At the forefront of this, SCALENANO will develop alternative environmental friendly and vacuum free processes based on the electro-deposition of nanostructured precursors. The project also includes the exploration and development of alternative processes with a very high potential throughput and process rate, as well as their extension to next-generation kesterite based absorbers, that will allow the proposition of an industrial roadmap for the future generation of chalcogenide based cells and modules.

The status of the project is briefly reviewed.

Further details: www.scalenano.eu.

Project partners

SCALENANO, **funded by the 7th Framework Program (Energy) of the European Union** with a budget of over EUR 10 million (CHF 12 mio.), is one of the largest R&D projects on PV ever funded by the EU. For its accomplishment an interdisciplinary consortium of 13 R&D groups was appointed. This comprises five research institutes, four universities and four companies from different industrial sectors. SCALENANO runs from February 1, 2012 to July 31, 2015.

IREC (Research Centre, Spain, Coordinator)

SUPSI (University, Switzerland)

EMPA (Research Centre, Switzerland)

IIT (Research Centre, Italy);

Uni-Luxemburg (University, Luxemburg)

Uni-Nottingham (University, UK) **rumors of quitting the project (2014)**

FUB Uni-Berlin (University, Germany)

HZB (Research Centre, Germany);

CEA (Research Centre, France);

NEXCIS (SME, France);

IMPT (SME, UK) **expected to quit project early 2014**

MERCK (Industry, Germany)

SEMILAB (SME, Hungary)

Involvement of SUPSI in the project

Within the project the **Institute for Applied Sustainability to the Built Environment Institute (ISAAC)** of SUPSI is actively involved in helping the industrial partners to scale-up the technology. SUPSI is in fact mainly involved and leads work-package WP5 (Scale-up processes: from cell to module) which started in m7 (August 2012).

SUPSI main opportunity in the project is that of building internal know-how in the field of module technology and of consolidating pre-existing knowledge in the field of performance testing of CIGS-based devices (power rating, life-time, energy yield, etc.).

SUPSI' main achievements

Electro-deposited $Cu(In,Ga)Se_2$ thin film solar modules: electrical layout

R&D activities have so far mainly regarded the optimization of the electrical layout of the module based on Nexcis' design (the so-called *hybrid interconnection* of cells).

This patterning approach, *hybrid interconnection* (HI) of cells, lies somewhere in between the traditional monolithical interconnection (MI) used for thin films and the tabbing of cells in c-Si modules. When compared to the conventional MI, the hybrid interconnection provides the following advantage: as the laser or mechanical ablation comes only at the end of the deposition processes, there is no need to interrupt the deposition of the semiconducting layers for the P2 and P3 cuts. This method would provide particularly valuable for vacuum-based processes as well. An additional advantage of this method is to be more flexible in terms of cell number and dimensions, and consequently in terms of output voltage and current.

SUPSI, based on the input parameters (provided by Nexcis and with the aim of optimizing the module's output in terms of efficiency, has modelled the electrical layout (IV curves) of the module's and laid down a road map (reduction of scribe losses, reduction of series resistances, improvement of material's quality) which could potentially bring to a +30% increase in the modules' power (see Fig.1).

Response to shadows under real operating conditions has also served as input for optimizing the electrical layout of the devices.

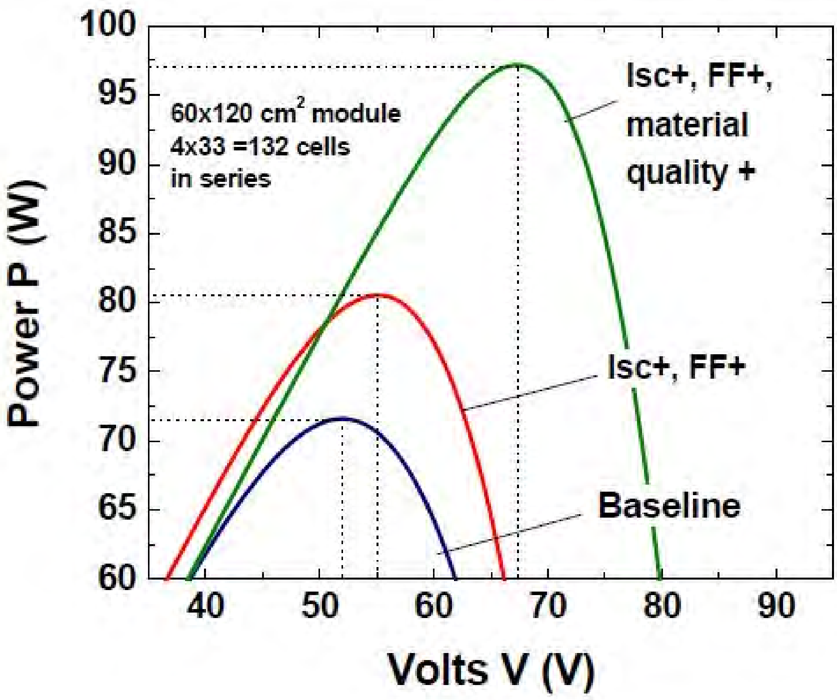

Fig. 1: *Baseline PV (power-voltage) curve and combination of strategies (1)-(2) (reduction of scribe losses + reduction of series resistance) and of strategies (1)-(2)-(3) (idem + improving materials' quality) for improving module's performance*

Encapsulation of modules

Preliminary activity is on-going at Nexcis using a laminator with limited capacity (size). Supsi has purchased and installed a laminator, which will be fully dedicated to this task. The laminator – shown in Fig. 2 - is operational since May 2013. Nexcis has provided SUPSI with un-encapsulated devices for preliminary testing and preliminary trails were performed jointly. The test of different encapsulant materials (EVA, PVB, ionomer, etc.) and edge-sealants is scheduled for year 2014. These devices will provide testing material for ageing/stress tests, which in turn will provide a feedback to the encapsulation process.

A protocol for assessing the quality of the lamination process was laid down by SUPSI and Nexcis. It consists of optical (transmittance), climatic (damp-heat, etc.) and mechanical (shear test) trials.

Fig. 2: *The Panamac laminator newly installed at Supsi for the Scalenano project and results of the first trials with scrap modules provided by Nexcis.*

Performance and reliability testing of electro-deposited PV modules

Another task in charge of SUPSI is the assessment of the performance (power, Wp), durability and energy-yield (kWh/kWp) of the devices manufactured within the project. Preliminary activities for a proper pre-conditioning procedure of the electro-deposited CIGS modules – prior to power rating – have started.

DURSOL

EXPLORING AND IMPROVING DURABILITY OF THIN FILM SOLAR CELLS

Annual Report 2013

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Project- / Contract Number	CCEM-Dursol
Duration of the Project (from – to)	2010-2013
Date	13.02.2014

ABSTRACT

The project objectives are focused towards the understanding of fundamental degradation phenomena in thin film solar cells and enhancement of lifetime. Degradation is due to complex mechanisms related to inherent material stability or interdiffusion phenomena across junctions. Device lifetime is also affected by external influences such as ambient atmosphere and solar light, and depends on the type of semiconductors being used in the devices and how the solar cells are encapsulated. The way degradation processes are identified relies on the observation of the temporal evolution of device performance and its relationship to microscopic changes in device materials and morphology. The goal of this project is to use the competences of the Swiss partners in micromorph silicon, compound semiconductors, dye sensitized and organic thin film solar cells, solar cell testing as well as modeling to scrutinize durability of thin film photovoltaic devices. An additional goal of the project is to provide a research platform for students and scientists in the field of photovoltaics (PV) offering workshops and conferences where world renowned experts can be meet personally. Major funding of the project is provided by the CCEM and swisselectric research.

Introduction

DURSOL is a project consortium consisting of the following Swiss research groups: Empa (FP and TFPV Laboratories, Dübendorf), EPFL (IMT and LPI Laboratories, Neuchâtel and Lausanne), ZHAW (ICP Laboratory, Winterthur), CSEM (Polymer Optoelectronics, Basel), SUPSI (Photovoltaic Test Center, Canobbio). Several industrial partners are involved as well: BASF, AMCOR, Flisom, Fluxim, Solaronix AG, Pramac, TEL Solar-Lab SA. Due to the fierce market situation in the last years, the two latter partners, unfortunately had to shut down in 2012 and 2014, respectively.

The project started on January 1st 2011 and is now reaching the end of its third and last year. Since the DURSOL project incorporates research and development objectives in several technological directions, a topical structure including four principal modules was defined as follows:

- Module 1: Chemical alteration of the PV device components by external influence
- Module 2: Improving morphological stability of the PV device layers
- Module 3: Mechanical effects of stress on device lifetime
- Module 4: Barrier properties of encapsulation materials

Periodical meetings were held and focused alternatively on the different module topics. These meetings also included a steering committee meeting as well as a laboratory tour at the host institution. All partners have hosted one of the meetings at their institution including PVlab (EPFL, Neuchâtel), ISAAC (SUPSI, Canobbio), CSEM (Muttenz), LPI (EPFL, Lausanne), Empa (Functional Polymers and Thin Films and PV, Dübendorf).

In course of the project, the planned tasks have been successfully carried out. Also, the majority of the planned milestones have been reached. One milestone dedicated to mini module testing was not tackled due to the lack of encapsulated modules for this purpose. Instead a calibrated solar simulator for smaller cells was built up and is used by the consortium to perform calibrated device performance measurements.

Results

CdTe thin film solar cells (Empa, TFPV)

In the course of this project the efficiency of CdTe solar cells in substrate configuration was raised from 8.6 % to 13.5 %. This was achieved by the use of new back contact materials, of which MoOx was found to be the most suitable. It was found that thermally evaporated MoOx performs better in terms of cell efficiency and lifetime. Other buffer layers based on Sb performed poorer. Also the mechanism of how Cu dopes CdTe could be elaborated allowing a deeper understanding of the functionality of CdTe solar cells in general. Stressing tests revealed a fast drop of the open circuit voltage for all buffer layers within 100 h. A similar degradation kinetics was observed for the fill factor when Sb based buffer layers were used. The origin of the fast efficiency drop during the first 100 hours of stressing is assumed to lie in the instability of formed Cu acceptors. This assumption is supported by acceptor density profiles calculated from capacitance-voltage (C-V) measurements showing a drop of acceptor density accompanied by an enlargement of the space charge region upon stressing (Figure 1).

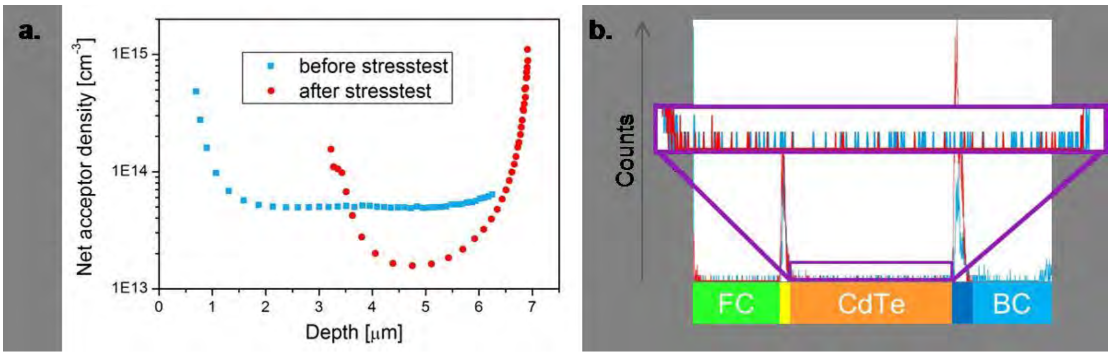

Figure 1: *a.) Depth (W) profile of net acceptor density N(W) calculated from C-V measurements performed at 30°C with a frequency of 3*105 Hz, an amplitude of 50 mV, and bias voltages between -1.5 and 0.5 V. Calculations are based on the formulas: N(W)=C^3 (qε dC/dV)^(-1)and W(V)=ε/(C(V)) (cf. Hegedus et al. Prog. Photovolt: Res. Appl. 2004; 12:155–176). b.) Secondary ion mass spectroscopy (SIMS) measurement of the depth dependent Cu distribution for a cell before (blue) and after (red) stressing. The sputtering started at the front contact (FC, green) then crossed the CdS (yellow) and CdTe (orange) and finally the back contact (BC, blue). The inset shows the magnification of the Cu counts inside the absorber; a reduction of Cu counts upon stressing is clearly visible.*

The stability of CdTe solar cells in substrate configuration was assessed by periodic performance measurements under stressing conditions in our self-built stress testing chamber. A very promising result with the least degradation of less than 20 % loss in efficiency upon a 1000 hour stress test at 80 °C and one sun illumination have been achieved.

Microcrystalline Thin film silicon solar cells (EPFL, PV-LAB)

The degree of crystallinity in microcrystalline silicon solar cells and its effect on stability have been thoroughly investigated and understood. Different kinds of substrate electrode morphologies have been tested to better clarify the influence of the electrode's roughness on µc-Si:H growth quality and, more particularly, density of defective zones. A smoothening ZnO capping on a standard rough front-electrode was introduced to further reduce the crack density in the Si absorber layer. A H2 plasma posttreatment of the completed device lead to an increase in stability and to a record efficiency of 10.7 %.

Regarding growth and stability of thin film solar cells based on amorphous Si, various deposition regimes have been explored. Efficient layers could be achieved at both high and low silane pressures.

Important testing equipment has also been set up. A new solar simulator, fully based on LEDs and allowing for up to 5 sun light intensity with tunable spectrum, was developed to study accelerated light induced degradation of amorphous silicon solar cells. For measuring adhesion in a reliable and reproducible way a compressive shear test was introduced to characterize adhesion of standard PV encapsulant materials (PVB, EVA, Silicones, TPU) to various rigid substrates (glass, PMMA, PC) before and after degradation in damp-heat conditions (300 h). Finally, an embedded miniaturized capacity sensor for in situ monitoring of moisture ingress in a photovoltaic module has been implemented.

Organic solar cells (EMPA, FP)

Within the DURSOL project, solution-processed, stable and high-performance organic solar cells based on cyanine dye molecules were developed. The research work has been mainly carried out in the topics of Modules 1 and 2. For device optimizations and lifetime studies, more than 1500 solar cells were fabricated in this study. Optimized devices based on trimethine dyes with efficiency of 3.7 % can now be achieved using regular and inverted device architecture. Accelerated lifetime testing of regular devices at 80°C for 17 days unraveled a burn-in period of ~3 days after which performance stabilized at 15 % of the initial efficiency. In the inverted architecture, cyanine cells were stable when stored in the glove box for several months, and no sign of degradation was observed under illumination in nitrogen (for 24 h) or ambient atmosphere (for 6 h), proving the inherent stability of these materials in solar cell applications.

An extended study of cyanine dye counterions showed their importance for thin film morphology and interface formation phenomena. For near-infrared (NIR) absorbing cyanine dyes, performance could be increased to 2.2 % upon choosing large counterions as compared to perchlorate anions. To inhibit diffusion of counterions out of the cyanine layer and to render the films insoluble, a universal crosslinking strategy for cyanine counterions was developed. This also allows to solution deposit further layers onto the cyanine film without dissolving the latter.

Device degradation in organic solar cells using phase separated blends of organic semiconductors often is due to reconstruction of the morphology with aging eventually leading to catastrophic failure. We therefore synthesized a fullerene functionalized with a single alkyl chain bearing a diacetylene moiety. In a thin film, the molecule self-assembles into lamellar arrays. The stabilization proceeds through solid-state polymerization of the diacetylene moieties (Figure 2). By blending the fullerene derivative with a cyanine dye, various nanostructure fullerene morphologies are obtained that can be stabilized by thermal polymerization. In ongoing work, we study the application of these stabilized blend morphologies in organic solar cells

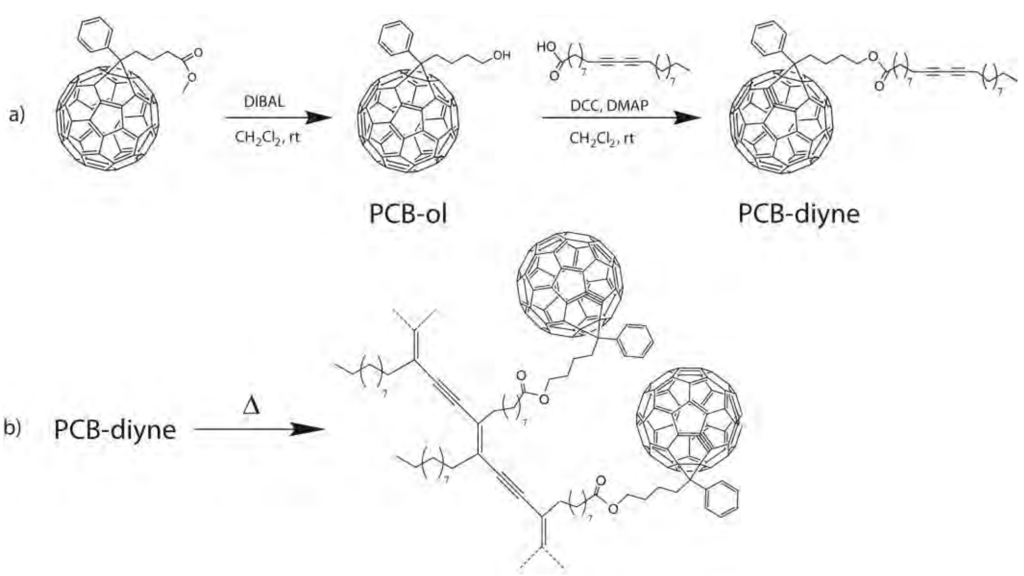

Figure 2: *(a) Synthetic route for a diyne-functionalized fullerene. (b) Crosslinking and stabilizing at elevated temperature.*

Polymer solar cells (CSEM, Polymer Optoelectronics)

The role of PEDOT:PSS anode buffer layer in uptake of water from the ambient atmosphere and subsequent degradation of polymer solar cells has been investigated. Other buffer layers consisting of MoO3 and V2O5, respectively, were benchmarked against commonly used conducting polymer PEDOT:PSSanode layers such as polythiophene derivative PEDOT:PSS. Laser beam induced current mapping was applied to investigate degradation of polymer solar cells using different hole transporting layers. Aging studies under the influence of water were completed with transient electrical measurements and the calcium test.

Dye sensitized solar cells (EPFL, LPI)

For realizing flexible dye sensitized solar cells, ionic liquids provide an attractive solution to the problem of solvent penetration through plastic foils. One of the main goals of the project is to understand the variations in the photovoltaic parameters of the dye-sensitized solar cells (DSSCs) during long-term stability tests of DSSC devices. The selected DSSC devices were fabricated with C106 dye in conjunction with various new ionic liquid electrolytes containing sulfolane as a plasticizer, Pt as a counter electrode. After 300 h aging under full sunlight intensity at 60°C the device performance dropped mainly due to the decrease in the fill factor. The reason for this kind of device behavior is due to the poisoning of counter electrodes. To confirm this observation, counterelectrodes made of a conducting polymer were used and the device performance was tested as a function of aging time. Electrochemical impedance spectroscopy allowed to understand the impact of fundamental processes in such solar cells. Device lifetime using conducting polymer electrodes were stable for 1000 h at 60°C, while those using Pt counter electrodes failed in about 200 h.

Physical simulation of solar cells (ZHAW, ICP)

Numerical models of the various solar cell techniques being investigated within the DURSOL project have been implemented for: DSSCs, OPVs and thin film silicon solar cells. The progress was achieved within collaborations with experimental groups (EMPA-FP, EMPA-TF, EPFL-LPI, CSEM and EPFL-PVLab). Among these various techniques, CELIV, impedance spectroscopy and electroabsorption were successfully set up. These techniques allow to better extract material parameters and to confirm results from electrical device simulation. A numerical model of the charge and heat transport in monolithically interconnected thin-film solar cells was developed and experimentally validated using lock-in thermography (LIT) measurements of amorphous silicon mini solar modules with where artificially shunts were introduced shuntsin the otherwise defect free module (Figure 3). A scalar light scattering model was extended for coherent layers and experimentally validated for microcrystalline/a-Si solar cells. The optical model for thin-film solar cells has been extended including bidirectional scattering distribution functions.

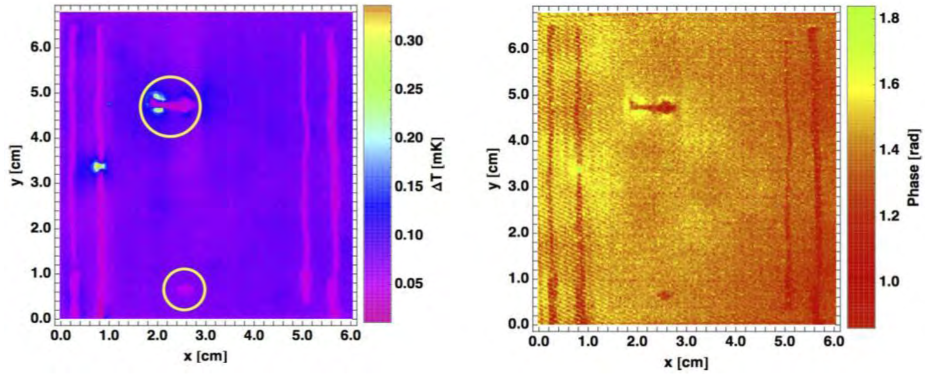

__Figure 3:__ Lock-in thermography (LIT) of an amorphous silicon solar module with two artificially introduced shunts (highlighted with yellow circles on the left image). The defects are observable in the LIT measurement, both in the demodulated amplitude (left) and in the demodulated phase image (right). A bias voltage of -4V, AC frequency 1Hz and modulation amplitude 8V were used.

Main achievements

Interface layers for increased stability of thin film PV technologies:

- Thermal evaporation of MoOx back contact as well as doping the active layer with copper increased CdTe efficiency from 8.6 % to a champion efficiency of 13.5% and lead to longer lifetime. Under harsh aging tests (1000 h at 80°C and 1 sun) 20% of the initial efficiency was retained (Empa, TFPV).
- Hydrogen plasma treatment of the back electrode was further optimized and lead to a record efficiency of 10.7% for microcrystalline silicon solar cells. Smoothening ZnO layers on top of the back electrode were found to avoid the formation of porous zones within the Si absorber layer and ensure good stability upon ambient storage (EPFL, PVlab).
- Annealing and hydrogen plasma treatments of fresh amorphous silicon devices considerably enhanced device stability as revealed by 40 days of ambient storage in the dark (EPFL, PVlab).
- Transparent NIR active solar cells based on heptamethine cyanine dyes, with average visible transmission >60% and efficiency of 1.5% were achieved. To achieve this, silver electrodes coated with a thin organic optical film were developed (Empa, FP).

Long term stability of DSSC using ionic liquid electrolytes containing sulfolane as plasticizer is affected by poisoning of the counterelectrode and is substantially improved by replacing Pt with PEDOT:PSS (EPFL, LPI).

Functionalized fullerene derivatives and cyanine dye salts were synthesized and thin films thereof could be successfully stabilized by crosslinking (Empa, FP).

New equipment has been installed and used by the DURSOL partners:

- A new solar simulator, fully based on LEDs and allowing for up to 5 sun light intensity with tunable spectrum, was developed to study accelerated light induced degradation of amorphous silicon solar cells (EPFL, PVlab).
- Compressive Shear Test was used to characterize adhesion of standard PV encapsulant materials (PVB, EVA, Silicones, TPU) to various rigid substrates (glass, PMMA, PC) before and after 300 h degradation in damp-heat (DH) conditions (EPFL, PVlab).
- Embedded miniaturized capacity sensors for in situ monitoring of moisture ingress in a photovoltaic module have been implemented (EPFL, PVlab). This measurement was combined with the Ca test method developed at CSEM.
- Climate chamber for accelerated solar cell and mini-module testing (Empa, TFPV).
- Encapsulation of selected samples employing novel AMCOR substrates with barrier layers were achieved (CSEM).
- In collaboration with Fluxim AG, know-how and hardware were built up for: charge-extraction by linearly increasing voltage (CELIV), electrical impedance spectroscopy (EIS), light pulse current response and others (ZHAW, ICP).
- A calibrated spectral response measurement set up was implemented to the existing steady state sun simulator (ISAAC, SUPSI)

National/international collaboration

Additionally to the remarkable achievements obtained during the three years of DURSOL, the intensive scientific and technical exchange between the Swiss PV research groups has to be outlined. A lot of bilateral exchange of know-how, processes and devices has taken place between the partners and the collaboration has given rise to new project initiatives, among which a large research proposal to the Swiss NRP70 program. The project has given rise to numerous conference contributions and prestigious publications, one being a Nature communication. Industrial contributions are greatly acknowledged. Amcor Flexibles AG provided encapsulation pouches for some of the project partners. BASF provided organic semiconductors for polymer solar cells. Solaronix SA participated in a dye sensitized solar cell demonstrator that was exhibited at the 2012 energy exhibition at the Swiss Museum of Transports. Fluxim AG made their numerical codes available to model various transient current experiments within the DURSOL consortium. Three DURSOL conferences and workshops were organized by the project partners. The first took place on April 4th 2012 at Empa and focused on Durability of Thin Film Solar Cells. The second took place on October 22nd 2013 at Empa addressing Environmental and Economic Impact of PV Energy Production. The third major event was a two day workshop at ZHAW in Winterthur on February 5th–6th 2014 related to Time and Length Scales of Degradation in Next Generation Solar Cells. Each of the conferences attracted about 70 participants.

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ORION

ORDERED INORGANIC-ORGANIC HYBRIDS USING IONIC LIQUIDS FOR EMERGING AP-PLICATIONS

Annual Report 2013

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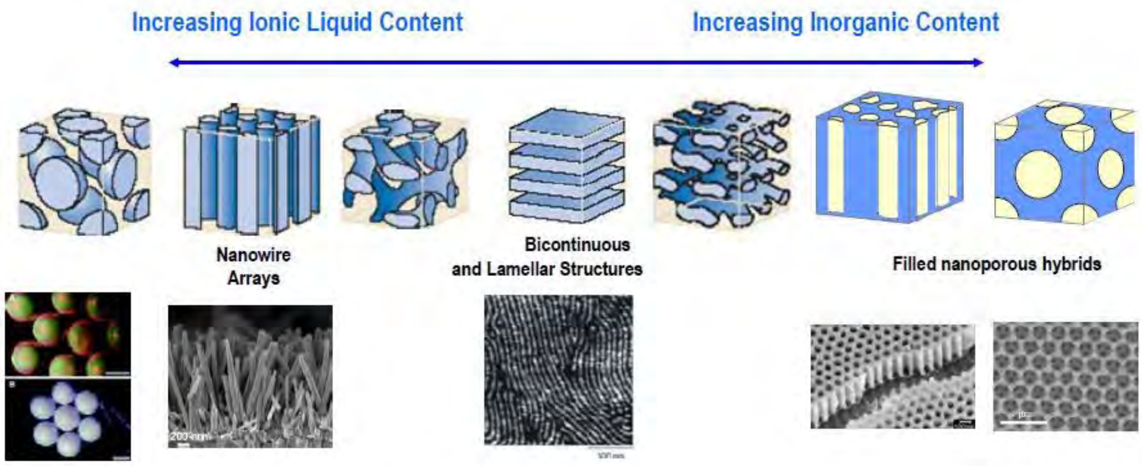
Project- / Contract Number	FP7-NMP-2008-LARGE-2-229036 / ORION
Duration of the Project (from – to)	01.10.2009 – 30.09.2013
Date	7 March 2014

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/Aims of the project

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 (TiO2, SiO2, ZnO, Si, Sn, LiCoO2) 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.

Generation 1	**Generation 2**

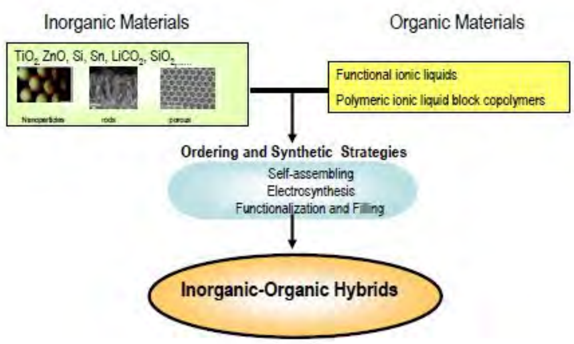
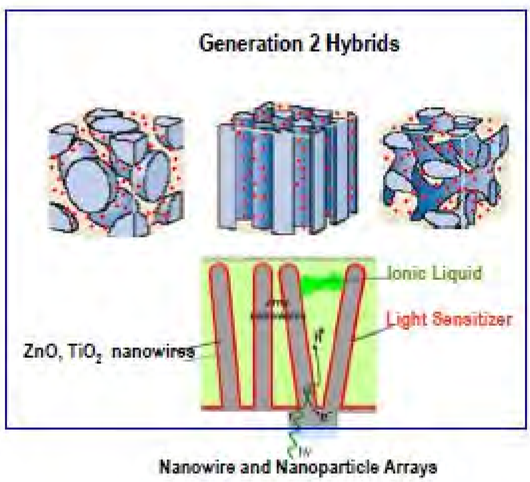

	

Illustration of the synthetic approaches to Generation 1 Ordered Inorganic-Organic Hybrids.	Graphical presentation of generation 2 hybrid architectures (inorganic nanoparticle or nanowires surface functionalized with a light sensitizer and embedded into ionic liquid media).

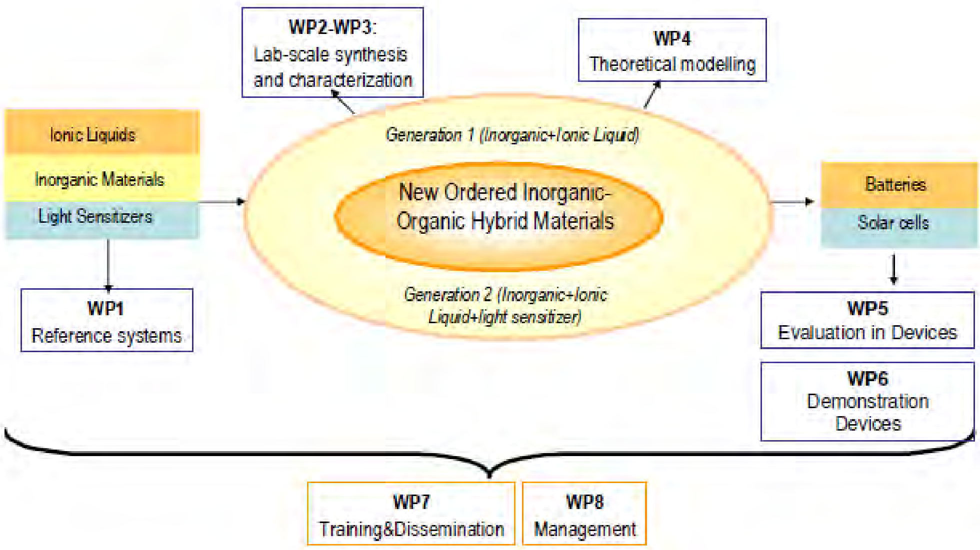
Scientific and technical objectives

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).

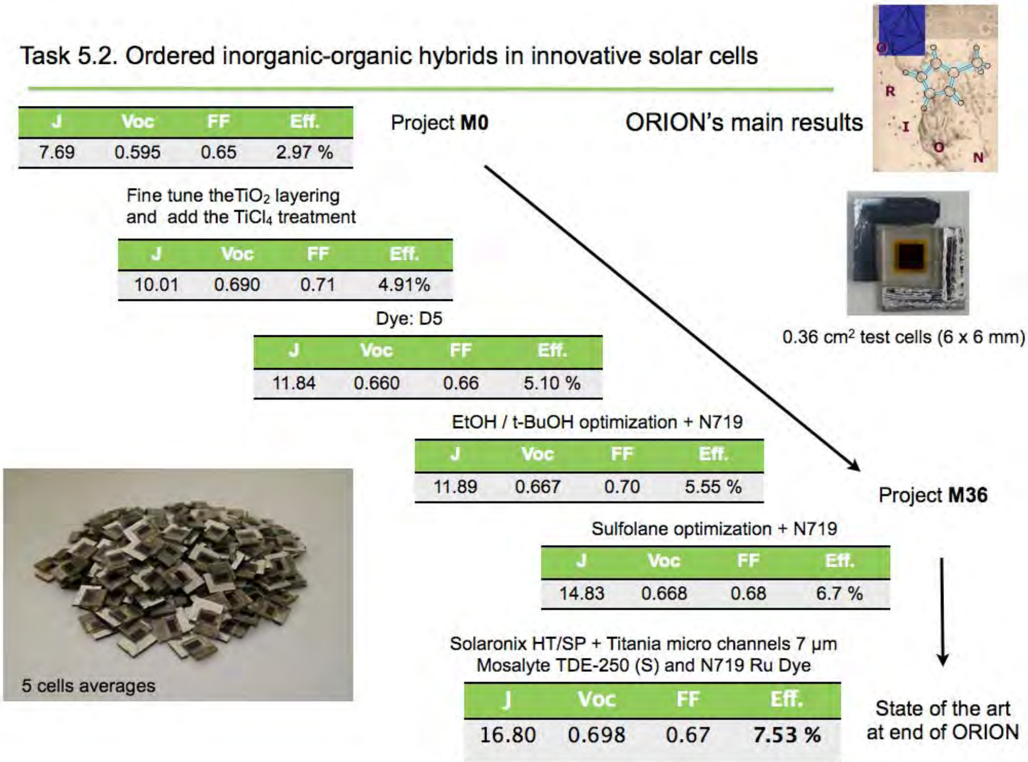
Project partners and role of Solarinox

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.



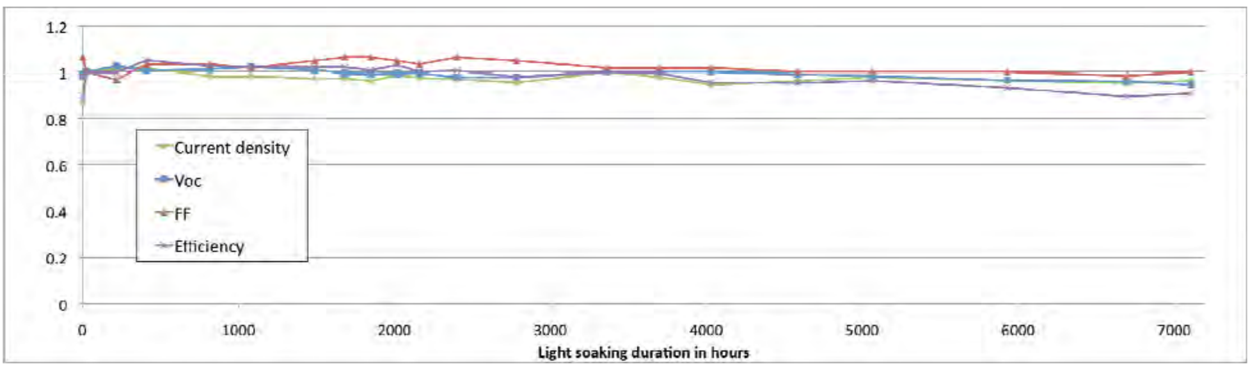
Work carried out and results achieved

During the WP5 «Evaluation in Devices», several formulations based on ionic liquid supplied by partner SOLVIONIC were evaluated in real devices using the classical ionic liquid test architecture. On the basis of the first results and according to WP2, WP3 development several optimizations were realized in order to increase device efficiency. Thousands of lab size dye solar cells were made during the 48 months of the project. Starting from around 2% at the beginning, due to a good feedback between partners and work packages, the progression was constant during the project. Finally, summing up all the improve-ments developed during ORION (WP2: new titania nanoparticles, WP3: processing methods) and using the optimized formulation coded Mosalyte TDE-250(S), the efficiency reached the impressive value of 7.53% in the last month of the project.



Task 5.2: Overview of ionic liquid cell efficiency progression during project duration.

Ionic liquid electrolyte cell stability was tested. Cells made with N-719 dye, Mosalyte TDE-250 or Mosa-lyte TDE-250(S) (with sulfolane additive) electrolytes, were placed under constant illumination, one sun AM 1.5G, at 65 °C. All cells exhibited extremely good stability (see graph below) with around 5% loss in 2900h in the case of sulfolane electrolyte and with less than 20% loss in 7000h in the case of Mosalyte TDE-250. Furthermore no physical changes could be observed during the light soaking accelerated aging or the thermal cycles (-40°C till +80°C) resistance tests which is crucial for the aesthetic aspect of the product. These stability tests results are really impressive and equivalent to several years of outdoor use under our latitudes.



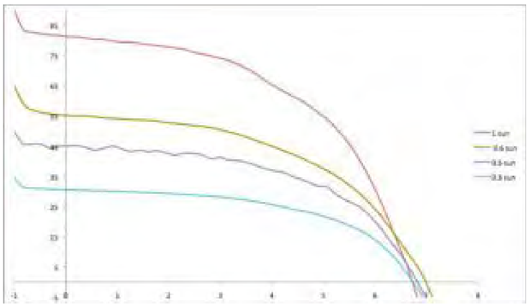
Aging using Mosalyte TDE-250 at one sun, 65°C, 24h/d.

Developments made in WP5, already led to a new addition to SOLARONIX catalog. Since January 2013, Mosalyte TDE-250 can be bought online and ORION was acknowledge on our website for the funding of the development. (http://shop.solaronix.com/electrolytes/non-volatile-electrolytes/mosalyte-tde250.html). In few months the sulfolane modified version Mosalyte TDE-250(S) will be introduced as well.

In the WP6 «Demonstration Devices», "W-type" modules were investigated to build up a prototype that consists in serially interconnected dye sensitized solar cells.

Summing up all the improvements and enhancements developed earlier in ORION, a state of the art W-module (10 x 10 cm, 65 cm2 active area) based on ionic liquid electrolyte and N-719 dye reached a nice power conversion efficiency (PCE) of 4.22 % (Voc = 6.8 V; Isc = 81 mA) under one sun (AM1.5G). This device was measured at various sun intensities (see table and I/V curves below) to evaluate the perfor-mance in situation matching real outdoors conditions. Under one third of sun the PCE was as high as 5.02 %.

This high efficiency is the highest achieved so far on ionic liquid electrolyte based module. This figure is impressive especially considering the effective active area of 65.1 cm2, the semi transparency of the module and the fact that the titania layer was only around 8 microns thick. It should be compared to the classical efficiency before ORION that was around 2% only.



Intensity	J	Voc	Efficiency
1 Sun	81 mA	6.8 V	4.22 %
0.6 Sun	55 mA	6.9 V	4.33 %
0.5 Sun	44 mA	6.8 V	4.9 %
0.3 Sun	30 mA	6.7 V	5.02 %

I-V characteristics of the state of the art module giving 4.22% PCE at 1 sun and 5.02 % PCE at one third of sun.

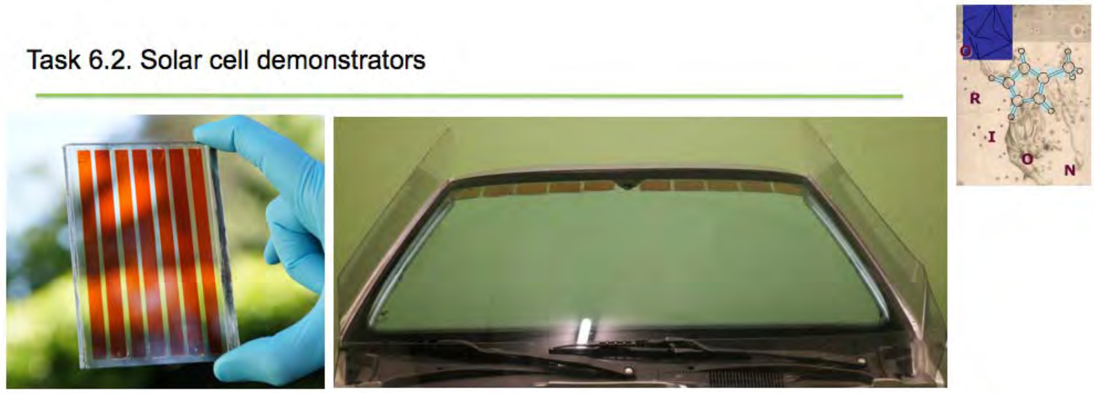
Further work consisted in developing thin glass based modules to build the ORION prototype. The idea was to apply the process previously developed for high efficiency modules to hundred microns thick flexible glass. A new design to fit the FIAT specifications was created and consisted in an interconnected module of seven individual cells on a 7 x 10 cm substrate.

Several steps of our classical process were successfully optimized for this thin glass like:

- FTO deposition
- Two glass lamination
- Hole drilling
- Titania printability and adhesion

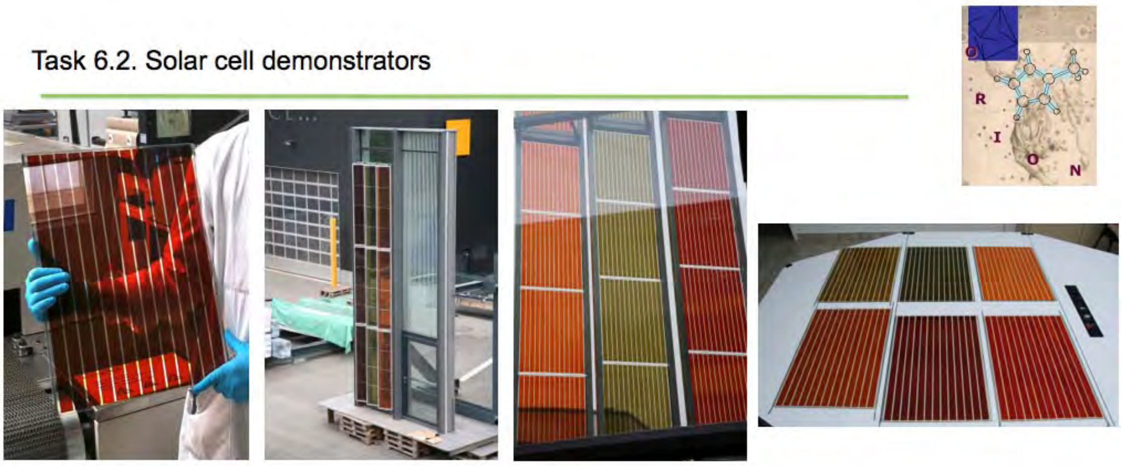
Unfortunately making modules using 0.1 mm glass is a real challenge. Due to the high fragility of this thin glass, some modules were produced but none of the final desired size to fit FIAT requirements.

A good compromise to the thick 2 mm and the fragile 0.1 mm glasses is using 1 mm glass. The process was then applied on 1 mm glass that led to the production of the first thin glass ionic liquid based mod-ules at SOLARONIX. To maximize efficiency an organic dye, D35, with a high molar extinction coefficient was used, giving a nice orange color to the modules. Twelve modules were sent to partner FIAT and fi-nally ten of them were integrated in a car windshield to power the ORION demonstrators.



Detailed view of a 7x10 cm W-module on 1 mm glass and integration on car windshield.

Progresses made during ORION in the field of ionic liquid electrolyte (WP5) and titania layer optimizations (WP2) allowed the first large scale building integrated photovoltaic (BIPV) application not to be a dream anymore and to become reality. The Swiss Tech Convention Center, located on EPFL's campus in Lausanne, has been designed to integrate the first semi transparent colored façade in the world. This facade is made using 1400 large area (35X50 cm) ionic liquid dye solar cell modules that were initially built during ORION. A real scale prototype, integrating the last ORION improvements, was setup in the Swiss Jura mountain, during summer 2012. Finally, SOLARONIX produced the required modules that will be mounted on the facade during November 2013, covering an area of 200 m2 in total.



First large area ionic liquid module made at SOLARONIX and real scale façade prototype.

Developments made in WP6, already led to new additions to SOLARONIX catalog. Since January 2013, SERIO 1010W11, SERIO 3030W11 and SERIO 3030W31, which are interconnected ionic liquid based dye sensitized solar cells, can be bought online and ORION were acknowledged on our website for the funding of the development.

http://shop.solaronix.com/dye-solar-cells/serio/serio-1010w11.html

http://shop.solaronix.com/dye-solar-cells/serio/serio-3030w11.html

http://shop.solaronix.com/dye-solar-cells/serio/serio-3030w31.html

In few months even larger versions of these modules will be introduced as well.

National and international cooperation

FP7-Project "CRONOS" - coordinated by Prof. Stefano Sanvito at the CRANN of the Trinity College Dublin, Ireland. The project aims to investigate the "Time dynamics and ContROl in naNOStructures for magnetic recording and energy applications", see http://www.cronostheory.eu/

FP7-Project "ARTIPHYCTION" - coordinated by Prof. Guido Saracco at the Politecnico Torino, Italy. This project aims to build a «Fully artificial photo-electrochemical device for low temperature hydrogen production». Started on 1st May 2012.

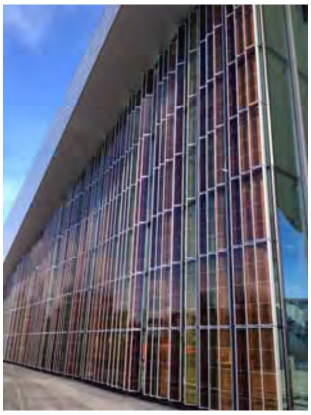
FP7-Project "ADIOS-Ru" - coordinated by Dr. Mashar Bari at the Solarprint, Ireland.
This project aims to take care of the "Advanced Design and Industrialization of Organic Sensitizers without Ruthenium for Dye Sensitized Solar cells". Started on 1st November 2012.

FP7-Project "ECO2CO2" - coordinated by Prof. Guido Saracco at the Politecnico Torino, Italy.
This project aims to build a «Eco-friendly bio-refinery fine chemicals from CO_2 photo-catalytic reduction". Started on 1st December 2012.

Submission on Octobre 2013 of the 2 years CTI project «High Efficiency Perovskite Solar cells» together with the EPFL (Pr. Nazerruddin at the LPI) - this project was granted and it starts in Spring 2014.

Evaluation 2013

During 2013 - the year this projects ends - the power conversion efficiency of 0.64 cm2 sized masked laboratory cells was improved to over 7 % using a sulfolane containing ionic liquid electrolyte, and 10x10 cm interconnected module achieved a 5 % efficiency in simulated sunlight at 1000 W/m2. This remarkable result opened the way for the production of 35 x 50 cm sized modules filled with ionic liquid, being used in the 250 m2 facade project for the Swiss Tech Convention Center at the EPFL campus, this world's first DSSC panel clad façade was completed in November 2013 thanks to the results of ORION that were obtained in the field of ionic liquid based electrolytes.

	
View from the inside to the Western façade of the freshly completed Swiss Tech Convention Center located at the EPFL campus	Outside view of the World's first DSSC panel clad façade at the Swiss Tech Convention Center in Lausanne.

References

http://www.cidetec.es/ORION/index.html

TREASORES

TRANSPARENT ELECTRODES FOR LARGE AREA, LARGE SCALE PRODUCTION OF ORGANIC OPTOELECTRONIC DEVICES

Annual Report 2013

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Project- / Contract Number	TREASORES / 314068
Duration of the Project (from – to)	2012-2015
Date	10.2.2014

ABSTRACT

TREASORES targets production of large area organic electronics using high throughput manufacturing technologies based on roll-to-roll (R2R) wet deposition processes. In particular, by developing large area (>1m^2) transparent conducting barrier foils which will be used for the production of flexible organic light-emitting devices (OLED), light-emitting electrochemical devices (LEC) and organic photovoltaics (OPV). This industry-driven project is a sustainable approach towards low cost production of organic thin film optoelectronic devices using low-temperature (<180°C) fabrication methods.

Introduction and Project Goals

The pioneering work of C. Tang at Kodak in the 1980s gave a strong impulse to organic semiconducting devices, boosting performance of organic light emitting diodes (OLED) as well as organic photovoltaic devices (OPV) to a level which reached technological interest. This opportunity was soon recognized by many research groups around the world, in particular in Europe and in the United States. Industrial realization and large scale manufacturing, however, mostly occurred in the Far East, especially in Japan. This is particularly true for OLED displays that are now manufactured by large companies such as SONY or Samsung. Also, these important industrial advances definitely removed scepticism about the claim that organic semiconductors have sufficient stability for reliable applications.

Despite the impressive advances led by Asian industrial efforts, Europe is at the forefront of industrial development in the field of large area optoelectronics. Key to this field is the possibility of fabricating functional devices from solution by processes similar to those employed in the printing industry. Processes based on high throughput production methods such as R2R fabrication are particularly price competitive but add a significant constraint on the materials used: substrates and functional coatings must be flexible in order to be compatible with R2R.

OLEDs have been identified as a technology for efficient lighting systems as evidenced by EU sponsored projects such as OLLA, OLED100 and CombOLED. These projects focused on multilayer devices on rigid substrates. Lighting panels, however, will be less bright than traditional point light sources; their area needs to be larger to have the same illuminating capability (roughly 0.5 m^2). Hence to enter the main stream lighting market these novel lighting systems must have large areas (> 0.5 m^2) and be produced by the previously mentioned cost efficient roll-to-roll approach which requires flexible substrates. OPV devices are very interesting low-cost alternatives for electrical current generation. Spurred by national and international research efforts, laboratory cell power conversion efficiencies now exceed 12% (demonstrated first by the European company Heliatek GmbH). Several OPV projects have been funded by the EU, including SUNFLOWER, ROTROT or X10D, which in part focus on high efficiency modules based on tandem architectures. As a leading company in this field, Konarka has brought the first consumer electronics products to the market, but unfortunately could not bear up to the enormous pressure exerted on the PV market over the last few years.

In order to achieve large scale adoption (> 1 GWp / year) and produce a real ecological impact, high throughput, low-cost processes have to be further developed. The quality and availability of flexible transparent electrodes is essential for industrial implementation. Besides lighting and energy conversion perspectives, several other applications for plastic electronics such as touch screens, LCD displays, signage devices would benefit from novel flexible electrode strategies to reduce cost.

The TREASORES project is focused on the integral production concept of large area R2R produced flexible organic electroluminescent devices and organic photovoltaic devices. It starts with flexible substrates including barriers and novel transparent electrodes, proceeds through optoelectronic stacks, and finishes up with stack encapsulation, all as an integral part of the R2R production process.

The most widespread flexible transparent and conducting material today consists of plastic foils coated with indium tin oxide (ITO) using plasma sputtering. The conductivities of these foils are insufficient for large area OLEDs and OPVs. Furthermore they suffer from cracking after repeated bending or strain which drastically increases surface resistivity to a level unacceptable even for small area OLED and OPV. Both OLEDs and OPV use materials that need to be protected from the atmosphere to prevent rapid device degradation. The barrier properties of ITO coated plastic foils are inadequate for this role. Last but not least, ITO is not a feasible option due to price increases of 10% - 20% per annum over the last 6 years. The use of indium to produce transparent indium tin oxide (ITO) electrodes has increased dramatically along with the popularity of LCDs, and is responsible for 80% of the indium usage today .

In organic optoelectronic devices, substrates and electrodes account for about half of the material cost. These substrates must in general incorporate additional barrier layers for protection against moisture and oxygen from the ambient atmosphere. For organic electronics to break through in large area deployment, the cost of electrode and substrate has to be well below conventional TCO coated glass substrates. This can be reached if the production processes involved are based on R2R fabrication, preferably including in-line addition of encapsulation and barrier layers. TREASORES therefore focuses on the development and R2R production of non-conventional transparent electrode substrates with embedded conductive lines incorporating high barriers for moisture and oxygen.

The main tasks and objectives of Empa in this project are:

- Characterize novel electrode barrier substrates
- Test novel flexible barrier substrates for solution based fabrication of organic solar cells
- Demonstrate laboratory scale devices fabricated by industrially relevant coating processes
- Coordination of the project

The consortium for this project includes 8 industrial partners, 6 research institutes (including Empa) as well as 3 key universities:

1. OSRAM AG, Germany
2. Canatu Oy., Finland
3. Sefar AG, Switzerland
4. Amcor Flexibles, Switzerland and Germany
5. ROWO GmbH, Germany
6. Eight19 Ltd., United Kingdom
7. Quantis Sàrl, Switzerland
8. NPL, United Kingdom
9. Amanuensis GmbH, Switzerland
10. Empa, Eidgenössische Materialprüfungs- und Forschungsanstalt, Switzerland
11. Fraunhofer Institute (4 institutes), Germany
12. CIC nanoGUNE, Spain
13. Technische Universität Dresden, Germany
14. University of Valencia, Spain
15. Aalto University, Finland

Selected Results

a) Fabric electrodes

Empa has been working closely together with Sefar AG to develop organic solar cells on fabric substrates. Electrical conductivity is conferred to the substrate by replacing a certain number of polymer fibers by conductive wires. The mesh of the fabric is filled up with a cross-linkable polymer such that a rather smooth but wavy fabric surface with protruding conductive wires is achieved (Figure 1).

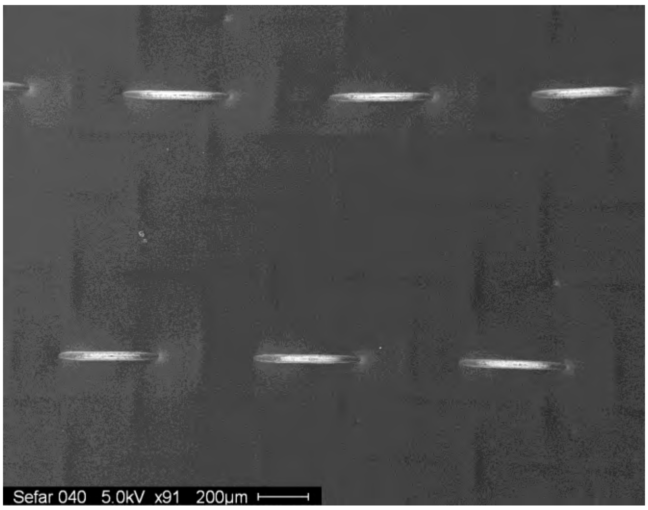

Figure 1. *SEM picture of a fabric electrode coated with PEDOT:PSS*

Polymer solar cells based on conducting poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) known as PEDOT:PSS, poly(3-hexylthiophene-2,5-diyl) P3HT and [6,6]-Phenyl C61 butyric acid methyl ester (PCBM) were deposited on fabric substrates using a standard device layer sequence: fabric substrate/PEDOT:PSS/P3HT:PCBM/Ca/Ag. The layers were all deposited by blade coating except for the metal cathode which was thermally evaporated under vacuum. The power conversion efficiency reaches over 2% for optimized solar cells.

Figure 2. *Photograph of 8 polymer solar cells where the active semiconductor was deposited by blade coating.*

Future work is directed towards increasing the active solar cell area and to assessing the fabrication yield on various fabric substrates from Sefar AG in order to determine the most suitable type of fabric substrate.

b) Nanowire electrodes

The Technische Universität Dresden (TUD) have synthesized copper nanowires without the use of hazardous hydrazine and obtained high aspect ratio wire networks comparable (Figure 3) to those based on silver. They applied a scalable spray-coating technique for deposition and investigated post preparative treatment steps to improve electrode performance. This advance is very interesting since copper is much cheaper and more abundant than silver. The nanowire electrodes were subsequently used in small molecule organic solar cells yielding an efficiency of about 3% [1].

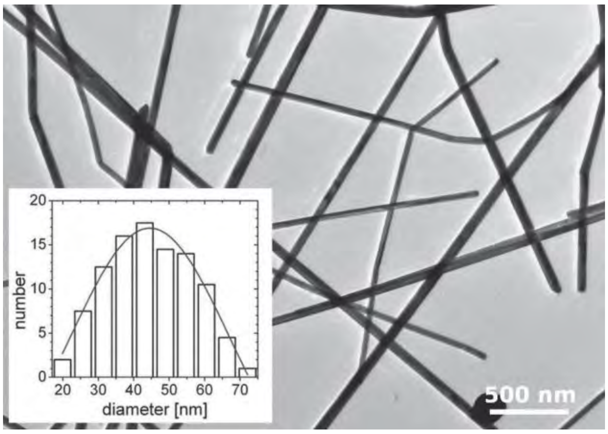

Figure 3*. Transmission electron microscopy (TEM) image of CuNWs drop-coated onto a TEM-grid with the corresponding diameter distribution as an inset*

Canatu Oy has developed a transparent conducting electrode based on carbon nanotubes with grafted fullerene moieties (NanoBud®, Figure 4). A dry printing manufacturing process of the electrodes allows for direct production of conductive electrode patterns on polymer foil substrates. Visible light transmission >90% combined with a sheet resistivity < 100 Ohm/sq make these electrodes interesting for application in organic solar cell and light-emitting devices

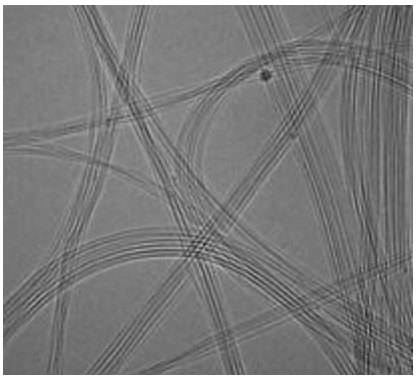

Figure 4. *TEM image of a typical NanoBud® network*

c) Sputtered silver electrodes with AZO

Fraunhofer ISE and ROWO Coating GmbH are developing electrodes based on ultrathin and transparent silver films embedded between two oxide layers (Figure 5). More recently, aluminum doped zinc oxide (AZO) was used as the top oxide layer that besides providing a protective overlayer for the silver also improves negative charge carrier collection in organic solar cells. Using this electrode in polymer solar cells together with an active semiconductor layer consisting of a bulk-heterojunction morphology made of low bandgap polymer PTBZ and PCBM, power conversion efficiencies of up to 6.1% were reached on this flexible and transparent electrode [2].

Figure 5. *Thin film silver electrode on PET substrate*

Similar AZO coated PET substrates have also been used to fabricate flexible high efficiency solar cells based on mixed halide methoylammonium lead perovskite sandwiched between organic hole and electron transporting layers, respectively [3]. Power conversion efficiencies as high as 7% were obtained together with excellent robustness with regard to repeated bending. The power conversion efficiency declined by only 0.1% after 50 bending cycles.

Appraisal 2013 and outlook 2014

The FP7 TREASORES project started at the end of 2012. Most effort so far has been focused on developing several substrates, characterizing them and providing feedback to the manufacturing industries. In the present year it will be decided which substrates shall be used for large area fabrication of optoelectronic devices, such that the end users in the project are able to adapt and optimize their processes for demonstrator fabrication.

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[3] Cristina Rold´an-Carmona, Olga Malinkiewicz, Alejandra Soriano, Guillermo M´ınguez Espallargas, Ana Garcia, Patrick Reinecke,cd Thomas Kroyer, M. Ibrahim Dar, Mohammad Khaja Nazeeruddin and Henk J. Bolink, Energ. Environmental Sci., DOI: 10.1039/c3ee43619e (2014)

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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

SUNFLOWER

Annual Report 2013

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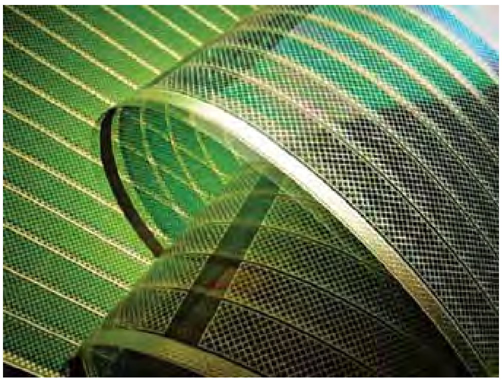
Project- / Contract Number	SUNFLOWER / FP7-287594
Duration of the Project (from – to)	01.10.2011 – 31.03.2016
Date	23.02.2014

ABSTRACT

Organic photovoltaics (OPV) represent the newest generation of solar-to-power conversion technologies. OPV provide a key opportunity for the EU to further establish its innovation base in alternative energies offering the benefits of flexibility, low weight, and freedom of design. OPV can operate under low light conditions and is shadow tolerant. These advantages and the ease of handling in subsequent product-integration processes will enable the development of consumer and portable electronics and building-integrated photovoltaic (BIPV) products.
The 17 project partners have a collective project budget of Eur 14.2 M of which 10.1 M is funded as Collaborative Project within the Seventh Framework Programme.

More information on the Sunflower project is available on http://www.sunflower-fp7.eu/.



Project goals

The Sunflower project encompasses the development of OPV technology from end to end. While working on increasing performance in terms of lifetime, efficiency, cost, and sustainability by means of R&D activities on the cell and module levels, Sunflower also addressed usage scenarios that are suited to OPV, as well as the technology's end-of-life environmental impact. With its 17 partners distributed along the value chain, Sunflower aims at major improvements in three fields: materials, processes, and tools and applications.

Project description

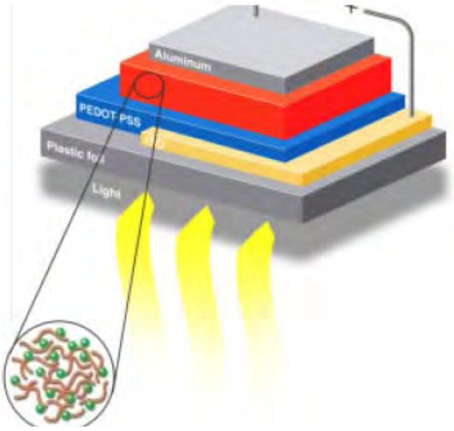
Overall, the photovoltaic industry is still a minor contributor to the global energy needs which are steadily increasing in quantity and variety. On the one hand of the spectrum, there is a post-industrial world with electricity-hungry devices, with sophisticated energy generation and transmission options (grid) available. On the other hand of the spectrum, there are billions of people with little or no access to "grid" electricity, depending on local or even portable generation. More breakthroughs are needed, notably in alternative, cost-effective and scalable photovoltaic energy production methods to address these wide ranges of needs and opportunities.

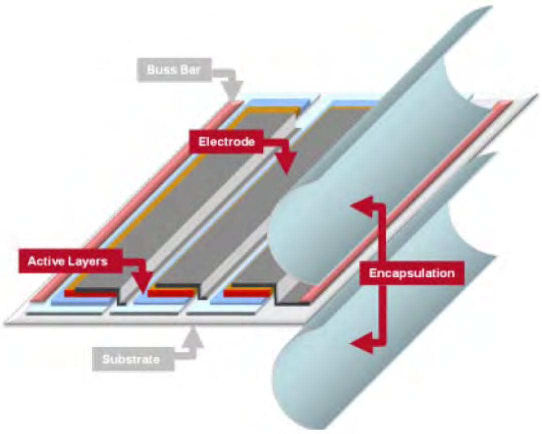
Organic Photovoltaics (OPV) represent the latest generation of technologies in solar power. In economic terms, the opportunities are new application areas e.g. the integration in facades and windows, the expansion of the innovation base in alternative energies and the development of manufacturing technologies requiring a high level of automation, highly trained personnel, low energy consumption and close proximity to suppliers and markets.

The EU is still very well positioned to drive these breakthroughs and simultaneously to benefit from them, given its competences in photovoltaics R&D, materials and manufacturing infrastructure including photo-absorbing "electronic inks", transparent printable conductors, substrates, encapsulation materials and roll-to-roll precision coating and printing equipment, and a large market for end-users.

The Sunflower consortium combines industrial, institutional and academic support to make a significant impact at European and International level, especially on materials and processes while demonstrating their market relevant implementations.

OPV technology is based on organic semiconductors, made using organic chemistry and tailored to its function. Sunflower uses polymeric semiconductors that are soluble and printable. Several layers of materials are printed on top of one another to create a functional device. Through morphological engineering, a so-called p-n heterojunction is established during the fabrication process. The power-conversion efficiency of the technology is increased by researching new semiconductors and by adding layers that absorb complementary parts of the solar spectrum (tandem cells).





Through processes which are newly developed yet based on proven manufacturing technology, OPV cells can be arranged to form modules. A combination of additive processes, such as coating and printing, and subtractive ones, such as dry-structuring, leads to fully functional modules. Compared to other technologies, the outer and inner form-factors can be tuned quite easily in order to allow for customized properties in terms of voltage, shape, and transparency. The lifetime of OPV modules is increased by using barrier and "weatherable" materials. Light guiding technologies are also used to increase efficiency.

OPV applications can differ significantly from those of traditional photovoltaic. Thanks to the advantages in terms of design and integration potential, completely new products are possible: OPV thus complements the portfolio of current photovoltaic technologies. New designs incorporating the given properties of OPV can be used as aesthetic photovoltaic solutions for building facades and integration into products we use in our daily lives. The Sunflower consortium has chosen three distinct demonstrators to highlight this opportunity.

Challenges include:

1) Increased efficiency of the panels
2) Reduction of the production costs
3) Increased lifetime of the panels
4) Evaluation and reduction of the environmental footprint (during the whole life cycle)
5) Identification of the early adopter markets

The project is structured along the following workpackages:

1. **Materials**: development of solution processable photoactive polymers, recombination layer materials (electron and hole extraction layer), flexible substrates including water vapour and oxygen diffusion barrier.
2. **Devices**: investigation of the structure, operational mechanisms and device physics of bulk heterojunction solar cells, and to transfer this knowledge into the fabrication of OPV cells, with novel architectures and including SUNFLOWER materials, able to achieve PCEs beyond the state-of-the-art.
3. **Tool development**: development of hardware an software for OPV electro-optical characterization, simulation of devices, light management structure simulation and realization; lifetime and permeation testing as well as mechanical testing
4. **Lifetime and environmental impact**: studies of the lifetime of critical materials,cells and modules ; LCA, ecotoxicity of selected materials, eco-sustainability assessment.
5. **Upscaling and demonstration**: OPV modules and proof of concept integration in devices
6. **Training and dissemination activities**: web site, publications, summer schools, public demo kit
7. **Exploitation and economic impact**: end-user relations, consortium IP , consortium partner exploitation plans
8. **Project Management**
9. **Specifications and requirements**: from end-users and accross consortium partners

Summary of key results

During the first official reporting period of the project (month 1 to 18) several results were achieved in terms of methodologies, new materials, device investigations and proof of process.

Several materials pipelines have been established in the consortium. These include photoactive materials for both low and high band-gap photo-absorbing polymers; the work in this area ranges from computer modelling to lab synthesis taking into account industrial-grade synthetic routes (Suzuki polymerization). Over 40 new polymers were synthesised and tested.

Printable formulation of zinc-oxide nanoparticles for the recombination layer were realized, tested and further optimized to enable atmospheric solution-processing of tandem cells

Silver inks for printable ITO-replacement layers as well as hole-injection layers (PEDOT-PSS) were developed ITO-free printed anodes compatible with tandem OPV cell structures were delivered to consortium partners.

Passivation and active barrier (getter) materials were heavily investigated, including UV stabilized PET, oxygen and water diffusion barriers, getter materials and composites combining several of these elements, which are now being tested by the consortium partners. This resulted in novel substrates including multilayer barrier and UV stabilized PET, providing oxygen and water vapour transmission rates lower than industrial reference material.

Functional materials were characterized in terms of processability, work functions and electrical properties. In the case of polymers, realistic candidate compounds were screened by making single BHJ devices.

The consortium partners are working in a concerted way towards up-scalable solution deposition processes, which is a very important aspect. For instance all key tandem cell processing partners are working on more realistic deposition processed such as blade coating process as opposed to spin coating to insure a faster and smoother transfer to actual prototyping processes that can be up-scaled to production.

The Sunflower consortium demonstrated OPV tandem cells by solution processing at different partners with comparable results, which will enable at later stages parallel experiments and more efficient cell and module development. An effective optimization tool has been developed allowing a fast assessment of the potential of a polymer for tandem cell application and over 40 photoactive polymers were tested. Tandem OPV laboratory cells with efficiencies above 5%, with potential for over 7% were realized. Solution processed (coated) tandem modules including (rigid) encapsulation were realized (CSEM).

The project effort was devoted to build and reassess tools necessary for the execution of the project. These include permeation, mechanical bending and cyclic tests, accelerated life-cycle methodologies to screen long-lived packaging of OPV modules. In terms of reliability, OPV modules were tested for over a million bending cycles in ambient conditions showing no performance degradation effects for instance.

Simulation tools for the design of the optical stacks and improve light in-coupling lead to first results, including proof of concept for light management structuring leading to > 15% relative increase in cell efficiency.

Electrical characterization of OPV materials and devices using impedance spectroscopy and CELIV made progress. One of these tools (PAIOS platform) is already an example of result exploitation as is commercially available.

The consortium established methodologies to assess the environmental, life cycle and eco-efficiency of OPV, taking as starting point the know parameters of the technology and available materials. The results are already being disseminated. The environmental indicators showed the highest impact for ITO and silver electrode. The SUNFLOWER project target to replace ITO should contribute to the reduction of these environmental impacts.

An eco-efficiency assessment show that the already existing single BHJ semi-transparent modules could be a viable option for the building integrated photovoltaic (BIPV) applications.

From an experimental point of view, the results of the first eco-toxicology experiments performed with the potentially environmentally relevant single components of OPVs including indicate that effects are observed only at environmentally irrelevant concentrations. The eco-toxicology of OPV is very important in case of large scale deployment, however is not well studied and these are some of the first results we are aware of in this field.

As coordinating partner, CSEM established an external advisory board to provide additional feedback and an independent perspective to support the consortium. The board can also provide input for dissemination and exploitation of the results.

National and international cooperation

The SUNFLOWER project (Grant number 287594) is supported by the European Commission through the 7th Framework Program on Research and Technological Development under the Information and Communication Technologies (ICT) thematic call: FP7-ICT-2011-7

The project consortium combines industrial, institutional and academic support to make a significant impact at a European and International level, especially on materials and processes while demonstrating their market relevant implementations. The industrial project partners are all well positioned along the supply chain of future OPV-based products: an important prerequisite for the creation of a significant socio-economic impact.

Current consortium partners

CSEM SA	Switzerland	*
DUPONT TEIJIN FILMS UK LTD	United Kingdom	
AMCOR FLEXIBLES KREUZLINGEN AG	Switzerland	*
AGFA-GEVAERT N.V.	Belgium	
FLUXIM AG	Switzerland	*
SAES GETTERS S.P.A.	Italy	
CONSIGLIO NAZIONALE DELLE RICERCHE	Italy	
FACHHOCHSCHULE NORDWESTSCHWEIZ	Switzerland	*
CHALMERS TEKNISKA HOEGSKOLA AB	Sweden	
FRAUNHOFER-GESELLSCHAFT	Germany	
LINKOPINGS UNIVERSITET	Sweden	
UNIVERSITAT JAUME I DE CASTELLON	Spain	
GENES'INK	France	
CENTRE NATIONAL DE LA RECHERCHE SCI.	France	
UNIVERSITEIT ANTWERPEN UA	Belgium	
BELECTRIC OPV GMBH	Germany	
MERCK CHEMICALS LTD	United Kingdom	(* Swiss partners)

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DEVELOPMENT OF LUMINESCENT SOLAR CONCENTRATORS

MOLECULAR ALIGNMENT CHIPS

Annual Report 2013

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Date	06.12.2013

ABSTRACT

The project aims to develop methods for the synthesis of arrays of silica nanochannels with disc-shaped morphology and tunable pore size. These so-called Molecular Alignment Chips (MACs) are promising host materials for the supramolecular organization of guests. The project investigates several applications of MACs with a focus on light-harvesting systems such as luminescent solar concentrators (LSCs). The fundamental project objectives concern the synthesis of MACs with well-defined particle morphology and tunable nanochannel diameter. Host materials of this kind provide a platform for the alignment of any desired guest species. In the field of LSCs, this ultimately opens possibilities for increasing the trapping efficiency and for reducing self-absorption losses.

Introduction / Project Goals

The project builds on our recent work on the synthesis and functionalization of mesoporous silica [1]. Representing the mesoporous counterpart of zeolites with one-dimensional channel systems, arrays of silica nanochannels (ASNCs) are of particular interest [2]. The fundamental project objectives concern the synthesis of disc-shaped ASNCs, so called Molecular Alignment Chips (MACs), and the fine tuning of the pore size of these materials. In a later stage of the project, the alignment of dyes in MACs will be studied.

Artificial light-harvesting systems constitute an essential part of solar energy research. A potential application of dye-loaded MACs is found in the field of luminescent solar concentrators (LSCs). A classical LSC consists of a transparent plate (plastic or glass) containing luminescent centers. Light enters the face of the plate and is partially absorbed and reemitted by these centers. A fraction of the luminescent light is trapped by total internal reflection and guided to the edges of the plate where it can be converted to electricity by a solar cell. As the edge area of the plate is much smaller than the face area, the LSC operates as a concentrator of light [3]. Despite the fact that this concept has been studied since the 1970's, no commercial application of LSCs in solar energy conversion devices has been developed. Dyes suitable for the application in LSCs feature an overlap between their absorption and fluorescence spectra, causing self-absorption and a decrease in optical efficiency [4]. Self-absorption has been recognized as the main problem in LSCs and research activities towards solving this problem have increased [3].

Recent work has shown that the trapping efficiency of LSCs can be increased by vertical alignment of the dyes, as this leads to preferential emission into waveguide modes [5]. Nanoporous hosts with one-dimensional channel systems are ideal for this purpose. Extending the high level of organization provided by a single nanoporous particle to the macroscopic scale requires particles with regular morphology and defined channel orientation.

General Concepts

The idea of using MACs to align dye molecules in LSCs is based on the ZeoFRET® concept [6]. ZeoFRET® materials are host-guest systems that exploit the alignment of dye molecules in the one-dimensional channels of zeolite L. Donor dyes absorb the incoming light and transfer the electronic excitation energy via FRET (Förster Resonance Energy Transfer) to acceptor dyes. A large donor/acceptor ratio reduces the self-absorption losses in the LSCs, because the emission of the acceptor dyes cannot be absorbed by the donor dyes (Figure 1). Zeolite L is used as a host material to fabricate ZeoFRET®. As the pore diameter of zeolite L is set at 0.71 nm, the choice of guest molecules is limited. MACs can extend the range of implementable dye molecules by providing means to adapt the pore diameter to the dimensions of the guest.

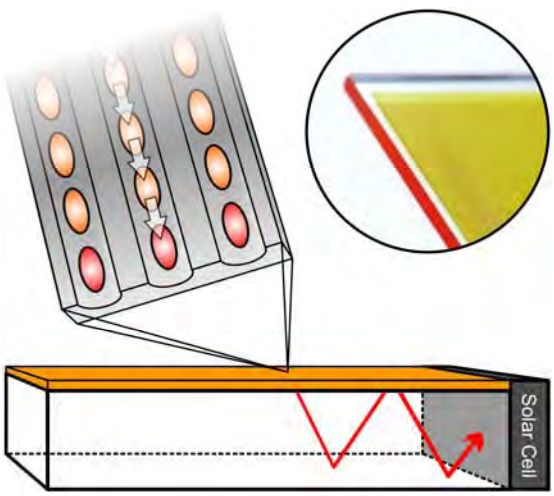

Figure 1. Luminescent solar concentrator based on a host-guest material as the active component in a thin polymer film on a waveguide. Dye molecules are aligned in the nanochannels of the host and harvest light by a FRET mechanism. Self-absorption of the emitted light is reduced by a well-selected combination of donor and acceptor dyes.

Results

A narrow pore size distribution (PSD) is an important prerequisite for the alignment of dye molecules in nanochannels. An extremely narrow PSD can be obtained with MCM-41 type materials [7], but the morphology of the particles is irregular (Figure 2). Contrary to classical MCM-41 type materials, ASNCs feature a hexagonal morphology with a defined direction of the nanochannels along the long axis of the particles. ASNCs with a narrow PSD can be obtained (Figure 2) [2], but tuning the pore size of ASNCs by adjusting the synthesis parameters (temperature, concentration of reactants, duration) has been unsuccessful. We have therefore started to develop procedures based on the postsynthetic deposition of silica layers that yield mesoporous silica with smaller pore sizes. Figure 2 (left) shows an example of a stepwise pore size reduction of a MCM-41 type material by a liquid phase deposition technique. We have also built a fully automated CVD setup that allows for a well-controlled solventless deposition of silica layers.

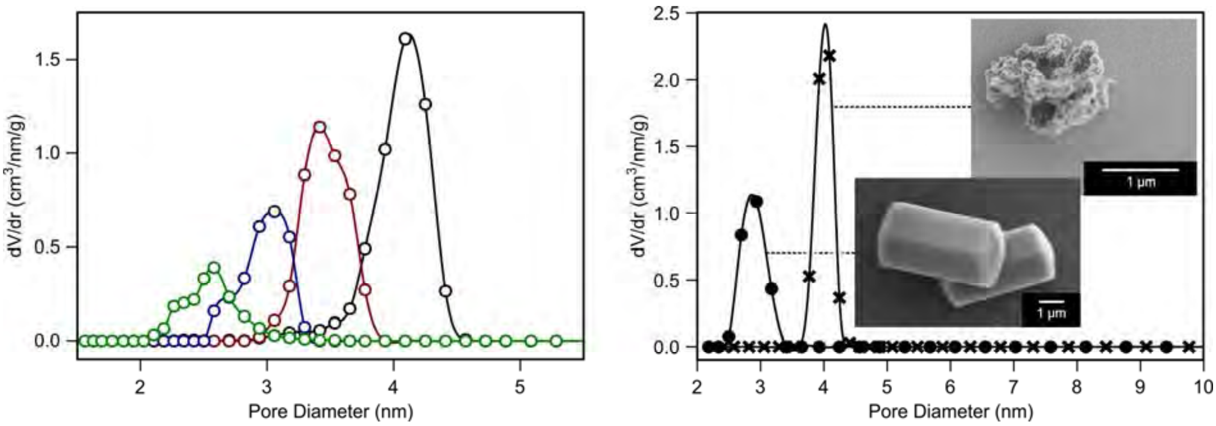

Figure 2. Left: Stepwise pore size reduction of a MCM-41 type material by liquid phase deposition of silica layers. Right: Pore size distributions and scanning electron microscopy images of mesoporous silica MCM-41 (crosses) and ASNCs (dots).

Particle morphology is a key topic in the development of MACs. The aspect ratio (length/diameter) of ASNCs is larger than one (Figure 3, left). Our goal is to significantly reduce the aspect ratio, thereby enabling orientation of the channels perpendicular to a surface by means of simple monolayer deposition techniques. We have recently started to study the influence of temperature, reactant concentration, co-solvents, and co-surfactants on the aspect ratio of ASNCs. First results are promising and show a substantial decrease of the aspect ratio (Figure 3, right).

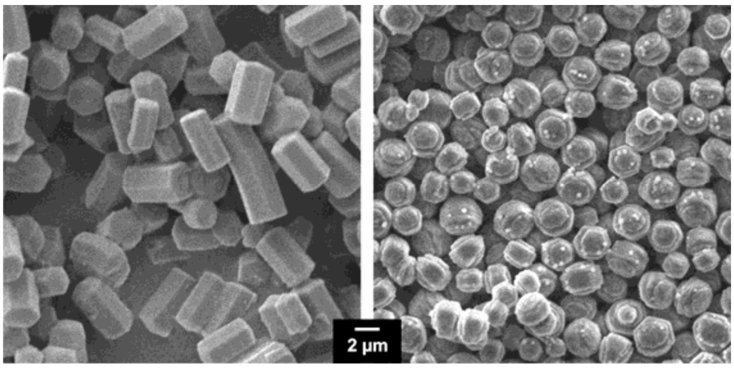

Figure 3. Scanning electron microscopy images of conventional ASNCs (left) and ASNCs with reduced aspect ratio (right). A single particle consists of approximately 200’000 nanochannels.

The alignment of dye molecules in the nanochannels requires full accessibility of the pores. Confocal laser scanning microscopy is employed to check for potential pore blocking effects. The coupling of the host-guest composites to waveguides is accomplished by adding the composites to a poly(methyl methacrylate) solution and subsequent casting onto the waveguide.

Assessment 2013 and Outlook 2014

The first phase of the project has primarily focused on the synthesis of the host materials. Methods were developed that allow a stepwise postsynthetic reduction of the pore size. In addition to liquid and gas phase deposition techniques, pore size tuning by pseudomorphic transformation will be investigated in 2014. Adjusting the aspect ratio of ASNCs has proven to be difficult, particularly regarding the generation of flat particle surfaces. First results show, however, that the aspect ratio can be reduced substantially by the addition of co-surfactants. This result is particularly significant regarding the vertical alignment of dyes (and thus of the electronic transition dipole moments) in luminescent solar concentrators.

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OPTIMIZED METHODS FOR INCREASED PERFORMANCE PHOTOVOLTAIC CELLS BY NANOPARTICLES INTEGRATION (OPTINOGEN)

Annual Report 2013

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ABSTRACT

The project targets the optimization and the development of new improved methods for enhancing of the overall performance and stability of nanocomposite solar cells (NSC) by introducing new physical principles such as e.g. plasmonic and quantum phenomena into functionality of NSCs with metal nanoparticles (NP), and new strategies of stabilization of the active nanocomposite layer morphology. Researches are focus mainly on the method of NP implementation, on different types of NP to be used and on the material investigation.

Firstly, a consistent state-of-the-art in the field of NP integration into the photovoltaic cells was performed. This research covers many aspects of the nanoparticle based photovoltaic cells starting from simulation of the idealized systems through nanoparticle synthesis routs to the implementation into the real system. The main attention was focused on the thin film organic photovoltaic (OPV) based on the organic semiconductors (e.g. poly(hexylthiophene), PCBM(6,6-phenyl-C61butyric acid methyl ester).

Possible ways of integration of the NP in the OPV (thin film organic photovoltaic) architecture were identified and divided into two groups with regards to the routes of NP synthesis and to their further manipulation.

In the second step, research was focused mainly on two aspects: NP synthesis and NP distribution in the active layers of OPV. Several batches of silver NP were obtained with size distribution 80 -120 nm with spherical and cubic shapes and further transferred to the final solution of active material.

Simultaneously to the NP synthesis, there were obtained continuous thin layers of titanium oxide follow the titanium oxide sol-gel precursor synthesis. Active materials containing Ag NP were prepared in form of continuous films and the nanoparticles distribution was further investigated.

For all investigated systems, best performance showed the cell with Ag NP disposed in photoactive layer with titanium oxide buffer layer. Synergetic effect of both Ag NP and TiOx layer gives efficiency as high as 4.65 %.

Project objectives

The energy demand increases due to the incessantly raising world population and improving standards of living. The need to develop and deploy large-scale, cost-effective, renewable energy is becoming important. The storage and conversion of sunlight into electricity during times of day with little sunshine is still a sticking point when it comes to optimizing solar cell function and appeal.

The nanocomposite solar cells (NSC) based on the organic-organic and the hybrid organic-inorganic nanocomposites represent a class of photovoltaic (PV) devices which promise breakthrough advances towards a large scale exploitation of renewable energy sources. Low weight, good mechanical properties enabling integration with various surfaces, and the possibility of large-scale manufacturing by the low-cost screen-printing and related technologies are the key advantages of NSCs, which fulfil the forward-looking demands for launching new low-energy-consumption, environmentally-friendly technologies and products that enhance spreading the sustainable energy conversion processes at a low ratio cost per watt generated. However, the highest PV conversion efficiency of polymer NSCs achieved so far is ca. 5 %, or ca. 7 % if they are used in the tandem arrangement; this value should be increased to above 10 % for NSCs can enter the real market as truly competitive large-scale products. Also the stability of NSCs should be improved.

The increase in the PV conversion efficiency of organic (OSC) and dye sensitized solar cells (DSSC, dubbed 'Graetzel cells') has stopped at values 5.4% for OSC (Plextronics [1]) and 11.1% for DSSC (Sharp [2]). The observed low PV conversion efficiency of real solar cells should be ascribed to drawbacks associated with the preceding (photoexcitation) and consecutive (transport and collecting charges) partial processes of the overall PV energy conversion.

A degradation of NSC components is mostly prevented by encapsulation that, however, does not prevent morphology changes at elevated temperature. Figure of merit for the economic effectiveness is the power efficiency of 10% with lifetime of 10 years and the highest power conversion efficiency achieved is about 7%. Several improvements of the NSCs overall power efficiency are foreseen based on the already established principles: synthesis of a low band gap polymer ([3]), fabrication of series tandem cell, using optical spacer. The Grätzel cells type DSSCs used with TiO2 or ZnO n-type semiconductor reach power efficiency about 12%. The liquid electrolyte used in this type of cells can be replaced by a solid-state electrolyte or directly by a semi conductive polymer. To increase the efficiency, the length, spacing and aspect ratio of the inorganic semiconductor nanostructure should be improved.

The project targets the optimization and the development of new improved methods for enhancing of the overall performance and stability of NSCs by introducing new physical principles such as e.g. plasmonic and quantum phenomena into functionality of NSCs with metal nanoparticles, and new strategies of stabilization of the active nanocomposite layer morphology. In the frame of the project, simulations and calculations will be conducted and confirmed by relevant experimental research in laboratory environment. Thus, the overall conversion efficiency will be improved and the reliability increased.

Due to the unique optical, electronic and magnetic properties noble metal (such as Ag and Au) nanoparticles (NP) were proposed to improve performance. Some authors ([4]) reported on the incorporation of very thin Ag and Au layers into the series tandem PV structure. Apparently, such layers provide efficient recombination centers for charge carriers to make the tandem structure functional but, additionally, they may cause an optical field enhancement.

Unfortunately, a combination of several effects does not correspond to the best figure of advantages for each system; somehow the system needs compromise to achieve the best performance. Therefore, an introduction of new physical principles is necessary to overcome present limits. High performances can be reasonably achieved only by use of optimized methods; thus one of the goals of this project is the optimization and the development of new improved methods for enhancing the overall performance and stability of NSCs by implementation of standard flow charts of the whole process of nanoparticles integration into the photovoltaic cell manufacturing, validated by tests.

Thus, the purpose of the project is to carry out further researches in the field leading to enhance the properties of photovoltaic cells based on nanoparticles and to overcome some of the challenges still unsolved. Researches will focus mainly on the method of nanoparticles implementation, on different types of nanoparticles to be used, on the material investigation.

The main deliverables of the project are:

1. Summary of current methods used for nanoparticles integration in photovoltaic cells,
2. Flow chart of the whole process for different types of nanoparticles integration,
3. Report on optimization of the current methods and of different components of the PV cells,
4. Report on validation of the new proposals for optimization,
5. Nanoparticles integration steps and procedure using new optimized methods,
6. Nanoparticles integration performance and definition of the tests,
7. Final report on results of the tests and identification of potential improvements of the nanoparticles integration.

Work performed and results

The Project was divided into four main parts. The first three are summarized as they were already performed in 2012 and presented in the Annual Photovoltaic Report 2012. Only the last part is detailed.

1. Investigation of current methods used for enhancing the overall performance and stability of different types of NSCs by nanoparticles integration.

Based on the literature search of current methods used for enhancing the overall performance and stability of different types of NSCs by nanoparticles integration a complete state-of-the-art was performed that allows to define the next step for further investigation.

One of the most important aspects of this work was finding of existing incoherentness in the scientific communications, especially when size, shape and the material of the nanoparticles are reported for implementation in deferent organic donor-acceptor systems (e.g. P3HT/PCBM). Based on this research it can be summarized that some of the identified problems need deeper understanding and further investigation: influence of the nanoparticle size on the charge carrier transport in the solar cell, experimental works dedicated mostly to the spherical nanoparticles of different size - different shapes (especially cubic ones) are considered only in simulation works, etc [5].

2. Investigation of current methods used for enhancing the overall performance and stability of different types of NSCs by nanoparticles integration.

The model system for further investigation was proposed based on the most common architecture for OPV. Architecture and the available methods of layers deposition give a wide range of possibilities of NP integration in the OPV.

A sketch of a fabrication process for organic photovoltaic with noble metal NP has been proposed and summarized. The possible routes of implementation of the PN were gathered and presented on the flow chart for the visualisation of the solar cell preparation and integration of different types of nanoparticles. The flow chart provides many possible routes of OPV preparation with use of variety of available substrates, concerning both the bottom-up or top-down NP synthesis routes and deciding on the place of NP integration during the production. Apart from NP integration, other known methods of OPV efficiency enhancing are included into this chart e.g. solvent and temperature annealing steps.

Three main possible places of NP integration for enhancing the overall performance and stability of the cell were identified: anode site, bulk of the active layer and cathode site.

3. Validation of optimized methods by nanoparticles integration into the photovoltaic cell.

Concerning this assumption there were proposed two deferent routes of noble metal NP synthesis:

a. Firstly, the synthesis of un-functionalized silver NP was performed. There are water soluble that allow their mixture with the PEDOT:PSS layer as well as with the TiOx layer. This gives an opportunity to the model PV system with NP placed at the beginning (anode), as well as on the end (cathode) of light path in the device. The NP can be immobilized in the adequate layer in one preparation step or settled in a separate step on the layer interphase e.g. at the interphase of TCO/PEDOT:PSS, PEDOT:PSS/semiconductor layer or semiconductor layer/TiOx.

The chosen synthesis for the silver nanoparticle is a seed mediated grown one and it follows the work of Zhang et all [1]. This synthesis allows controlling the size on Ag NP from 5 nm (for the seeds) up to 200 nm. The main advantage is that the size on NP is controlled mainly by the time of the reaction. Furthermore it is relatively easy to up-scale reaction that is important for up-scaling the overall cell production. On the other hand it allows synthesizing both spherical and cubic NP. That opens the perspectives for better understanding and possible comparison with simulation works on the absorption enhancement in thin-film organic solar cells [2].

b. Second step is the synthesis of the functionalized NP soluble in organic solvents for integration into donor-acceptor layer. The main concept of this part of work was to prepare a systematic study of the NP size effect on the organic solar cell performance for better understanding of the influence of plasmonic effects and the light diffraction effects on the overall cell performance and how the synergism of these two effects can be used in the proposed model system. This allows understanding the real influence of the size of nanoparticles especially when implemented into the donor-acceptor layer.

Thus, to summarize, in this part silver nanoparticles (Ag NP) were synthesized using two different synthesis routes by use of silver trifluoroacetate (CF3COOAg) and silver nitrate (AgNO3) as NP pre-cursors. Both of these syntheses allowed obtaining spherical Ag NP with 80 to 120 nm in diameter; moreover synthesis using AgNO3 under nitrogen atmosphere gave cubic shaped NP. The average NP size and shape were investigated by use of dynamic light scattering (DLS), transmission electron mi-croscopy (TEM) and atomic force microscopy (AFM), see Fig.1.

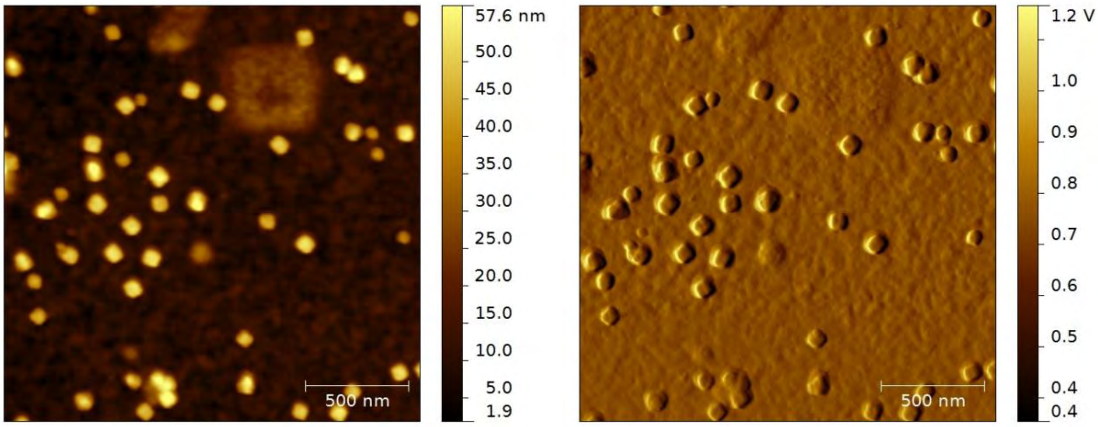

Fig. 1. AFM height (left) and amplitude contrast (right) image of spin-coated layer of AgNP in TiOx.

4. Manufacturing and tests of the photovoltaic cells.

During the last part of the project, in 2013, photovoltaic cells were prepared on two types of ITO coat-ed substrates: patterned and unpatented ones. In the first case, cells were illuminated through a shadow mask with 2 cm^2 of active area for the patterned substrate.

The general architecture of the prepared cells was as follows:

1. ITO coated glass (transparent electrode)
2. PEDOT:PSS hole transporting layer (HTL)
3. P3HT-PCBM blend –photoactive layer (PL)
4. TIOx electron transporting layer (ETL)
5. 5.metal electrode

Based on this scheme, 3 groups of cells were prepared:

a. Reference cell: glass/ITO / HTL / PL / metal electrode (Al)
b. Cell with TiOx layer: glass/ITO / HTL / PL / TiOx / metal electrode (Al)
c. Cells with AgNP depending of the place of their implementation:
   glass/ITO / HTL+AgNP / PL / TiOx / metal electrode (Al)
   glass/ITO / HTL / PL+AgNP / TiOx / metal electrode (Al)
   glass/ITO / HTL / PL / TiOx+AgNP / metal electrode (Al)

All processable materials solutions were deposited using a spin coater, in the inert gas (nitrogen) atmosphere, inside the glove box. The only moment of direct exposure to ambient atmosphere was after TiOx deposition. Cells were kept in air allowing the deposited sol-gel TiOx layer to hydrolyse and form continuous layer. Afterwards, metal electrode was deposited through a shadow mask by thermal evaporation. All prepared devices were first measured using source meter unit controlled by LabView based program. All the measurements were done with the Lot Oriel solar light simulator equipped with the air mass filter AM 1.5 at 1000 W/m^2 radiation power. Each measurement serie was started by light source calibration with certified reference silicon cell.

In this final step, firstly, the influence of TiOx layer on the overall cell efficiency was investigated. The results showed high increase of cell performance.

The reference cell exhibit efficiency of 3%, short circuit current density Jsc = 10.2 mA/cm^2 and open circuit voltage Voc =0.533 V and fill factor FF = 0.566, while cell prepared with TiOx layer shows 3.9% efficiency at Jsc = 10.8 mA/cm^2 , Voc = 0.534 V and FF = 0.667.

This result is directly correlated with increased FF of the cell with TiOx layer, which suggests better charge carrier separation at the electrodes. TiOx layer serves as electron selective buffer layer witch exhibit efficient electron extraction capability.

Addition of Ag NP to the TiOx layer results in efficiency decrease that is inversely proportional to the Ag NP concentration in TiOx layer. One of the possible reasons is the charge carrier trapping at the Ag NP/TiOx layer, thus decreasing electron transport through the buffer layer.

For all investigated systems, best performance showed the cell with AgNP disposed in photoactive layer with titanium oxide buffer layer. Synergetic effect of both AgNP and TiOx layer gives efficiency as high as 4.65 %.

The main results are presented here below allowing fast comparisons of best results obtained for measured photovoltaic devices:

REFERENCE	Jsc = 10.2 mA/cm2 | Voc =0.533 V | FF = 0.566 | efficiency = 3.07%
TiOx	Jsc = 11.8 mA/cm2 | Voc =0.534 V | FF = 0.667 | efficiency = 3.93%
TiOx+Ag NP_1	Jsc = 11.2 mA/cm2 | Voc =0.583 V | FF = 0.583 | efficiency = 3.80%
TiOx+Ag NP_2	Jsc = 10.2 mA/cm2 | Voc =0.603 V | FF = 0.601 | efficiency = 3.70%
TiOx+Ag NP_3	Jsc = 10.4 mA/cm2 | Voc =0.599 V | FF = 0.507 | efficiency = 3.19%
TiOx+Ag NP_4	Jsc = 9.1 mA/cm2 | Voc =0.593 V | FF = 0.531 | efficiency = 2.87%
TiOx/HTL+Ag NP	Jsc = 11.1 mA/cm2 | Voc =0.610 V | FF = 0.404 | efficiency = 2.73%
TiOx/PL+Ag NP	Jsc = 17.1 mA/cm2 | Voc =0.625 V | FF = 0.436 | efficiency = 4.65%

Wettability of the P3HT/PCBM surface with TiOx precursor must be carefully controlled. The AFM investigation of the deposited layers proofs the dewetting process on the PL surface when TiOx was deposited without any P3HT/PCBM layer post-treatment. This effect was successfully eliminated by PL layer conditioning under low vacuum (inside the glove box antechamber). This procedure allowed getting rid of most of the remaining solvent from the surface without thermal treatment of the cell.

Cooperation at the national and international level

The continuous progress of the project is ensured thanks to the cooperation (on the national level) with Adolphe Merkle Institut (AMI), University of Fribourg – where all the chemical synthesis are performed under supervision of Prof. Alke Fink who is one of the leaders of the “Bionanotechnology group” at the AMI.

Final cell design, preparation and characterization are performed together with Prof. Marc Jobin and his group at the "Institut des Sciences et Technologies Industrielles" at "Haute école du paysage, d'ingénierie et d'architecture (HEPIA)" in Geneva.

On the international level, there exist continuous collaboration between EIA-FR and Lodz University of Technology (Lodz, Poland) that is the Home institution of Dr. Michal Wiatrowski.

Assessment for 2013

In summary, the cubic shape Ag NP was synthesized and arranged in active layers of organic photovoltaic solar cells based on poly(thiophene) and fullerene derivative organic semiconductors.

Titanium oxide precursor was synthesized by sol-gel method and used in cell architecture as whole blocking-electron conducting layer. Synergetic effect of both Ag NP and TiOx layer gives efficiency of 4.65 %.

During the last project duration the following deliverables have been fulfilled:

1. Validation of the new proposals for optimization
2. Nanoparticles integration steps and procedure using new optimized methods
3. Nanoparticles integration performance and definition of the tests
4. Results of the tests and identification of potential improvements of the nanoparticles integration

The chosen system brings high performance increase. However, it still needs further investigation that will be continued by the evolved institutions. This investigation will cover mainly charge transport and trapping phenomena in organic photovoltaic cells with noble metals nanoparticles.

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Module und Gebäudeintegration

UNIQUE AND INNOVATIVE SOLUTION OF THIN SILICON FILMS MODULES BUILDING INTEGRATION

ARCHINSOLAR

Annual Report 2013

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Duration of the Project (from – to)	From 01.04.2010 to 31.03.2013
Date	7th of November 2013

ABSTRACT

The ArchinSolar project aimed at designing new low-cost PV products for building integration in urban environment with a higher level of acceptance thanks to colors and shapes matching the traditional roofing materials, while maintaining low costs. In order to achieve this goal, a highly multidisciplinary approach had to be used, combining the competences of architects, specialists of buildings physics, professionals of the PV engineering and design, material sciences engineers and thin-films physicists. Over three years, the five academic partners from EPFL, ETH and EMPA went together through a complete product development cycle from lab research to pre-industrialization, finally delivering three innovative products to the market.

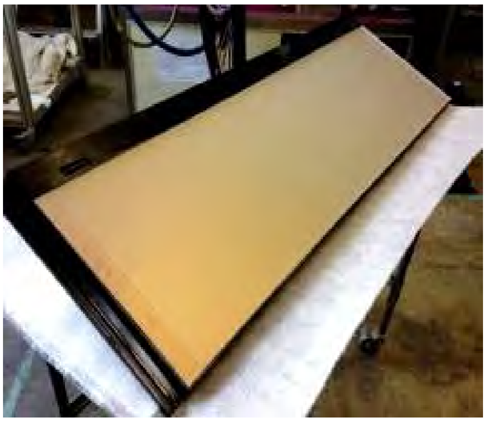
1. Which product for which market?

The first task addressed by the ETHZ and EPFL partners including architects and engineers was to define the characteristics of the perfect PV product for aesthetical building integration. Thanks to a market survey performed by the Solar Energy and Building Physics Laboratory (LESO-PB, EPFL) in collaboration with the Photovoltaics and thin-film electronics laboratory (PVLAB, EPFL), it was soon detected that a single product would not be able to match the different demands of the market, due to the high discrepancies of expectations in terms of shape, color, weight, price and efficiency. Therefore, in order to maximize the chances of market penetration, three different specialized products were designed and produced, all based on the thin-film silicon technology which brings already more freedom in terms of final products shape and colors as compared to standard c-Si technologies, while keeping decent efficiencies and of course low production prices. A state of the art description of the Building Integrated Photovoltaics (BIPV) market and challenges was also published[1].

A) Full-size glass/glass terra-cotta PV modules for standard low-cost on/in-roof integration

- Perfect terra-cotta color with high angular stability and homogeneity
- Based on a standard technology allowing low manufacturing costs
- Standard on/in-roof integration
- Perfect for large size installations
- The developed product is now commercialized by the Swiss company ÜserHuus[2]

B) Multifunctional colored PV tile with composite material backing for aesthetic building integration

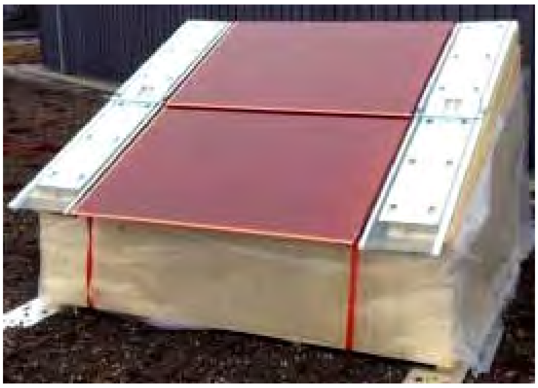


- More appealing aspect ratio matching architects demands
- Design matching standard tiles allowing both partial and complete roof coverage
- Tunable color thanks to high-end interferential filters
- Multifunctional composite backstructure providing structural rigidity, quick mounting, roof water-tightness and lightweight product

[1] P. Heinstein, C. Ballif, L.-E. Perret-Aebi "Building integrated photovoltaics (BIPV): Review, potentials, barriers and myths" *Green*, 3, 2, (2013).

[2] www.userhuus.ch

C) Pre-fabricated building elements using combined solar-thermal (PVT) collector



- Hybrid collector able to provide low temperature heat for heat pumps and thermal regeneration of geothermal probes
- Pre-fabricated element enabling easy and rapid mounting of very large structures
- Already industrialized by the Swiss company 2Sol[3] in collaboration with the Meyer-Burger group

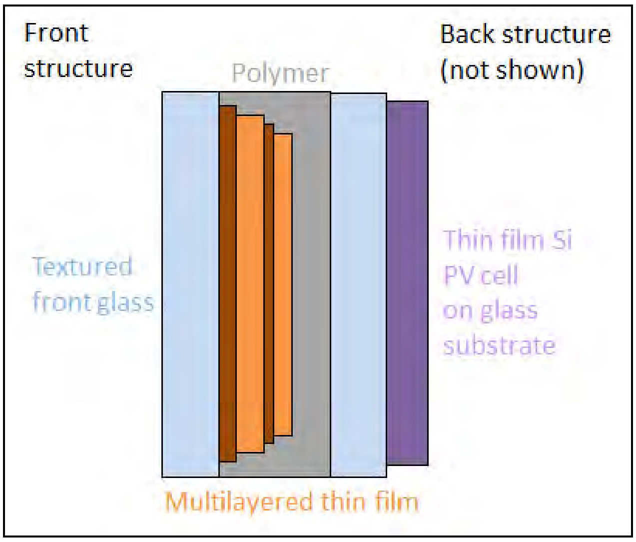
2. Changing the PV module color

The first and the most important element pointed out by the market survey was the need to change the PV module color from the blue-purple tones of standard technologies toward a more terra-cotta like color matching the traditional roofing materials. If this could be achieved, a large part of the market actors would agree to lose up to 10% of power production and even accept to suffer a slight cost increase.

Taking advantage of the knowledge in materials for PV encapsulation of the PV-Lab engineers and in functional thin-films of the LESO-PB physicists, two different approaches were explored to tune the PV modules appearance.

2.1 Adding an interferential filter above the active layers

The advantage of this technique, depicted in figure 1, is that the active device structure is left untouched, benefiting thus from the very high reliability of the PV packaging in terms of active layers protection. However, the challenge to be addressed is the need to reduce as much as possible the reflection losses induced by the color generation.



- **Figure 1 : Schematic representation of the colored Archinsolar PV module by mean of multilayered interference filters**

A very promising first generation of interferential filters based on TiO_2/SiO_2 stacks deposited by magnetron sputtering were developed by the LESO-PB and tested by the PV-Lab at the device scale. Unfortunately, the angular stability of the obtained color was not high enough, as shown on figure 2.

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[3] www.2sol.ch

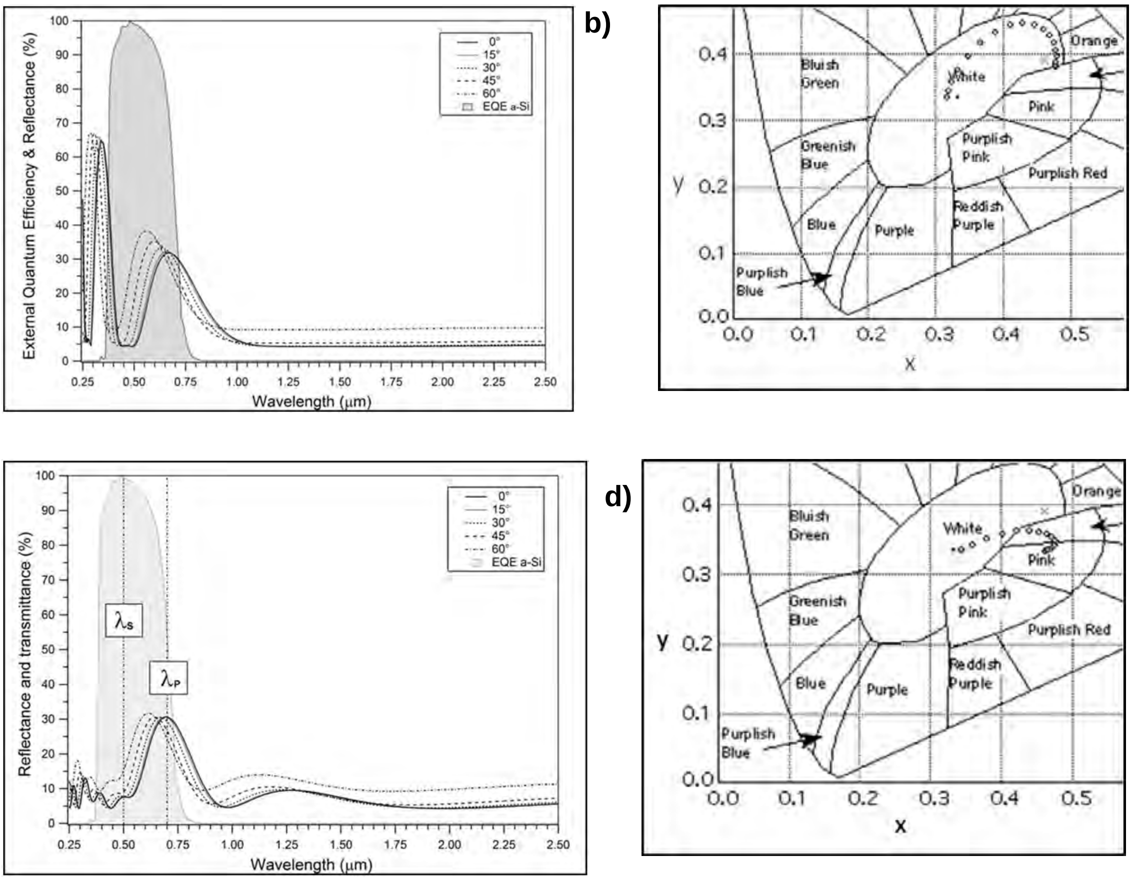
Moreover, the presence of a second reflection peak in the blue light lead to unwanted power loss by light reflection with no color gain in the orange tones.

- **Figure 2 : First generation interference filters produced by magnetron sputtering technique laminated with amorphous PV module. The color rendering changes as a function of the incidence angle**

Shifting from the initial "two-peaks" architecture (one reflection peak in the blue and one in the orange) to a "peak and shoulder" architecture (see fig.3) and changing from TiO_2/SiO_2 to Ta_2O_5/SiO_2 lead to the production of second generation filters with a much higher color stability and improved performances at the device level with less than 10% of power loss when applied on a-Si PV modules. This result leads to a PCT application[4].

a)

c



- **Figure 3 : a) First generation filters wit a 2-peaks architecture (left image) leading to poor color stability (right image). The grey area shows PV device quantum efficiency. b) Second generation Ta2O5/SiO2 filters with "shoulder-peak" architecture (left) and improved color stability (right).**

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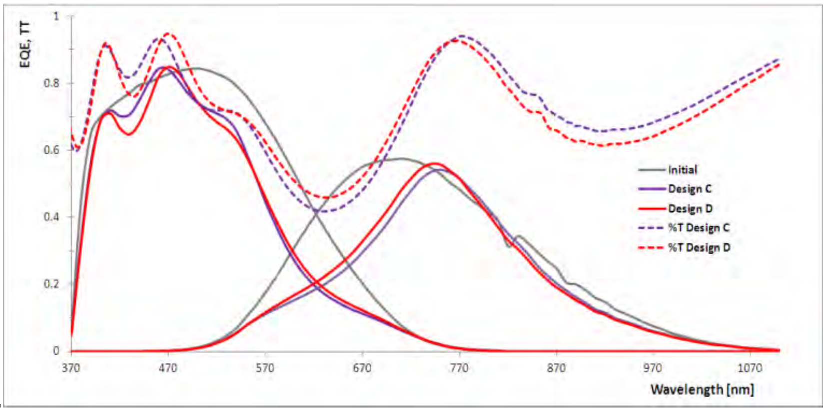
[4] n°PCT/IB2012/054998 : "*Interference filter with angular independent orange color of reflection and high solar transmittance, suitable for roof-integration of solar energy systems*"

The only disadvantage of the second generation of interferential filters was to lead to high power loss when applied to the micromorph technology, due to the uneven current loss in the top and bottom cells. Therefore, a last adjustment of the peak position was performed to produce a third generation minimizing the power loss when applied to the micromorph technology. In those filters, the main reflection peak is shifted towards the EQE overlap of the two cells involved in the micromorph technology (see fig.4). The resulting color is a little bit shifted towards reddish tones, but the power loss could be reduced by a factor 2 from 40 to 20%.

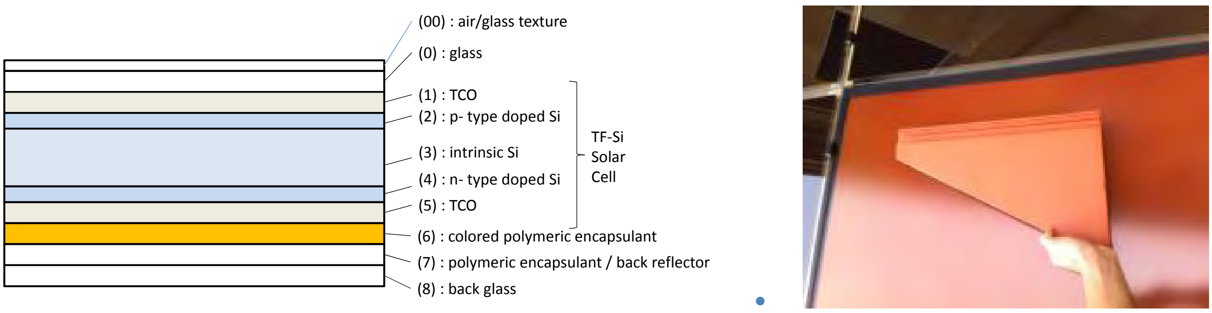


- **Figure 4 : total transmission spectrum (dashed lines) of generation 3 filters and correlation to the external quantum efficiency (solid lines) of the micromorph cells**

The fabrication process was successfully transferred from a magnetron sputtering to a sol-gel dip-coating equipment, enabling large scale production of the filters at low cost. Finally, a special chemical etching has been developed by the LESO-PB and applied to the opposite side of the filter in order to further homogenize the color rendering and suppress unwanted specular reflections. The company SwissInso already commercializes these products.

2.2 changing the module backside: colored encapsulation

Another way to tune the module color is to play on its encapsulation and on the active layers thickness. By reducing the absorber layer thickness, it was possible to produce semi-transparent devices which color could be tuned by laminating colored polymers behind the active layers, as shown on fig.5a. Using at the back of the semi-transparent device a multilayer structure made of white and colored PVB encapsulants, the PV-Lab could produce industrial size a-Si modules with terra-cotta color matching perfectly existing roofing elements (see fig.5). Thanks to the addition of a very high transparency textured glass on top of the device, it was even possible to match the "feeling of diffusivity" of the tiles appearance. This innovative coloration process resulted in a PCT application[5].



- **Figure 5 : addition of a colored encapsulant at the back of semi-transparent a-Si cell enables device color tuning**

This approach holds two advantages. First, as compared to the interferential filter solution, no additional layer is added in front of the PV cell, except a high transparency solar-grade textured glass, and, therefore, the reflection losses are minimized. Second, the lamination process stays identical to the

[5] PCT application,"*Manufacture of colored PV modules*" L.-E. Perret-Aebi and al., deposited in 09.2013

one used in standard modules and no costly materials are needed (only a colored polymer layer and a commercially available textured glass). Therefore, this product enables terra-cotta tones matching at low price and maximum reliability. The only disadvantage was shown to be the slight efficiency reduction as compared to standard opaque (purple tones) a-Si due to the introduction of the colored polymer layer between the cell and the white back reflector. Tuning the colored polymer layer thickness, it was possible to reduce the power loss to 8%, below the acceptable threshold of 10% defined during the market survey.This market survey was sent to more than 1,800 architects, in order to characterize architectural sensitivity regarding freedom in choosing module size, colors and texture, and the willingness to pay for these features. The survey showed that architects are very interested in installing PV but are looking for specific characteristics rarely available on the market: the possibility of choosing dimensions, color, type of surface and jointing. This study also showed that they were ready to pay the price (extra cost or reduced efficiency) for a suitable product.

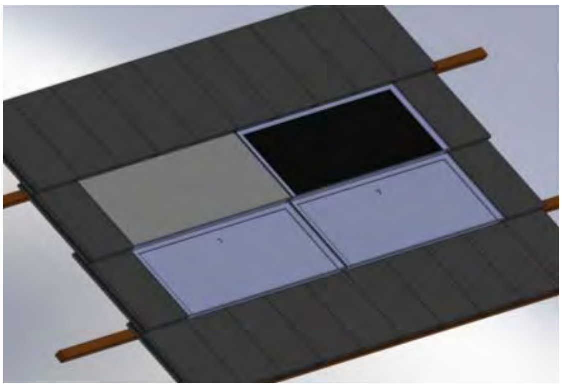
Discussions are on-going now with two private landlords for a possible installation / demonstration on roofs in Neuchâtel. Some simulations of power output and performance on the terra-cotta modules installed on these roofs were performed using the PV-SYST software and showed the nice generation potential of those roofs. This procedure is still ongoing and the installations should take place in 2014.

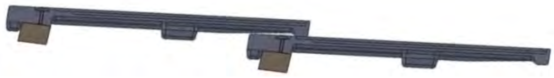
3. Designing a multifunctional structure for easy and aesthetical building integration

The second challenge, after the module color, was the wish of the architects to dispose of a PV product with a high aspect ratio (in landscape format) that could be easily installed, matching existing tiles, while staying lightweight.

In order to match this demand, it was needed to design a structure in composite materials in order to obtain the wanted lightness while keeping stiffness high enough to ensure the product mechanical stability. The design of this structure was done jointly by the Laboratory of Polymer and Composite Technology (LTC, EPFL), the LESO-PB, EPFL and the PV-Lab, EPFL and allows:

- Quick and easy in-roof integration thanks to its light weight (15kg per complete tile of ½ squared meter) and simple screw fixation system
- Roof water tightness through an optimal horizontal and vertical overlap
- Compliance to all roof pitches from 15° to 60° thanks to the tunable vertical overlap (see fig.6, right)
- Compliance with the Tegalit tiles from the company Braas, allowing highly aesthetical solutions for both complete and partial roof covering with the PV elements (see fig.6, left)
- Structural integrity thanks to the stiffness of the composite material (compliance to IEC 61215 checked by the mean of FEM)
- Excellent weathering capability of the well-known PVC material
- Tunable color to adapt different PV technologies and to meet customer requirements
- Easy and safe storage, transportation and handling through additional features on the backside

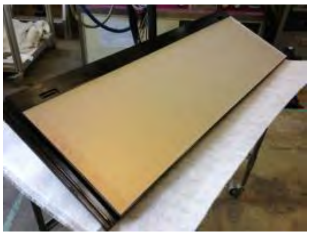




- **Figure 6 : Left: Complete integration of four ArchinSolar PV tiles matching with Braas Tegalit tiles. The composite back-structures are represented in blue, the active PV element in black, the textured front glass in light grey and the Tegalit tiles in dark grey. Right : *vertical alignment with the tunable overlap ensuring both vertical water-tightness and compatibility with roof pitches ranging from 15° to 60°***

Once the design ready, a material selection step was undertaken at LTC by the mean of a product cycle analysis in which the balance "cost / production rate / environmental impact" was optimized. The selected solution consists of a glass fiber reinforced PVC (GFR-PVC) processed by glass-mat thermoplastic (GMT) (preheating in IR Oven then direct molding by pressure). This process leads to a product that is recyclable, highly UV and corrosion resistant and which color can be tuned using pigments. Some prototypes were produced in collaboration by the PV-Lab and the LTC using the colored filters presented in §2.1 to tune the PV element appearance, as shown in fig.7

a)



b)

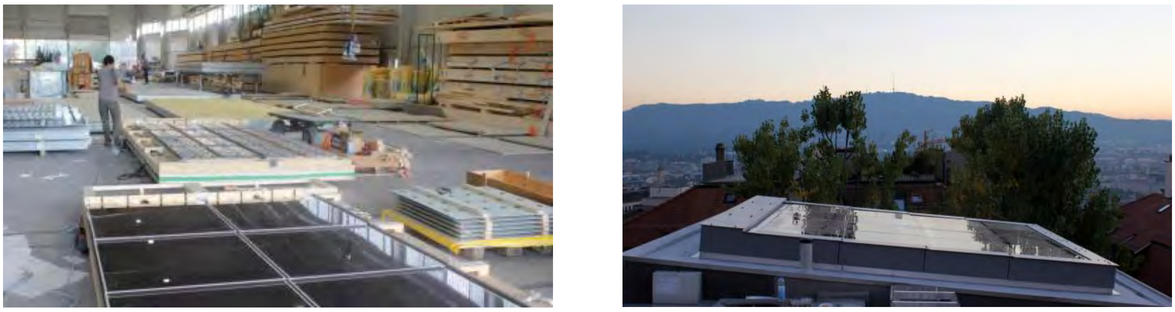
- **Figure 7 : a) all black tile-like BIPV product, b) colored-tuned tile-like BIPV product, thanks to the previously developed interferential filters. Note that the composite backing color can be tuned to match the filter color.**

4. Designing a PV/T product for integration in pre-fabricated roofing elements

The last product development challenge consisted in answering the will of architects to dispose of prefabricated roofing elements that can at the same time produce electricity and low-temperature heat to be used in synergy with heat pumps. These elements are intended to be used both in new constructions aiming low energy impact as well as in building refurbishment.

To do so, a special heat absorber was designed at the ETHZ and applied on the back side of large size colored modules (presented in §2) to create a PV/T product. The PV/T module was then integrated in a prefabricated design consisting of a wooden frame acting as supporting structure, an insulation layer with low U-value and water vapor permeability to prevent water condensation behind the PV/T collector. The water-tightness system is ensured by the thermal collector that also acts as a mounting structure for the PV module.

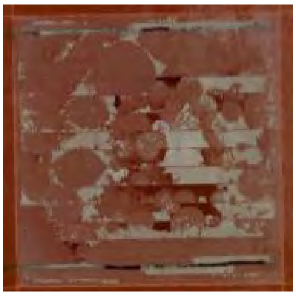
After a series of outdoor tests needed to assess the water-tightness and electrical/thermal performances of the developed concept, the ETHZ could start the production of real size prefabricated roofing elements that were applied on a real roof in the city of Zürich (see fig.8). The developed solution is now industrialized by the Swiss company 2Sol in collaboration with the PV industry leader Meyer Burger.



- **Figure 8 : left) manufacturing of the prefabricated elements using black micromorph modules, right) a roof realized with the developed prototypes in Zürich**

5. Ensuring high reliability

The introduction of new materials and changes in the module encapsulation architecture lead to the evident need to check that the end products reliability was still as high as possible. To do so, the PV-lab conducted extended studies including potential induced degradation (PID, high voltage test under hot and humid environment), adhesion tests before and after degradation in damp-heat (85°C/85%RH) using a specially developed procedure[6] and moisture ingress tests.



a)

b)

- **Figure 9 : corrosion of the ZnO electrode due to application of high voltage under hot and humid environment (a) couls be suppressed using a moisture blocking polymer applied on the edges of the PV module (b)**

It was observed that the new architectures developed showed an increased sensitivity to moisture penetration, which lead to high adhesion loss and potential induced corrosion on the ZnO back electrode of the PV cells (see fig.9). In order to mitigate this effect, a dedicated protective tape made of moisture-blocking technical polymer was applied at the product level around all interfaces (either during the lamination or during the framing processes, depending on the design). Addition of the protective tape was then shown to decrease the moisture ingress to similar level as observed in standard and certified commercial products.

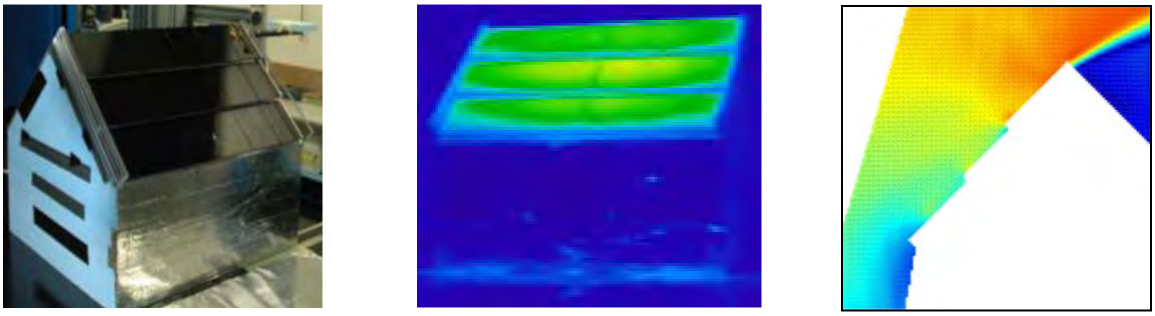
The realized reliability study and the addition of the moisture blocking polymer ensure that the developed product can be safely commercialized and if needed certified according to the existing PV standards (EN61646)

6. Studying cavity ventilation to overcome the overheating of BIPV solutions

Even though BIPV solutions are preferable from an aesthetic point of view, the proximity of the active layers to roofing insulation material usually induces overheating of the PV module resulting in efficiency losses.

A study was then conducted in collaboration between the PV-Lab and EMPA in order to evaluate the influence of different mounting designs on the PV modules temperature. Therefore, a mock building on which small PV modules can be installed in different configurations was realized (fig.10a) and placed in a wind tunnel under a sun simulator. The PV modules temperature was monitored by thermography (see fig.10b), while the airflow was observed using particle image velocimetry (see fig.10c).

[6] Chapuis, V., Pélisset, S., Raeis-Barnéoud, M., Li, H.-Y., Ballif, C. and Perret-Aebi, L.-E. (2012), Prog. Pho-



a) b) c)

- **Figure 10 : a) the mock structure placed in wind tunnel, b) example of thermography imaging of the mini PV modules, c) image of the air velocity around the PV installation**

The conducted study evaluated six different PV modules mounting schemes and the impact of the airflow regime on removal from the PV panel was clearly demonstrated for both open and closed mounting architectures. It was moreover shown that a stepped arrangement of the PV modules, such as realized with the tile-like product presented in §3, had a significant advantage in cooling the modules than standard flat constructions. This study resulted a scientific publication[7] and in guidelines for the mounting of BIPV that strengthened the design choices made for the BIPV tile and the prefabricated elements developed during this project.

7. Conclusions

ArchinSolar has been a three years long success story in which the well established close collaborations between academic partners from highly different research fields was shown to be the key in overcoming the proposed innovation challenges from lab scale research to pre-industrialization of prototypes. Thanks to the high personal investment of each collaborator involved, ArchinSolar is now able to propose innovative BIPV products to the market that will surely contribute to make photovoltaic energy more accessible and more attractive, particularly in built-environments or protected areas. This project also demonstrated the possibility to manufacture innovative BIPV elements by working on the “packaging”, functionality, aesthetic and mounting aspects of the modules and not only on the core of the PV modules (the solar cells). This “transformative” strategy of modifying existing PV elements is the only way, today, to allow sufficiently low costs to give a chance to BIPV elements to be successful on the market.

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CONSTRUCT PV

CONSTRUCTING BUILDINGS WITH CUSTOMIZABLE SIZE PV MODULES INTEGRATED IN THE OPAQUE PART OF THE BUILDING SKIN

Annual Report 2013

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ABSTRACT

The project is financed by the EU-FP7 program under the Grant agreement number: 295981.

Construct-PV will develop and demonstrate customizable, efficient and low cost BIPV elements for opaque surfaces of buildings. Opaque surfaces were selected because they represent massive wide-area spaces of untapped harvesting potential across Europe. The project consortium consists of 12 partners from 5 different countries, representing crucial parts of all the whole value chains: e.g. architects, PV-manufacturers, inverter manufacturers, research institutions and construction companies. In order to develop highly efficient systems, the most promising PV technologies have been selected, i.e. back contact cells fabricated with MWT technology and hetero-junction technology (provided by Meyer Burger). These technologies allow more frontal surface area for energy harvesting, leading to higher efficiency. Construct-PV systems multifunctionality renders them an attractive solution for the market. Opaque surfaces are ideal for retrofit building envelopes that harvest also energy at the same time. To do this, the Construct-PV consortium involves selected partners, leaders in the industry and research sector and more in particular in the fields of PV technology and building construction. Construct-PV defines an integrated approach that streamlines the value chain by introducing BIM and CAD/CAM tools that enable customizable mass production by providing all the actors in the value chain access to the same information. Thus, Construct-PV will be attractive for the majority of SMEs in the building value chain. Demonstration activities will cover all aspects of the value chain. Two large scale demonstration sites will allow architects to have the liberty of designing solutions integrated in large districts. So, by choosing beautiful designed PV cell and module technology and by being customizable, Construct-PV is architect friendly. ISAAC will contribute in WP1 and 2 with the identification of possible design solution for new BIPV customizable modules and system. Task 5.1 is lead SUPSI and a new BIM tool will be developed together with Zublin in order to offer the main stakeholder an innovative tool for the design of different BIPV envelope. Finally SUPSI is responsible for the dissemination activities and the distribution of the project achievements.

Aims of the project

The final goal of Construct-PV is to obtain BIPV modules that are targeting the expected performances described in SEII1[1] with respect to the module efficiency range and applicable to at least 80% of the buildings in an urban environment.

The targeted market for Construct-PV solutions is:

1. New buildings that, being designed from scratch, will be designed in order to meet optimal requirements for effective BIPV installation (i.e. building orientation, shading, building placement, road access, roof and façade dimensions).
2. Existing buildings undergoing deep retrofitting:
    a. If modifications of the façade appearance are allowed, it will be possible to install BIPV systems following Construct-PV integrated approach that includes: identification of optimal position for BIPV systems, aesthetic design for architects, technical requirements for builders and BIPV manufacturers and finally guidelines for installers;
    b. If modifications of the façade appearance are not allowed or only partially allowed in line with building codes, it will be possible to install BIPV on roof top of building; moreover other alternative solutions will be possibly identified by architects to allow smaller intervention to improve energy efficiency of the building.

To cover the last mile before market uptake, Construct-PV will aggressively demonstrate its results across all aspects of the value chain. Specifically:

1. A Small scale demonstration of manufacturing line for BIPV will be prepared to demonstrate the high replication potential of the developed results: in particular the focus will be on the optimization of the manufacturing line in order to allow for a more flexible production.
2. A Small scale demonstrators for building elements to be applied on roofs and façades obtained with the integration of low-cost and high efficiency PV systems will be performed after first test laboratories. The small scale roof demonstrator will be installed in SUPSI campus.
3. A Large scale demonstration will be performed on two different demo-sites available for Construct-PV (see Fig. 1)
    - The first is an existing building located in National Technical University Zografos Campus of Athens (NTUA) where roof application of developed BIPV will be mainly pursued, since panels in horizontal orientation offer better performances at this latitude. This building is one of the many buildings in the same campus that could be retrofitted after project closure, representing an initial market replication potential for the proposed approach.
    - The second is a new building of Züblin in the district of Möhringen (Stuttgart). Roof and façade application are foreseen here.


Fig. 1: The left photo shows the Züblin building in Stuttgart and the right picture the building located in Athens.

The features of these demonstration sites will also allow evaluation of the possibility to use electricity at a district level, integrating the Construct-PV idea in a wider "district level approach". The outcome of

[1] "Implementation plan 2010-2012" of the Solar Europe Industry Initiative (SEII), EPIA 2010.

the project in the area of the Züblin Campus will raise awareness of sustainability and new products which are available. Ed. Züblin AG has full intentions to replicate the results of this project as a means to offer more competitive bids to tender offerings that are ready for the upcoming policy requirements.

Detailed description of the project

The project, whose duration is estimated to be 48 months, has been broken down into 8 Work Packages (WPs) to achieve the S&T Objectives and expected impact (e.g. the development and demonstration of a radical evolution of BIPV). The first two years of the project are mainly devoted to research and development activities, laboratory testing, market analysis and all tests necessary to set the conditions for the success of the demonstration activities. In particular, the focus will be given to the involvement of all the partners in the analysis of building requirements from the point of view of architects, PV producers and construction companies. A task will be also dedicated to understand in which way the market is most quickly reachable for opaque BIPV solutions. This will help the identification of essential requirements, which will be then translated into technical specifications during the conceptual design of Construct-PV solutions.

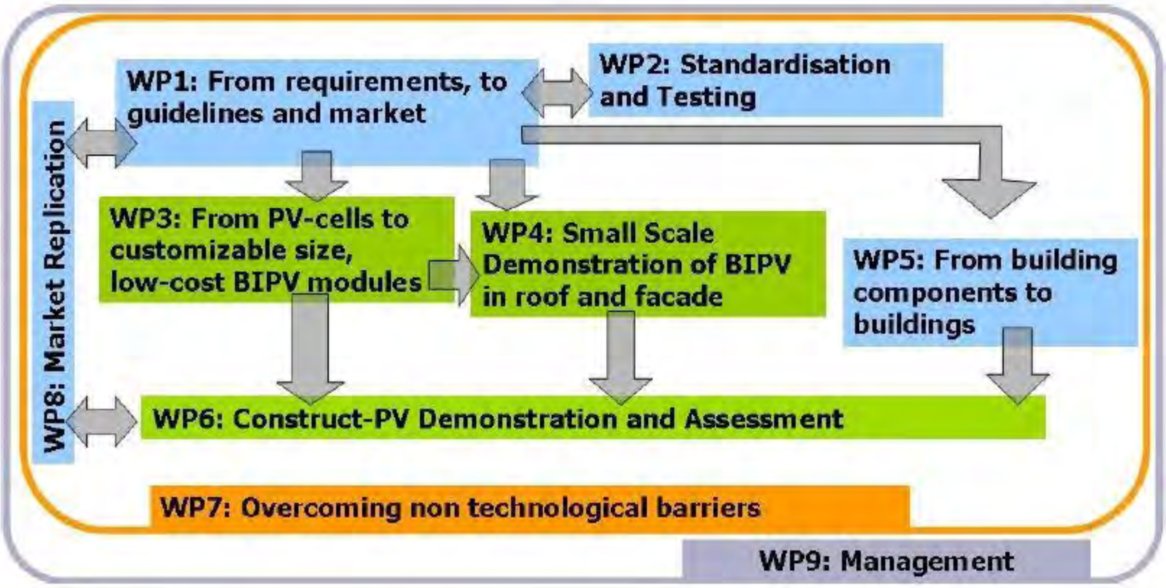

Fig. 2: Project flow and work packages definition.

Work carried out and results achieved

The project officially started in February 2013 and will be finished in January 2017. Only WP1 and WP2 have been started so far together with WP7 (dissemination and web-site).

The main activities of WP1 were dedicated to the definition of the requirements of BIPV opaque solutions such as façade cladding elements and roof tiles. Moreover the identification of existing technical requirement was completed. The idea of the project is to treat the BIPV system as a conventional building construction.

As already discussed in a previous publication [1] when dealing with photovoltaic in buildings we have to comply with a series of international and national construction directives and regulations. The construction Product Directive (in force until July 2013) and now the Construction Product Regulation CPR [2] together with all relevant standards for façade, roof, balcony, etc. represent the legal framework for any Building Component (or BiPV). This first difference makes the legal framework for a "Multifunctional" Building component more complex. A solar tile (active roof tiles) has to compete with common tiles such as a Clay roof tiles (Marselleis) or a Canadian tiles (tegola canadese) and a semi-transparent PV module must "race" with an insulated triple glaze unit for example. In all cases (some of them are reported in Fig. 3) the PV component has an "added" value, respect to the common building component: the electricity production when exposed to the sunlight.

Fig. 3: Different parts of a building skin can be "transformed" in renewable energy producers. Each component has to be treated independently with its constraints and freedom (source [5]).

Within WP1 also different partners guided by UNStudio, and the support of SUPSI and ENEA are contributing with a broad range of ideas to establish an overview of the important elements for the functional and aesthetical application of PV panels in the building's envelope. These ideas and the resulting list of architectural requirements will be used as a guideline for the design work in the later stages of the project. The formulated architectural themes and resulting requirements have been discussed and paired with the technical requirements as formulated by Fraunhofer ISE.

The requirements from the point of view of the architect were first discussed and shared among all partners in a brainstorm session in Freiburg. Four main topics were identified in the brainstorm, each describing a number of key aspects by using existing reference material from the building industry, PV industry and various technological products with PV capability and integration.

The main important aspect to consider are: the need to adapt the product to the building envelope (different situations by integrating additional properties and easy to install); forms and customization needs (at cell scale and module scale); the performance to be achieved and the behaviour and the importance of details and finishing to enhance the user interface and improve acceptance of the architects.

Different design levels options are being identified:

1 – Cell & material design level options

2 – PV module design level options

3 – Façade design level options

4 – Building design level options

5 – Environment design level options

Considering all this levels, a matrix is being developed considering all aspects to be taken into account for the proper development Construct-PV research project.

Following this discussion, in parallel to WP1, **WP2** (**Standardization and Testing**) is investigating the standards and testing procedures required to certify Construct-PV products (with an important aspect being a contribution to standardization for the loosely regulated BIPV sector). The results of such activities will be further discussed in the framework of CENELEC working group, which is preparing the new standard for Photovoltaic in building prEN 50583. SUPSI is part of this group and will transfer the achievement of the project to CENELEC.

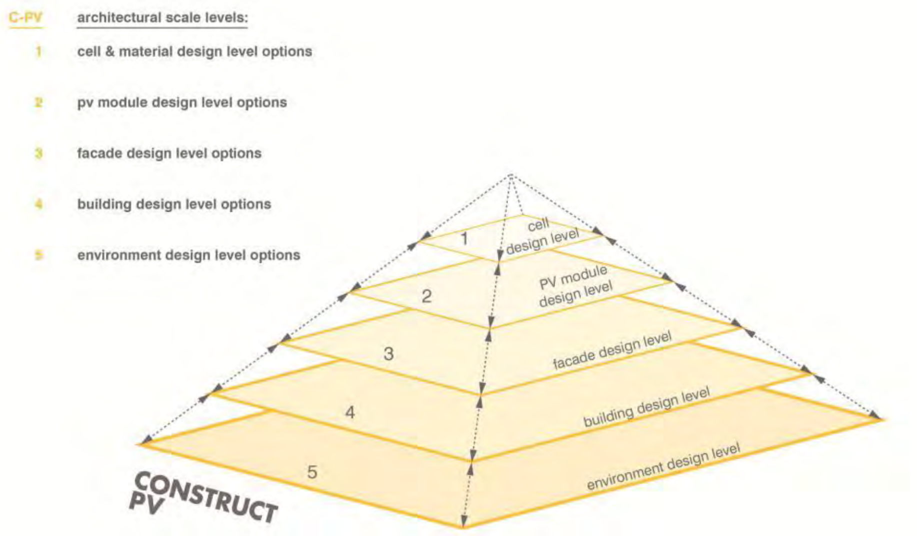

Fig. 4: Construct-PV pyramid showing the relation between different architectural design scales (source UNS).

The activities for **WP7** (**Overcoming non technological barriers**), where SUPSI is WP leader, will ensure a widespread and effective dissemination of project results to the relevant target groups. Also the website of the project, developed by SUPSI, is now on-line (http://www.constructpv.eu/) and will contain the most relevant project information. The Web page will be updated as the project will be developed. This channel intended to be a good strategy for communicating that influence policy-makers and other stakeholders about the benefits and the value-chain on BIPV systems and especially the photovoltaic solutions developed in the project.

National and international collaborations

Within the project the following partners, together with SUPSI, are included:

- Ed. Zueblin Ag (Coordinator) (Germany)
- Alkion Anonimi Techniki Kai Emporiki Etairia (Greece)
- D'appolonia Spa (Italy)
- ENEA (Italy)
- Fraunhofer ISE (Germany)
- Meyer Burger AG (Swiss company, that is providing solar cell and PV modules) (Switzerland)
- NTUA (Grece)
- SMA (Germany)
- Technische Universitaet Dresden (Germany)
- Tegola Canadese Spa (Italy)
- Van Berkel & Bos U.N. Studio B.V. (Netherlands)

2013 Evaluation and future prospects

The project is running properly.

The first deliverables of the project are expected for February 2014.

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[2] CPR (EU) no 305/2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC
[3] SOPHIA RI, http://www.sophia-ri.eu/
[4] CENELEC project: prEN 50583:2012 Photovoltaic in building
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OPTIMIZATION OF THIN FILM MODULE TESTING AND PV MODULE ENERGY RATING AT SUPSI

Annual Report 2013

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Date	01.12.2013

ABSTRACT

The project aims to improve the measurement accuracy for thin film technologies through the definition of new test procedures and the upgrade of the test equipment. The focus is on the characterisation of multi-junction devices and the pre-conditioning of thin film modules, which needs to be improved to guarantee a higher comparability and repeatability of power measurements. The results, in combination with long term outdoor data monitoring and modelling activities, will be used to increase the understanding of the performance of thin film modules in comparison to the one of crystalline silicon technologies and to verify the applicability of the present energy rating procedure to thin film modules. Side activities as measurement round robins and collaborations with industry and other test institutes will help in the evaluation of the introduced changes.

The activities of 2013 focused on the upgrade of test procedures and equipment for the characterisation of multi-junction modules, the investigation of meta-stabilities within CI(G)S and CdTe modules and the exploitation of PV module data from our outdoor energy yield test facility :

- The spectral response measurement procedure for single-junction modules was accredited ISO 17025. The solar simulator was equipped with an enhanced spectral irradiance measurement system and a new electronic load for the simultaneous measurement of up to 4 reference cells have been introduced.
- The effect of dark storage and current biasing before I-V curve measurements was investigated for a set of commercial CI(G)S and CdTe modules with very different results.
- A new simplified performance model for the simulation of PV modules was introduced and tested on a single junction amorphous silicon and a crystalline silicon module.
- In the framework of the International Agency's Photovoltaic Power System Programme (IEA PVPS) Task 13, SUPSI participated at the collection and analysis of thin film module data from different locations.

1. Aim of the project

The project aims to improve the measurement accuracy for thin film technologies through the definition of new test procedures and the upgrade of the test equipment. The focus is on the characterisation of multi-junction devices and the pre-conditioning of thin film modules, which needs to be improved to guarantee a higher comparability and repeatability of power measurements. The results, in combination with long term outdoor data monitoring and modelling activities, will be used to increase the understanding of the performance of thin film modules in comparison to the one of crystalline silicon technologies and to verify the applicability of the present energy rating procedure to thin film modules.

2. Work carried out and results achieved in 2013

2.1 Test procedures for the characterization of multi-junction devices (WP1)

The spectral response measurement setup for multi-junction modules, introduced and successfully validated in 2012 [1], was widely used for research purposes. In 2013 the spectral response measurement procedure for single-junction modules was accredited ISO 17025, which is the first step to prepare the final measurement procedure and uncertainty analysis for multi-junction modules. In the meantime SUPSI, in quality of Swiss expert, is contributing within the IEC technical committee 82 at the preparation of a new standard for current-voltage and spectral response measurements of multi-junction cells and modules.

A new measurement intercomparison campaign with TEL-Solar (former Oerlikon Solar) led to the investigation of the impact of the spectral mismatch to the current-voltage characterization of a-Si/µc-Si modules: both the impact on the short-circuit current (thus the selection of the most appropriate reference cell) and on the open-circuit voltage were measured in detail [2]. The latter impact represents a novelty in the specific literature.

The intercomparison drove the planned development of a re-styling of the data acquisition system, involving “live” measurement of the spectral irradiance of the solar simulator, for spectral mismatch correction. A fast spectroradiometer from AVANTES was adapted to the new use and test procedures and uncertainty calculations have been performed, involving spectral irradiance measurements and a procedure for the internal calibration. The same setup can now be used also for measurements of absorbance and transmittance of testing materials.

Furthermore the PASAN IIIB solar simulator was updated with a new electronic load and software developed in collaboration with PASAN [3]: the new setup allows now spectral tuning with tiny variations of the total irradiance and detection of partial irradiance in different wavelength bands via up to four filtered reference cells.

2.2 Stabilization procedures for thin film modules (WP2)

Polycrystalline thin film modules as CIS and CdTe can be influenced by internal meta-stabilities, which may in some cases, strongly influence their state even after very short-exposure times (seconds, hours) to light. If the devices are stored in the dark, their performance may decrease considerably and additional possible pre-measurement effects could occur.

In the first stage of WP2 the behaviour of polycrystalline thin film modules of different manufactures were investigated in terms of (1) dark storage after long term outdoor exposure and (2) short preconditioning with bias current.

Initial characterisation as performance measurement at STC, low light behaviour, temperature coefficient and spectral response measurements had been carried out. Figure 1 shows the spectral response measurements of some of the investigated CI(G)S and CdTe modules in comparison to a crystalline silicon module. All modules are commercially available modules.

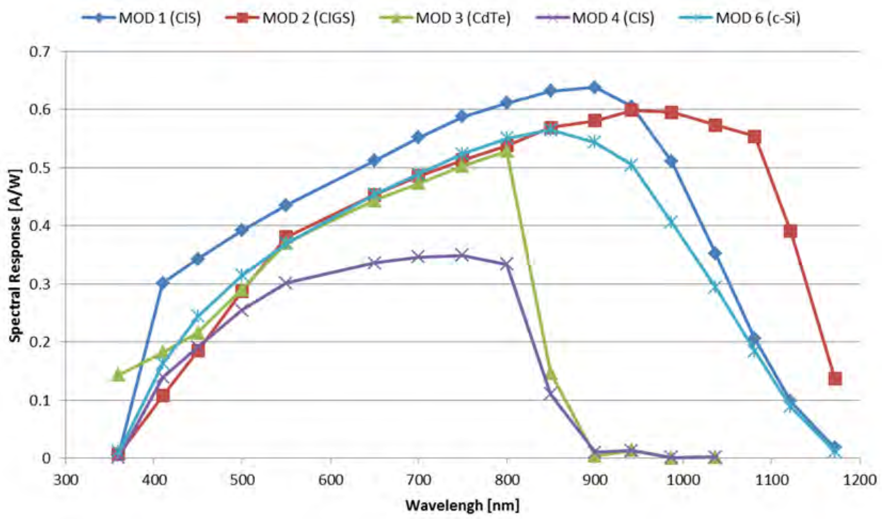

Figure 1: *Measured spectral response of three CIS modules of different manufactures, one CdTe and one c-Si module.*

<u>Effect of dark storage after long term outdoor exposure</u>

Three CIS modules from different manufactures were taken from the energy yield measurement campaign (test cycle 12). The modules were exposed outdoors for more than 2 years from January 2011 to April 2013. To investigate the typical meta-stabilities, the modules were disconnected and transported to the laboratory. After temperature stabilisation to 25°C, continuous STC measurements in steps of 1, 5 and 10 min were performed during the first hour of dark storage. The time between disconnecting the module and their first measurement is less than 20 min. The modules were then stored in dark at 25°C and STC measurements were performed every 24h until their power became stable within ±1% over three days.

Table 1 shows the results of the tested modules. Module MOD 2 shows the strongest degradation in the first minutes. The difference in Pm after 5 minutes to the first measurement is -1.6% and after 1 hour the difference is about -3.6%. Stabilization was observed after 11 days of dark storage and its difference to the initial STC measurement is -10.4%. MOD 4 and MOD 7 showed instead slower degradation of -1% in the first hour. Out of the tested modules, MOD 7 showed the lowest degradation of -2% after 3 days of stabilization. It was also observed that the short circuit current Isc is stable during the dark storage for all three modules. However, the open circuit voltage Voc of MOD 2 and MOD 4 decreased over time while Voc of MOD 7 was stable.

Module	Dark storage	ΔPm [%]	Observation
MOD 2 (CIGS)	5 min	-1.6	Isc stable Voc decrease
	1h	-3.6	
	75h	-7.5	
	265h	-10.4	
MOD 4 (CIS)	1h	-1.0	Isc stable Voc decrease
	75h	-7.2	
	164	-8.5	
MOD 7 (CIS)	1.5h	-1.0	Isc stable Voc stable
	79h	-2.0	
	248h	-2.0	

Table 1: *Results of dark storage after long term outdoor exposure. Modules are stored indoors over 14 days and continues STC measurements were performed.*

Effect of short (10sec to 1hour) preconditioning with bias current (Irev)

After dark storage and stabilization of Pm as described before, the modules were tested to observe whether or not they gave any response to a short bias current of a few seconds. The modules were connected to a power supply and a bias current (Irev) equal to the Isc was applied for 10 seconds before the IV-measurement. The time between disconnecting the module from the power supply and the IV-measurement is less than 2s. The tested CIS modules show different behaviour to the short bias current. MOD 2, MOD 7 and MOD 3 (CdTe) show a power increase between 5 and 8% while MOD 4 does not show any response to the bias current. Other module technologies such as c-Si and a-Si do not show any response either.

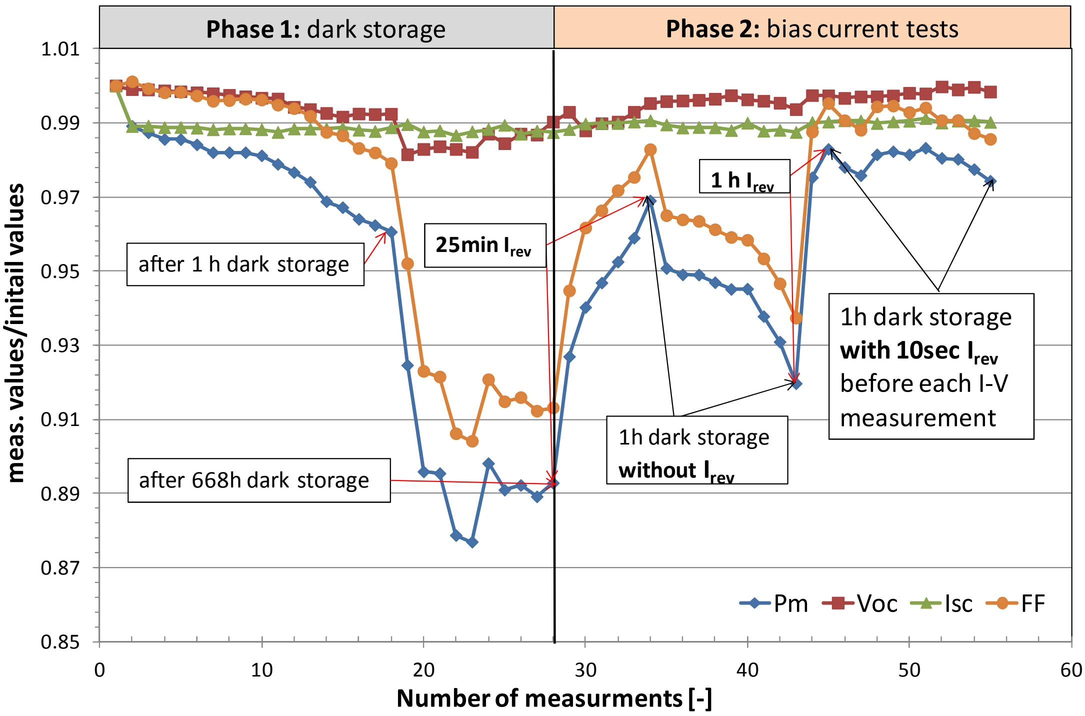

***Figure 2:** Dark storage and bias current preconditioning tests on a outdoor exposed CIS module (MOD2).*

Figure 2 shows the response of MOD2 to dark storage (Phase 1) and to different preconditioning tests with bias current (Phase 2). Dark storage leads to a general relaxation of module power, whereas current biasing to an increase of power. Phase two is carried out in two parts. On the first part, the bias current (Irev) is applied to the module for 25 minutes followed by a 1 hour dark storage. The module's temperature is kept at 25°C while intermediate Pm measurements are carried out. As a result of the bias current, the module's power increases by 7.5% and decreases by -5% in the dark.

On the second part of the test, the bias current is applied for 1 hour leading in a increase of power of 5.5%. In the following dark storage, intermediate Pm measurements were performed with a short bias current of 10 seconds before each IV-measurement. These short bias currents allowed to maintain the power stable within ±1% during dark storage.

Other tests with longer exposure times (Irev), different technologies and inter-comparisons with standard light soaking procedures are ongoing and will be presented in a later stage.

2.3 Outdoor Performance of thin film modules (WP3)

The second year of the project focused on the exploitation of the before presented outdoor data [1] for modeling activities and the development of a standard approach for the representation and analysis of PV module field data from different test facilities and locations. The last activity was performed in collaboration with TÜV Rheinland within the framework of the International Agency's Photovoltaic Power System Programme (IEA PVPS) Task 13. The outdoor measurement campaign of 11 different thin film technologies is still ongoing and new results will be presented at a later stage.

2.3.1 Simplified performance model for amorphous silicon modules

The here summarized simplified model is based on a former work presented by Fanni and coworkers in order to model the energy performance (for clear-sky days only) of a quasi-horizontal, fully integrated 15 kW_p PV plant realized with triple-junction a-Si modules [4]. Due to the very peculiar characteristics of this installation, in order to assess the validity of the model and extend it to a more general situation, we use the same approach to model the daily performance ratio (PR_d) of a single module installed in a more common fashion (open-rack, south-facing at 45° tilt). Data of a single junction amorphous silicon module from the outdoor test facility (test cycle 12) have been used therefore. The full approach has been presented at the 27th EUPVSEC conference [5].

Approach

The performance ratio PR of a PV system or single module varies as a function of day time or can be averaged on a full day (PR_d). The PR expresses a ratio between the efficiency (in terms of energy) of the system/model exposed to real operation conditions ($\eta_{en} = E_d$ / H_d) and the efficiency (in terms of power) of the same device at STC ($\eta_{p\_STC} = P_{STC}$ / G_{STC}). In other words it provides an indication of how the device will perform under real operation conditions compared to STC ones.

For simplicity our approach to model the PR_d focuses on days of clear-sky conditions and on four main *losses/gain mechanism* only: (1) temperature, (2) spectral-effects, (3) reflection losses, and (4) Stabler-Wronsky effects (SWE).

By focusing on clear-sky days only, other effects (e.g. diffuse/direct irradiance ratio, low-irradiance, humidity, etc.) which may have a remarkable influence on PR_d for days with different climatic conditions (or instantaneously on PR(t)) are here neglected or averaged out by the model.

Input parameters

Air Mass AM and the Angle-of-Incidence AOI (with respect to the module's normal) are geometrical parameters which are available or can be calculated for any location. The module's temperature T_{mod} requires a direct monitoring, even though approximate relations based on nominal operating cell temperature (NOCT) between T_{mod} and ambient temperatures exist

Instead of using instantaneous values for these parameters input for our simulations are *daily aggregate data* weighted on the irradiance of the corresponding day T_{mod}, AM and AOI. The idea of focusing on aggregate values -weighted on the irradiance - reflects the fact that in a single day the energy production of a solar module is perfectly phased with the irradiance profile (i.e. the highest amount of energy is produced in the central part of the day). So that, in order to model the daily energy performance of a PV device, values of T_{mod}, AM, and AOI should be given a higher weight around noon time.

This model requires a very limited characterization of the device under test: power rating at STC (W_p), temperature coefficients, spectral response and angle-of-incidence dependency.

Definition of loss/gain and efficiency factors

The modeled losses and gains (with respect to STC) are shown in Figure 3. The four distinguished phenomena are expressed in four *performance efficiency factors*: ε_{sp}, ε_T, ε_{AOI}, ε_{SW} (ε_x = 1 corresponding to the performance at STC) which coupled results in a

combined performance efficiency factor: $\varepsilon_{comb} = \varepsilon_{sp} \cdot \varepsilon_T \cdot \varepsilon_{AOI} \cdot \varepsilon_{SW}$ (1)

The relative daily average performance losses (or gains) - with respect to STC (25°C, AM1.5, normal incidence) - for the single contributions are modeled by inserting daily weighted $\underline{AM}_d$, $\underline{T}_{mod\_d}$, and $\underline{AOI}_d$ in the following expressions.

(1) Spectral losses/gains: $\Delta P_{sp} = -\alpha_{sp} \cdot (\underline{AM}_d - 1.5)$ (2)

(2) Temperature losses/gains: $\Delta P_{temp} = -\gamma_{rel} (\underline{T}_{mod\_d} - 25)$ (3)

(3) AOI losses (where $\underline{AOI}_d = \Theta$): $P_{AOI}(\Theta) = b_0 + b_1 \times \Theta^1 + ... + b_6 \times \Theta^6$ (4)

According to previous works for Lugano the seasonality related to SWE (degradation/regeneration effects) for single-junction a-Si devices can be modeled with ±4% fluctuations around an average value [4, 6]. The trend, which can be modeled with a sinusoidal or 4th grade polynomial, reaches a maximum in late summer (mid-August/early-September) and a minimum in winter time (February).

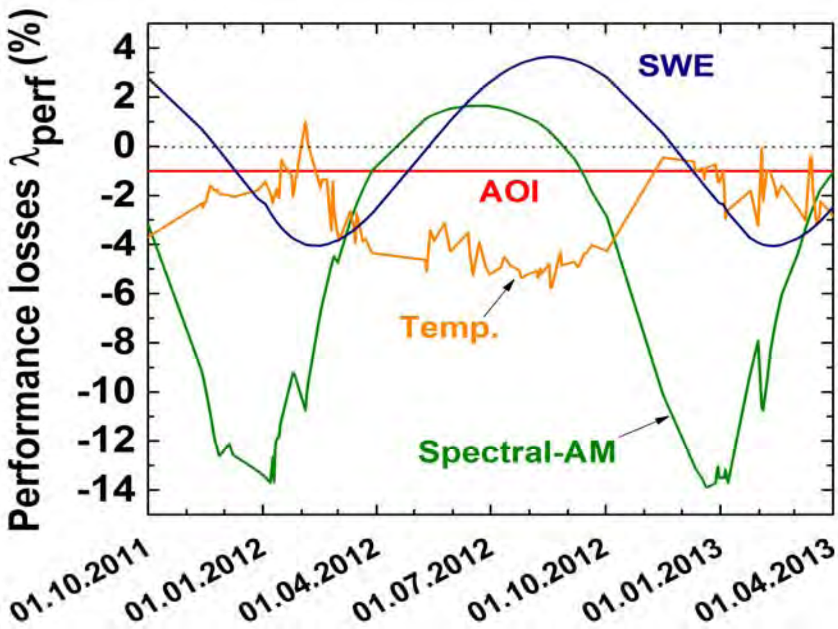

Figure 3: *Calculated or assumed performance gains/losses with respect to STC related to (1) spectral effects, (2) temperature, (3) reflection (AOI), and (4) Stabler-Wronsky effects (SWE).*

Results

Figure 4 shows measured daily performance ratio PR_d values for days of clear-sky conditions from Oct. 1st, 2011 to April 1st, 2013 together with the simulated model for ε_{comb}. Missing data correspond to periods for which the acquisition system was not working properly or in which the modules were removed for indoor control testing. PR_d values show a seasonal behavior typical for a-Si with a maximum around August and a minimum in February. Maxima and minima originate mainly from the superposition of spectral and SWE phenomena which are clearly distinguished but act with very similar time-phases, as reported in Ref. [6].

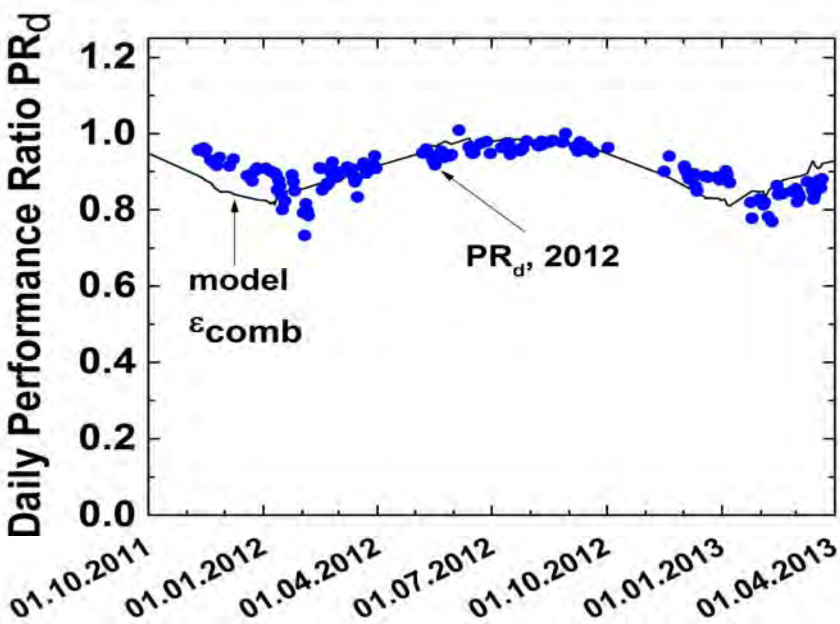

Figure 4*: daily PR_d for clear-sky day conditions from Oct. 1st, 2011 to Apil 1st, 2013 (blue circles) and modeled combined performance efficiency factor ε_{comb}* (black line).

To calculate PR_d a value of 96.6 W_p (slightly lower than the nominal 100 W_p) for the power of the module was used. This value is an average of the indoor-measured P_{max} tested at different intervals in year 2012.

For the data of year 2012 the model fits very well the measured data, whereas it slightly underestimates and overestimates, respectively, data for year 2011 and 2013. We believe that this discrepancy from the model, which warrants further consideration, could be an indication of an intrinsic degradation of the module's performance.

As the PR_d is directly correlated to the daily energy yield of a given device/plant, we believe that this model could be used to forecast the energy yield of amorphous silicon (or other technologies) in different locations or for different types of installations (e.g. fully-integration, horizontal, facades, etc.).

2.3.2 Comparison of different PV module technologies in different climates

In the framework of the International Agency's Photovoltaic Power System Programme (IEA PVPS) Task 13, SUPSI participated at the definition of a standard approach for the representation and analysis of PV module field data from different test facilities and locations (to be published). Data including the one from SUPSI (test cycle 12) have been collected and analyzed therefore. Figure 5 shows an example of selected crystalline silicon and amorphous silicon based modules data from 7 locations (Norway, UK, Germany, USA, Switzerland, France and Cyprus). The data clearly shows the opposite seasonal trends of performance ratio (PR) of the two technologies and a high spread for the a-Si modules due to the instability of STC power and a still higher measurement uncertainty.

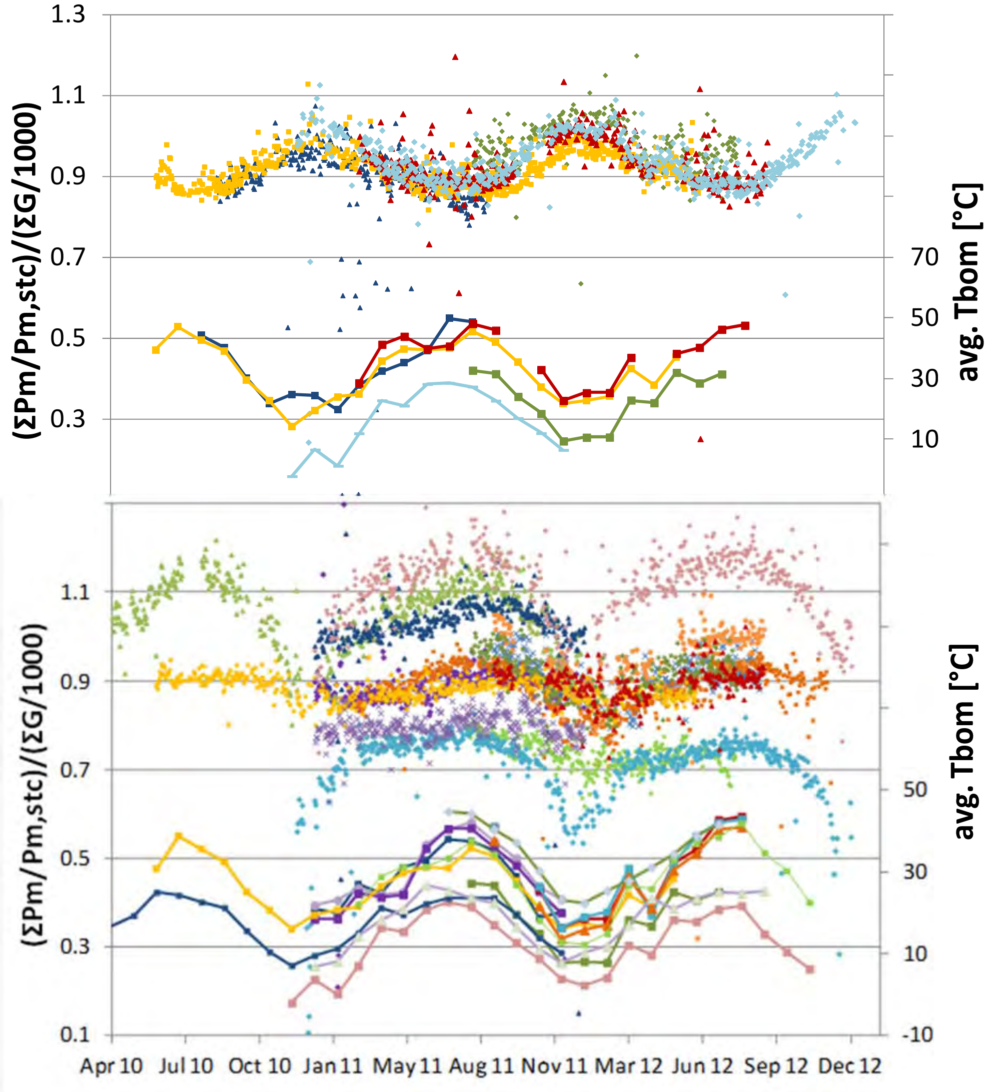

***Figure -5**: Average daylight back-of-module temperature (line plots) and daily PR of Pm (dot plots) for some c-Si and a-Si based modules measured in different locations during the period May 2010 to December 2012.*

3. International collaboration within the project

In 2013 SUPSI staff was involved in the following activities:

- Preparation of a new standard for the characterisation of multi-junction technologies: 82/771/NP (future “IEC 60904-8-1 Measurement of spectral response of multi-junction photovoltaic (PV) devices”) and 82/772/NP (future document “IEC 60904-1-1 Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices”).
- Results of this project are used to support the preparation of technical reports within IEA PVPS Task 13 ‘*Performance and Reliability of Photovoltaic Systems’*
- Participation at the 3rd international spectral irradiance intercomparison campaign held in Puertollano (Spain) organised by RSE and in cooperation with JRC-Ispra.

4. Summary and outlook 2014

The spectral response measurement procedure for single-junction modules was accredited ISO 17025 and the solar simulator up-graded with a new electronic load and spectrum radiometer, which is the first step to prepare the final measurement procedure and uncertainty analysis for multi-junction modules and to extend the accreditation.

First current bias tests on polycrystalline thin film modules gave promising results and will be considered in future stabilisation procedures. In parallel an enhancement of the existing light soaking facility is ongoing, which will be fully implemented in 2014.

The monitoring of 11 different thin film modules have been continued and the data used for the validation of a new modelling approach and for an inter-comparison of module performance data from different locations. The last year of the project will be used to finalise the analysis of the performance data and for the inter-comparison of different modelling approaches.

Last but not least a new procedure for the measurement of angle of incidence effects will be introduced.

5. References

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PERFORMANCE PLUS

Annual Report 2013

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Project- / Contract Number	PERFORMANCE PLUS / 308991
Duration of the Project (from – to)	From November 2012 to November 2015
Date	December 5th 2013

ABSTRACT

For a continued decrease of levelised costs of electricity from photovoltaics (PV), the prices of modules, inverters and balance of system (BOS) components have to be further decreased while performance, functionality, reliability and lifetime on the component and system level need to be increased. The PV industry has made large technological progress with PV cells, modules and inverters in terms of costs and reliability. However, in an integrated view, PV system performance emerges from, but is not limited to the performance of the components. Consequently, Performance Plus explicitly focuses on the PV system rather than on the component level. Modules and inverters are studied with focus on their functioning within a system. The main idea of the project is to optimise the system as a whole rather than the separate components only.

Goals

The consortium aims at developing and demonstrating models and tools, beyond the state of the art, for monitoring, control and testing of PV systems, thus serving to optimize and enhance the performance, reliability and lifetime of commercial PV systems. Means for a better integration of PV-generated electricity into the power system shall be provided by methods for short-term forecasting, integrated energy management and storage control, PV system monitoring and control. The goal is to improve the competitiveness of PV on the system level. This will be achieved by optimizing the system as a whole rather than the separate components only.

The resulting collection of tools (toolbox) will be applicable to the decisive phases in the life cycle of a PV plant, namely, design, operation and maintenance. All R&D results and models will be validated with empirical data. The resulting tools will be demonstrated.

The specific scientific and technical objectives of Performance Plus are:

- Robust system design modelling for diligent design and bankability,
- Robust operational modelling for optimizing the system output,
- Integrated energy management and storage control,
- Real time monitoring and control: sensors communication and feedback,
- Hardware and software tools for testing,
- Validation, demonstration and target control.

Brief description of the project

For a continued decrease of levelised costs of electricity from photovoltaics (PV), the prices of modules, inverters and balance of system (BOS) components have to be further decreased while performance, functionality, reliability and lifetime on the component and system level need to be increased. The PV industry has made large technological progress with PV cells, modules and inverters in terms of costs and reliability. However, in an integrated view, PV system performance emerges from, but is not limited to the performance of the components. Consequently, Performance Plus explicitly focuses on the PV system rather than on the component level. Modules and inverters are studied with focus on their functioning within a system. The main idea of the project is to optimise the system as a whole rather than the separate components only.

Activities performed and achieved results

The main activities performed by SUPSI are related to two of the nine work packages, WP3 and WP5.

During 2014 and 2015 a big effort will be accounted also the WP7, related to define future possible commercial possibilities (software and tools) from the experience and the knowledge achieved.

WP	Work package title	Leader
WP1	PV system design modelling	IMEC
WP2	Operational PV system	UOL
WP3	**Integrated energy management and storage control**	KUL
WP4	Tools for monitoring and control	3E
WP5	**Procedures and tools for laboratory and field testing**	SUPSI

WP6	Demonstration and validation of overall tools	AIT
WP7	*Valorisation*	SUPSI
WP8	Dissemination and networking activities	3E
WP9	Project management	3E

Inside WP3 the SUPSI role is to develop and test a simplified model for energy storage with batteries inside the Modelica framework, to achieve this objective is under testing a model that includes calendar aging and cycling aging.

International collaboration

Performance Plus is the result of unique international collaboration between the market, the industry and high level research. The 8 partners in Performance Plus consortium represent expertise from system operators, PV component manufacturers, renewable energy experts and researchers.

The main interactions for SUPSI are with:

3E sa

Established in 1999, 3E is an independent consultancy & software services company. 3E provides guidance as well as solutions to improve renewable energy system performance, to optimize energy consumption and facilitate grid and market interaction. 3E pursues innovation to provide leading energy intelligence and practical solutions to our customers. 3E is certified ISO 9001:2008 since early 2010. 3E has worked on projects in more than 30 countries and operates with an international team of around 100 experts from its headquarters in Brussels and offices in Toulouse, Beijing, Istanbul and Cape Town.

Katholieke Universiteit Leuven

KU Leuven boasts a rich tradition of education and research, which dates back six centuries. KU Leuven is the largest university in Belgium in terms of research expenditure, which exceeded EUR 347 million in 2010, and research output, e.g. 5200 international peer-reviewed publications and 626 PhD degrees in 2010. KU Leuven participates in over 370 highly competitive European research projects (FP7, 2007 up to 2011), including 33 of the prestigious European Research Council grants and 85 Marie Curie Actions, which places KU Leuven fifth in the European HES ranking (4th FP7 monitoring report, Aug. 2011). KU Leuven is core partner in InnoEnergy and delivers the European institute of Innovation and Technology (EIT) PhD degree label.38% of KU Leuven’s PhD students and 36% of its postdoctoral researchers are international scholars.

KU Leuven’s contribution to Performance Plus will come from the research group Thermal Systems (TS) within the Division Applied Mechanics and Energy Conversion (TME). The research focus of the Thermal Systems group is on thermal systems, for which it has been shown that significant energy savings can be reached by using model based predictive control (MPC) strategies.

AIT Austrian Institute of Technology GmbH

AIT Austrian Institute of Technology GmbH is Austria’s largest non-university research organisation with more than 900 employees. In the field of electricity networks and distributed energy resources AIT’s main expertise is in low and high voltage technology, power quality, safety and reliability analysis. AIT has long term experience in active integration of distributed generation in distribution networks and related applications.

Furthermore, AIT is represented in several technology platforms and is involved in the European Electricity Grid Initiative (EEGI), the EERA Joint Programmes on Smart Grids and PV and several Implementing Agreements of the International Energy Agency (ISGAN, IEA-PVPS).

Evaluation of year 2013 and perspectives for 2014

During 2013 the SUPSI activities focused more on WP3 where our researchers developed a simplified model for Modelica of a standard battery, taking in account the main phenomenon that affect performances:

- Relationship between state of charge and open circuit voltage
- Lifetime and depth of discharge
- Calendar aging
- Self-discharge

The purpose of this submodel is to be implemented inside a more complex system that includes also photovoltaic arrays, inverters and loads; inside this system Katholik University of Leuven will test their own algorithm to optimise the overall performances. The goal of this optimisation can be set to achieve different goals, namely maximum self-consumption, maximum lifetime, reliability, or a combination of these.

Regarding the Work Package 5, the revision of existing procedure for indoor and outdoor testing is in progress.

For next year SUPSI planned to put a big effort on WP5, that and the main activities planned regard existing and innovative analysis on PV systems, both indoor (at module level) and outdoor (at module and system level):

- Determination of statistical distribution of module performances over system lifetime, mismatches in array, degradation variability, interaction between these effects and on inverter maximum power point tracking
- Study of possible analysis through impedance spectroscopy
- Improvement on the uncertainty determination
- Extrapolation of STC or other conditions
- Evolution over time of Fill Factor
- Low irradiance performances
- Sorting methods for module installation
- Potential (or Polarization) Induced Degradation
- Thermography
- Distribution of environmental parameter (temperature, humidity and wind speed) over module arrays

These activities will be performed typically on medium and big size plant (from 100kW to multi MWs) thanks to users group of the project, further measurements will be performed on TISO 10, the 30 years old photovoltaic installation in SUPSI facility, that can give a lot of knowledge about modules and system aging.

Moreover during 2014 it will continue the support to Leuven group to improve our model inside their library of optimization algorithms.

References

http://www.perfplus.eu/ Website of the project

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

CARACTERISATION DES MODULES PHOTOVOLTAÏQUES A COLORANT DE L'ENTREPRISE G2E

Annual Report 2013

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Project- / Contract Number	SI/500794 / SI500794-01
Duration of the Project (from – to)	2012 - 2014
Date	02.12.2013

ABSTRACT

The company "Glass To Energy" (g2e) in Yverdon, is industrializing dye solar panels on the basis of DSC "Grätzel" technology, developed at EPFL.

The panels will be integrated on walls and other building elements.

A solar simulator for measuring the performance of such electrical panels, including an IV measurement tool, is going to be realized.

Then the panels will be installed in real conditions and monitored over a complete year, in order to characterize and have the necessary perspective on this technology.

The project started in October 2012. Since, various electronic loads have been developed for 10x10cm and 60x100cm panels. The schedule is retarded for the measurement structure on the roof.

Résumé

L'entreprise Glass To Energy (g2e), à Yverdon, industrialise la fabrication de panneaux solaires à colorant sur la base de la technologie DSC «Grätzel» développée à l'EPFL. Les panneaux sont développés pour être intégrés dans des façades et autres éléments construits.

Dans un premier temps il s'agit de mettre en place un simulateur solaire pour la mesure des performances électriques des panneaux, dit outil de mesure IV, I courant, V tension. Cet outil sera dédié à cette technologie et adapté aux tailles de panneaux réalisés par g2e.

Ensuite il est prévu d'installer des panneaux en condition réelle et de les suivre sur une année complète, afin d'avoir le recul nécessaire sur cette technologie et d'en établir les caractéristiques.

Le projet a démarré en octobre 2012. Depuis, deux charges électroniques ont été développées, spécifiques aux panneaux de taille 10x10cm et aux panneaux de taille 60x100cm. Un support climatisé pour le test des cellules 10x10cm est en cours d'achèvement. La partie test en conditions réelles est retardée ; les développements côté charges et mesures sont développés mais l'entreprise g2e a subi du retard dans la fabrication des panneaux. L'installation sera montée et les mesures réalisées dès que ceux-ci nous seront parvenus.

Buts du projet

L'objectif de l'entreprise g2e est de favoriser l'utilisation de la technologie DSC et de développer un produit industriel de grande taille à intégrer dans les façades. Le produit est développé en fonction des besoins du marché en partenariat avec de grands industriels façadiers. La perspective est pragmatique et délibérément orientée vers des applications concrètes. L'atout principal de cette technologie est sa transparence, sa flexibilité dans le design et le choix des couleurs.

Les panneaux DSC de type industriel issus de la fabrication g2e ne sont pas encore connus, les cellules doivent donc être caractérisées de manière à établir leurs performances.

Dans un premier temps il s'agit de mettre en place un simulateur solaire pour la mesure des performances électriques des panneaux, dit outil de mesure IV, I courant, V tension. Cet outil sera dédié à cette technologie et à cette taille de panneaux.

Ensuite il est prévu d'installer des panneaux en condition réelle et de les suivre sur une année complète, afin d'avoir le recul nécessaire sur cette technologie.

A partir de ces campagnes de données, il sera possible de faire des modèles afin de les rendre exploitables par les logiciels de simulation photovoltaïque classiques de type PVsyst.

Puisque la technique est orientée vers l'intégration aux bâtiments, il s'agira ensuite de créer un logiciel de simulation dédié, pour les acteurs du domaine tels les architectes, les énergéticiens mais aussi des services techniques des administrations ou des entreprises. Le rôle de de la HEIG VD sera ici de constituer la base de donnée nécessaire au futur développement d'un tel logiciel.

Travaux effectués et résultats acquis

Les travaux effectués peuvent être résumés de manière suivante:

- 9.10.12 démarrage du projet (kick-off meeting avec l'entreprise g2e le 8.11.12).
- Octobre à décembre 2012: réalisation des charges électroniques passives et de l'acquisition
- Année 2013: conception et réalisation d'une électronique passive permettant la mise en charge et la mesure/acquisition de 25 panneaux solaires « g2e » de manière simultanée. Conception d'un plateau climatisé (-10 à +90°C) et d'une charge électronique active permettant des tests étendus des cellules 10x10 cm. Etude pour la réalisation d'une charge active pour les panneaux 60x100cm.

La charge électronique développée en 2012 (voir Fig. 1) est uniquement résistive. Ceci implique qu'elle n'impose aucune tension ni courant à l'objet testé. Elle se comporte comme une résistance variable pouvant varier de 0.1 Ω à environ 30 kΩ. Les limites extrêmes de la charge en tension et courant sont adaptables (physiquement) aux différents types de cellules/panneaux. La plage de travail de la charge dépend de la configuration physique de certains éléments sur la carte électronique. La charge est commandée à l'aide du logiciel Labview, depuis le PC branché sur la charge au moyen d'une connexion USB. L'acquisition des résultats se fait par le même canal.

La charge a été intégrée dans le simulateur solaire et la place de test présenté sur la Figure 1.

Fig. 1 : Place de travail avec charge électronique et acquisition sur PC

Le logiciel d'acquisition basé sur Labview effectue une calibration lors de la première utilisation, puis la mesure est réalisée en commençant par détecter quels sont les extrêmes de la cellule à mesurer (Icc et Uoc). Ensuite la caractéristique de la cellule est parcourue en contrôlant la tension, en partant de Uoc jusqu'à 0 V. Sur l'interface PC (voir Fig. 2), l'utilisateur peut régler les différents paramètres de mesures, permettant certains ajustements selon l'expérience pratique avec les différentes cellules ou conditions d'éclairage.

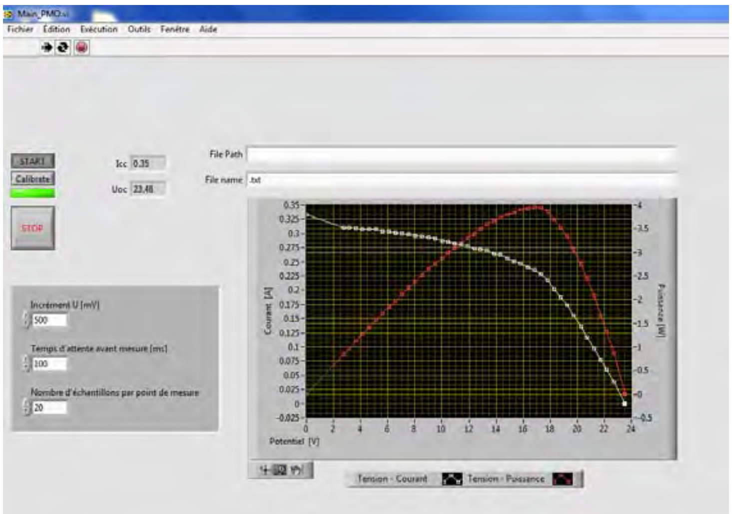

Fig. 2 : Interface utilisateur avec réglages et visualisation de la caractéristique UI

Un post-traitement Matlab permet l'édition d'un rapport avec les caractéristiques de la cellule type « catalogue » et la représentation de la caractéristique VI.

Charge électronique pour des tests en conditions réelles

En 2013, afin de mettre en œuvre le système de test des panneaux en en condition réelle, une charge dédiée a été réalisée. En se basant sur le principe testé et approuvé de la petite charge passive, une charge similaire a été réalisée. Cette-ci est composée de 25 charges indépendantes, permettant de tester 25 panneaux en parallèle (voir Fig.3).

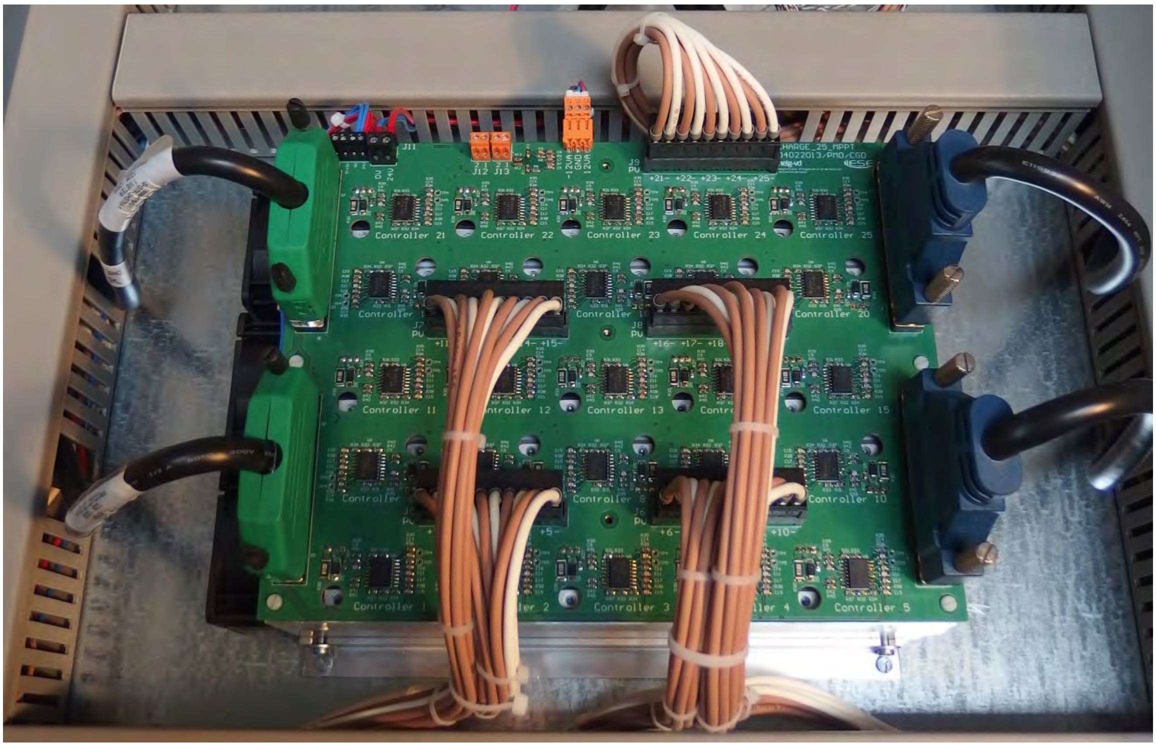

Fig. 3 : Charge électronique 25 MPPT

Le système développé permet de mettre 25 panneaux solaires photovoltaïques en charge (MPPT ou caractérisation IV), faire l'acquisition de la tension, du courant et de la température des 25 panneaux ainsi que de mesurer les conditions ambiante, à savoir la température ainsi que l'irradiation directe et diffuse. Ce système fonctionne de façon autonome. Une fois que les mesures auront commencé, les données seront accessibles via ftp sur le réseau local de la HEIG-VD (ou via le VPN, de l'extérieur) ou par USB directement sur le système d'acquisition.

Charge électronique active avec contrôle de la température

Afin de caractériser des cellules de façon plus étendue, une charge active (permettant d'absorber ou de fournir de l'énergie aux panneaux) a été conçue. L'intérêt d'une charge active est de pouvoir mesurer les points d'intersection de la caractéristique IV avec les axes de tension et de courant. Pour ce faire, il faut pouvoir travailler dans trois quadrants (voir Fig.4). Ceci implique de pouvoir imposer une tension supérieur à celle générée par la cellule, ainsi qu'une tension négative.

D'autres applications sont de pouvoir mesurer le courant d'obscurité de la cellule ou d'appliquer un courant forcé.

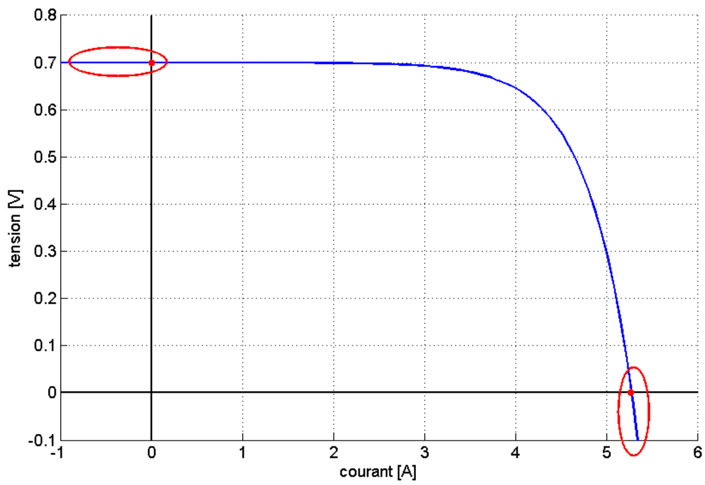

Fig.4 : Illustration des intersections avec les axes de tension et de courant

La figure 5 illustre la carte électronique conçue. Cette carte sera contrôlée via un programme Labview qui permettra de contrôler le plateau climatisé ainsi que la charge active, selon les besoins de l'opérateur.

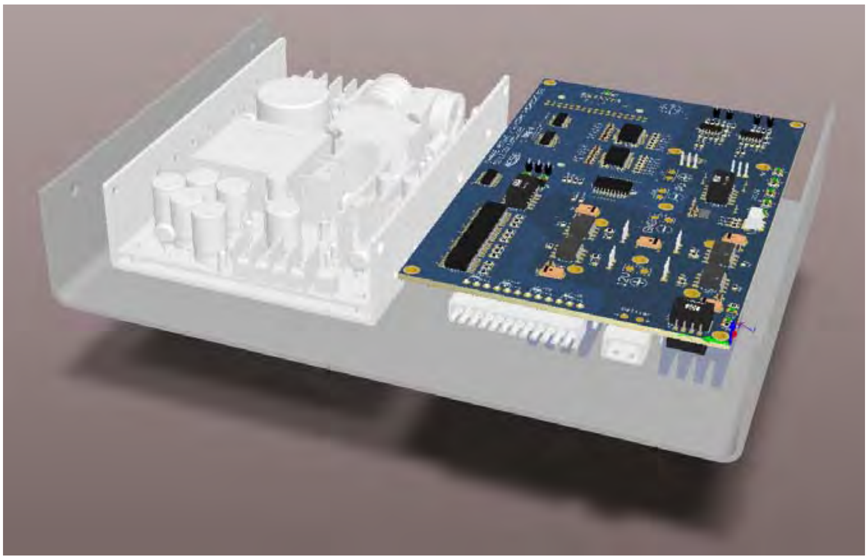

Fig. 5 : Illustration de la charge électronique active avec contrôle de température

Le plateau climatisé aura une amplitude de réglage de [-10 à +90°C]. Ceci permettra de pouvoir caractériser les cellules en température. La figure 6 illustre le prototype de plateau thermique réalisé. De la bande adhésive noire mate a été collée sur le plateau afin d'avoir une lecture correcte de la température lors de la thermographie.

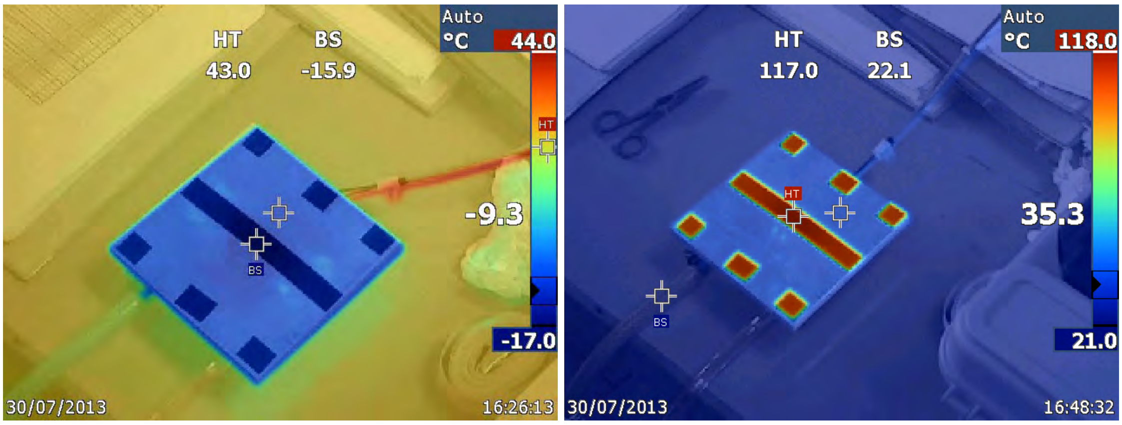

Fig. 6 : Illustration du plateau climatisé réalisé

Charge électronique active pour des panneaux 100x60 cm

Une charge active permettant de caractériser des panneaux entiers a été étudiée. Celle-ci pourra caractériser des panneaux « g2e » de 100x60 cm. La capacité de cette charge sera de ±60V, ±10A. Elle sera réalisée prochainement, le matériel nécessaire est en commande.

Collaboration nationale

Cette collaboration ainsi que les premiers éléments développée sont régulièrement présentés par l'entreprise g2e aux investisseurs et partenaires de l'entreprise. Des demandes d'offres pour le développement de systèmes similaires sont parvenus à la HEIG-VD; à suivre.

Collaboration internationale

Aucune collaboration internationale n'a été établie pour le moment dans le cadre de ce projet spécifique.

Évaluation de l’année 2013 et perspectives pour 2014

Les charges électroniques pour deux types de panneaux ont pu être développées fin 2012, ainsi que le logiciel d’acquisition des courbes IV. Celles-ci fonctionnent à satisfaction, et ont déjà permis à l’entreprise g2e d’effectuer des contrôles de base.

L’année 2013 a vu la conception et la réalisation d’une électronique passive permettant la mise en charge et la mesure/acquisition de 25 panneaux solaires « g2e » de manière simultanée. Toutefois, le montage des panneaux g2e sur le toit et leur branchement à ce système a dû être retardé, faute de panneaux disponibles. L’entreprise souhaite attendre et tester un meilleur lot, fabriquée avec de nouveaux produits, présentant de meilleures caractéristiques. D’entente avec g2e, il est convenu d’installer/mesurer le plus vite possible déjà 5 panneaux, à placer dans les positions principales E, S, O, N et horizontalement. Les 12 autres prévus (sur 17) seront placés au printemps 2014.

L’intégration du contrôle de température (-10 à +90°C) et de la charge électronique active permettant des tests étendus restent à faire pour les cellules 10x10cm. La réalisation d’une charge active pour les panneaux 60x100cm reste à réaliser. Aucune difficulté n’est attendue pour atteindre ces objectifs.

La priorité pour l’année 2014 est l’installation des panneaux dans l’installation de test « outdoor » en conditions réelles, les mesures et leur analyse. Nous espérons dégager des premiers résultats en été 2014. La prolongation du projet jusqu’à la fin 2014 s’avère nécessaire.

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Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

PHOTOVOLTAIK IM VERBUND MIT DÄMMSTOFF FOAMGLAS

Annual Report 2013

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Project- / Contract Number	SI/500582 / TP Nr.: 8100146-02
Duration of the Project (from – to)	Dezember 2010 - März 2014
Date	16. Dezember 2013

ABSTRACT

As a pure electrical power producer, the photovoltaic technologies are established. The development of “In-roof-systems” has proved to be effective. Besides the electrical power production, in-roof-systems serve also as roof panels and water protection. Unknown are systems, where the photovoltaic in addition to the power production and the water protection has the function of thermal insulation. The scope of this project is the development and realization of building integrated photovoltaic (BIPV) including the feature of thermal insulation. A pilot plant with modules combined of photovoltaic modules and Foamglas insulation shall be build.
The project “Photovoltaic with Foamglas insulation” was initiated in spring 2010 and was started officially in December 2010. In 2011 the market requirements and main concepts have been elaborated. In 2012 the concepts have been detailed and proved in various tests. Furthermore, a pilot project has been evaluated.

Following results were achieved in 2013:

- Outdoor test
  The measurements of the outdoor test have been continued and the final report by SUPSI, Gabi Friesen and Thomas Friesen, Lugano 22 jul.2013 has been released.
  Outdoor energy yield measurements confirmed, that façade integrated micromorph modules leads to the same performance, independently of the level of integration (thermal back insulation or back ventilation).
- Pilot Project
  Oerlikon AG sold its division Oerlikon Solar to Tokio Energie Limited (TEL).
  A reorganization with the new management from Japan lead to postponement of the pilot project by almost a year. However, In December 2013 the management from TEL gave green light to go ahead with the pilot.

Short summary of the targets for 2013:

- It is planned, to start with the opening of the facade in February 2014 and to install the new insulation with PV modules in March 2014 and to start the measurements.

Outdoor Test Results

Summary of the final Report by SUPSI Gabi Friesen and Thomas Friesen, Lugano 22 jul.2013.

Test facility

On the outdoor test facility modules and temperatures are monitored. To determine the effect on module performance of the back insulation the best of the 2 ventilated modules, module H3, is chosen for reference. The module H3 has the highest initial STC power and low light performance (P1, GCO1).

Fig. 1: Outdoor test facility (source: SUPSI)

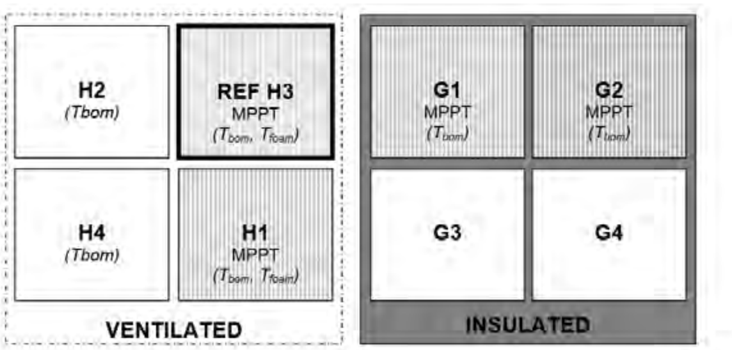

Fig. 2: Concept of measurement outdoor test facility (source: SUPSI)

Module temperature

The daily profiles show a systematic higher temperature of the top ventilated module respect to the bottom ventilated module and of the insulated modules respect to the ventilated one. The insulated modules are in average about 4 °C warmer than the ventilated modules. If no thermal annealing would occur the insulated modules should perform slightly worse than the ventilated one, but as shown later the thermal annealing compensates the thermal losses leading to an almost identical performance when having the module mounted into a façade.

Performance Ratio

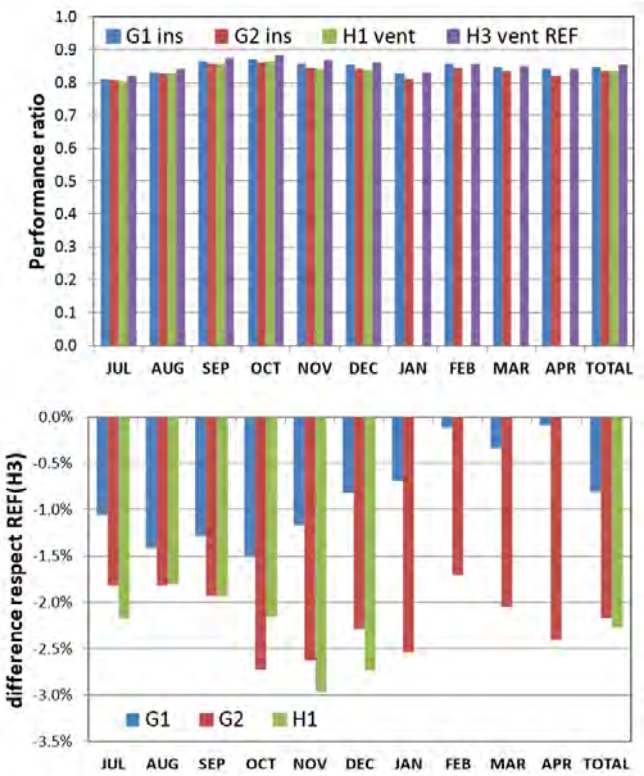

Fig. 3: Results of the outdoor performance measurements (source: SUPSI)

With nameplate power Pnom as reference, the PR differences with respect to the module H3 is all within 0 to -3%. The PR differences are below the module manufacturer tolerance and the STC power measurement accuracy and can be consequentially considered to be not significant.

The technological inter-comparison with measured STC power (P1) as reference, leads to an almost identical performance of ventilated and insulated micromorph modules. The higher thermal losses due to back insulation and a negative temperature coefficient are fully compensated by thermal annealing.

Performance at Standard Test conditions (STC)

To have the highest possible accuracy the reference STC power for kWh/Wp calculations are measured with a class A+A+A+ solar simulator and a spectrally matched reference cell. To detect any degradation, the modules are measured before and after outdoor exposure.

Negative changes in the range of 2- 6% have been measured. How much of the variations are due to a real degradation of the modules and how much due to the measurement accuracy or stabilization procedure is not clear. The differences are actually within today's measurement accuracy of multi-junction devices and at this stage no real conclusion on degradation can be done.

Conclusions

Outdoor energy yield measurements in combination with indoor performance measurements confirmed, that façade integrated micromorph modules manufactured by Oerlikon leads to the same performance, independently of the level of integration (thermal back insulation or back ventilation). The thermal losses (due to the negative temperature coefficient) of the insulated façade modules are fully compensated by the annealing effects occurring at higher temperatures.

Both solutions (1) ventilated façade and (2) insulated façade lead potentially to the same energy yield.

Pilot Project

Oerlikon AG sold its division Oerlikon Solar to Tokio Energie Limited (TEL).

A reorganisation with the new management form Japan leads to postponement of Pilot Project by almost a year. However, In December 2013 the management from TEL gave green light to go ahead with the pilot.

Fig. 4: Visualisation on overview of the planed pilot project in Trübbach (Source Google maps)

Fig. 5: left: south west facade with insulated and a ventilated field (12 modules each)
right: south east facade with 10 insulated modules

It is planned to start with the opening of the facade in February 2014 and to mount the new foamglas insulation with PV models in March 2014 and to start the measurements.

SOLAR BRICK

INNOVATIVE PHOTOVOLTAIC AND THERMAL INSULATING BUILDING MATERIALS

Annual Report 2013

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Project- / Contract Number	KTI13186.1
Duration of the Project (from – to)	01.12.2011 – 30.09.2013
Date	29.11.2012

ABSTRACT

The project is financed by the KTI under the project number: 13186.1 PFFLI-IW.

Goal of the project is to develop a photovoltaic and thermal insulating building material suitable for roof installation. This building material has been intensively tested and demonstrated by SUPSI on a prototype installation including said material. The economic and technical feasibility were central and have been complemented by many laboratory tests and simulations before install it on a real building. SUPSI/ISAAC and Designergy SA (which has developed a Patent portfolio of the “solar brick” concept) were the main partners for the engineering. This team was further completed by a third partner, namely Alex Gemperle AG, which provides financing, engineering and the workforce necessary for the final complete installation on a real building. In the framework of this project SUPSI developed special test for BIPV system in order to prove the reliability of the system also in accordance with the building and electrical regulations.

Aims of the project

At present day, there is a huge potential in the building sector to diminish the energy demand of the existing building stock, first of all by reducing the heat losses of the envelope by reducing the building construction's the heat transfer coefficient (U-value). In particular the roof, together with the window area, is responsible for the main heat losses during the cold seasons. Secondly, if we would like to reduce the energy balance of a building we can produce the energy needed by the building itself, thanks to the installation of onsite Photovoltaic PV (or Thermal) systems. Presently, Building Added PV (BAPV) applications are, in most of cases, a common solution to install PV on buildings especially in retrofit solutions; while different international research programs encourage and support solutions that favour the complete integration of photovoltaic devices as an architectural element since many years: Building Integrated Photovoltaic (BIPV).

How to provide the building sector with only a "one piece system," including all building coverings (e.g. roof) and a PV system, and install it in one step reducing also the used material is the ambitious goal DESIGNERGY and SUPSI addressed with this project.

Indeed, the Solar Brick project focuses on the development of a photovoltaic and thermal insulating building material (called Structurally Integrated Solar Building Element "SISBE") and in parallel to plan and construct a prototype installation, including the mentioned material. The economic and technical feasibility were central and have been complemented by many laboratory tests and simulations before installing it on a real building.

SUPSI/ISAAC and Designergy SA were the main partners for the engineering. Further research partners were Pramac Swiss SA, which provided, at the beginning of the project, photovoltaic modules for the first prototypes and Alex Gemperle AG, providing engineering support when needed and which offers a complete roof for the final installation in Sins.

The advantages of this new concept are multiple:

- Reduce the investment cost of roof and PV system;
- Reduce pay-back time of the PV system;
- Reduce in a longer term pay-back the whole roof and
- Provide a tailor made thermal insulation in a roof

After 21 project months the project came up with an innovative BIPV solar element, that can be installed both on new and existing buildings replacing the conventional roof and thermal insulation. Different module dimensions and PV technologies are possible in order to answer customer's needs.

Fig. 1: Left picture shows a special rain penetration test developed by SUPSI. The whole roof is completely water-tight. Right photo shows the prototype roof installed at Sins.

The building integration photovoltaic sector becomes more popular and, consequently, professional interest is increasing. The photovoltaic technology is the only way to achieve integrated delocalized electrical energy production. The cost of the modules is decreasing more quickly than other building elements. At present, most roof-top PV systems and the roofs underneath are separate entities. In Building Integrated Photovoltaics (BIPV), the PV modules substitute the most external building layer, as for example the tiles.

The core idea of the SISBE (Structurally Integrated Solar Building Element), patented by Designergy is to integrate different functions of the building envelop (such as thermal insulation and water protection) in one element and system which is able to produce electricity thanks to the integration of photovoltaic modules present on the outer surface. This approach allows therefore also achieving the highest thermal insulation standards required in modern buildings that are usually not considered while mounting a PV system on a roof.

Work carried out and results achieved

The project officially started in December 2011 and finished in September 2013.

1. Define the material suitable for the SISBE preparation

A technical team was created with the target of developing the final idea of SISBE. After several follow up meetings the first prototype and the related installation design was defined. Main requirement of the SIBSE were:

- Electricity production by means of integration of Photovoltaic technology
- Thermal insulation (U-value of the whole SISBE less than 0.2 W/m2 K)
- Water tightness of the roof system by the use of ad-hoc fastening system
- Mechanical stability
- Reliability of the system
- Architectural integration
- Aesthetical quality
- Standard compliance

Different photovoltaic technologies have been tested within the project in order to quantify the requirements described above. In particular the reliability of the system and the influence of the working temperature and of the humidity on the photovoltaic module efficiency and on the system.

Thin film technology (micromorph modules) and crystalline modules have been evaluated.

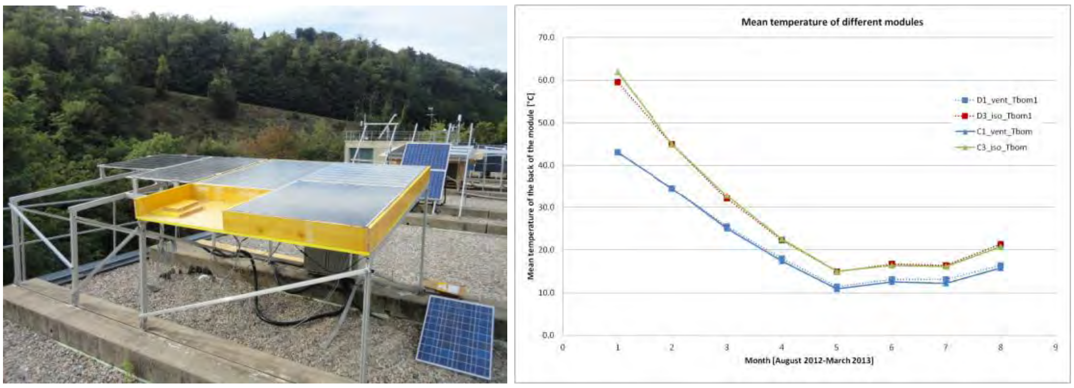

Fig. 2: Left picture shows a test stand where different technologies have been investigated during the project. Right pictures show the mean temperature of ventilated and non-ventilated modules.

2. SISBE Prototype roof

Different SISBE prototypes where produced at Swiss PV Module test centre (SWPVMTC, SUPSI) in order to be able to perform different tests: mechanical and aging tests mainly. By the end of 2012 Designergy was able to design and install a first production line that is able to assemble the SISBE accurately and faster.

First hand made PV roof element where installed in Trevano Campus in order to simulate a wood structured roof and test the whole system (9 BIPV modules connected with a new mounting system developed within the project) under real condition: irradiation, rains, snow. The way to install the roof has been also tested.

Special tests have been developed at SUPSI to prove the water tightness of the roof (see Fig. 3).

The inclination of the wooden structure roof is about 6°, which according to Swiss construction regulation SIA is supposed to be the lowest roof inclination possible for the solar tile installation and represents extreme conditions.

Fig. 3: In order to test the water tightness of the roof and of the developed fastening system a special outdoor test was installed to simulate rain and wind.

3. Development and implementation of a monitoring system

In terms of monitoring tools we installed in the roof thermal, humidity and water sensors and 4 of the 9 SISBEs were connected to MPPT (developed by ISAAC-SUPSI) in order to measure and keep track of the productivity of the PV modules. Special software was also developed.

4. Identify the best PV technologies through outdoor tests and measurements

Different PV Technologies were tested and monitored in order to identify the best solution in term of cost-effectiveness of the SISBE (energy performance, cost,…)

The first monitoring campaign of Micromorph and Crystalline Technology modules gave positive results for the identification of the commercial module to be integrated in the SISBE (see Fig. 2).

5. Define a roadmap through the SISBE qualification (IEC and CE mainly)

Since a specific standard on BiPV modules, which could be suitable for the SISBE and its mounting system is still missing, an overview and a deeper analysis of the exiting PV (in particular IEC) and Construction (in particular SIA and construction product regulation CPR) standards have been done in order to test and validate the SISBE system as a multifunctional Building component.

6. Pilot production line

The production pilot line was installed in Designergy head quarter in February 2013 (in Lugano) and it was used for the production of more the 45 elements for the first real roof installation on a building owned by the installing partner GEMPERLE AG. The roof is located in Sins.

48 modules were installed with two different orientations (East and West). The pitched roof has an inclination of about 6°, which represents the limit we suppose to cover with the SISBEs.

Different modules have been equipped with thermal couples and humidity/water sensor in order to monitor the behaviour of the roof.

Fig. 4: West side of the first roof in Sins.

Evaluation 2013 and future prospects

The project was completed successfully.

An innovative building material for integrated photovoltaic (BIPV) roof has been developed within the present project; according to the purposes of the project, the element can be used to cover pitched roofs. Further development can be done by Designergy to optimize the system cost and to increase the industrialization of the system. The large prototype roof in Sins will be continuously monitored by SUPSI and Designergy in the next year in order to be able to further optimize the system.

The project pointed also out that it not easy to test and qualify special BIPV product due to the lack of harmonized standard for these system. For this reason SUPSI developed special test to be able to verify the reliability of the BIPV system.

SOLAR FALTDACH – URBAN PLANT
Steueralgorithmus und Modulmontage

Annual Report 2013

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Date	31.01.2014

ABSTRACT

The approach of BOS cost reduction presented here is a newly developed PV plant which automatically stores the PV modules in a protection box in case of bad weather conditions. Avoiding the mechanical load stress at bad weather conditions implies that only a fraction of the mechanical load is present on the PV modules and the structure, enabling light weight structural design. Light Energy developed the urban plant as a promising double-use of land application for PV power production in urban areas using PV carports onto parking lots, which require less massive structures and foundations relative to fixed existing solutions.

The newly developed PV plant is folding the PV generator into a protection box and will pull out the PV generator, carried on two supporting cables for operation during good weather conditions. Thus one of the main tasks of the presented research project is the development of an innovative autonomous control system. Thus local meteo sensors and regional weather information are used to generate the automatic activation of the safety mode status. The PV modules of the 48kW Urban Plant prototype in Balzers, Liechtenstein are mounted six meters above a parking lot with the benefit of full double use of the land below. Thus a PV system has been built with currently 48 kW nominal power, 16 meter wide, with a folding roof of PV modules expanding 25 meters in one direction. The system can be extended to 96 kWp with a second folding roof expanding into the other direction. As special PV system design was developed with a light weight PV generator using module laminates with special mounting elements. Moreover the system comprises innovative string wiring and inverters that can be also integrated into the safety box.

Einleitung / Projektziele

Dieses Forschungsprojekt hat zum Ziel neue Steueralgorithmen sowie neue Montagesysteme für die vollständig neue Modulunterkonstruktion von Solarmodulen über z.B. Parkplätzen zu entwickeln, die bei extremen Wetterbedingungen eingefahren werden, um so z.B. Vorteile beim Materialeinsatz gegenüber fest montierten PV-Modulen zu erzielen.[1] Die Modulhalterungen von konventionellen grossen z.B. 200kW PV-Dachkraftwerken haben in den letzten Jahren enorm an Bedeutung gewonnen. Dies im gleichen Masse, in dem die Kostenanteile der Solarmodule an den Gesamtkosten auf etwa 45% gefallen sind, bei verbleibenden Kosten für die Unterkonstruktion inkl. Montage von ca. 30%.[2]

Die Start-up Firma LE - Light Energy Systems AG (Light Energy) hat sich in Zusammenarbeit mit den beiden ZHAW Departementen Technik, was die PV Technologien betrifft und dem ZHAW Department Architektur bezüglich der Unterkonstruktion dieser Fragestellung angenommen. Diese Projekt wird von der KTI mitfinanziert, worüber hier ein kurzer Zwischenbericht gegeben wird.[3]

Anlagenkonzept

Die Firma Light Energy konnte im Juni 2013 den ersten Prototypen der Urban Plant mit einer Nennleistung von 24kW in Balzers in Betrieb setzen und erweiterte die Anlage auf 48 kWp im Juli 2014. [4] Die Photovoltaikmodule (1m x 2m mit 72 kristallinen Siliziumzellen) wurden zu 2x20 Stück im String in Serie geschalten. Jeweils zwei solche Modulpaare wurden nebeneinander in 10 Reihen (4 Meter breite Bahnen) auf Tragseilen montiert.(Abb. 1) Ein umlaufendes Steuerseil faltet den PV Generator für den Normalbetrieb auf eine Länge von ca. 20 Meter aus. Eine SPS Steuerung [5] gibt aufgrund eines Algorithmus der unter anderem auch auf die Daten der lokalen Meteosensoren zugreift, den Befehl zum Einfahren in die Schutzposition, sodass alle PV Module in der „Protection-box“ vor Wind und Wetter geschützt sind.(Abb. 3)

Das Urban Plant Produktfamilie ist modular konzipiert in Vielfachen von UP50 Einheiten die auf einer Grundfläche z.B. eines Parkplatzes von 25 Meter mal 16Meter Platz finden. Beispielsweise beherbergt die UP100 in der „Protection-box zwei 48kW PV Module die sich in beide Richtungen ausfalten lassen, sodass sie eine Gesamtlänge von 50 Meter überspannen.(Tab. I)

Um sicheres Einfahren auch bei Stromausfall des Energieversorgers zu gewährleisten, ist ein Batteriespeicher eingesetzt der dann während der Einfahrphase die etwa eine Minute dauert, die Versorgung der Antriebsmotoren übernimmt.

Der Vorteil dieses Faltsystems liegt darin, dass die mechanische Unterkonstruktion der Modulhalterung nicht auf den maximalen mechanischen Lastfall bei Sturm und Schnee auslegt werden muss, da sich das Faltdach bei widrigen Bedingungen in der Schutzeinrichtung befindet. So benötigen fixe PV Carportlösungen massive Betonfundamente (ca. 900 kg/kWp) und eine aufwändige Stahlunterkonstruktion während das Urban Plant nur ein Zehntel dessen benötigt, was sich sowohl positiv auf die Kosten, den CO_2 Foot-print, wie auch auf die Bauzeit auswirkt.

Abbildung 1 Urban Plant 48kW Prototyp wurde im Juni 2013 in Balzers in Betrieb genommen.

Tabelle I: Urban Plant Nennleistungsdaten

	Pn[kW]	Länge[m]	Breite[m]
UP50	48	25	16
UP100L	96	50	16
UP100W	96	25	32
UP200W	192	50	32
UP200L	192	100	16
UP400	394	100	32

Entwicklung eines optimalen Steueralgorithmus

Die Analyse der Solareinstrahlungsdaten für den Standort des ersten Urban Plant Prototypen im föhnigen Rheintal zeigt, dass nur 5% der jährlichen Solareinstrahlung bei windigem Wetter, mit mittleren Windgeschwindigkeiten von über 6.7m/s im 10 Minuten Intervall vorliegt.(Abb. 2) Die empirische Annahme, dass dann die Windböen mit einer maximalen Geschwindigkeiten von ca. dem Doppelten der mittleren 10 min Windgeschwindigkeit entsprechen, konnte hier auf der Basis von 1 Sekunden Messwerten für den Standort Vaduz bestätigt werden. Daraus folgt, dass bei optimalem Steueralgorithmus an einem Föhnstandort mit 5% Solarverlusten zu rechnen ist und dabei die maximale Windböe mit der die PV Module belastet werden kleiner 14m/s ist. Aber es zeigt auch, dass 1% Solarverlust mit maximalen Böenspitzen von ca. 18m/s zu erwarten ist. Die Detailanalyse zeigt auch, dass diese maximalen Windgeschwindigkeiten in der Böe hier nur etwa 10 bis 20 Sekunden über dem Wert von 10 m/s liegen. Allerdings ist in einem Fall auch eine maximale Windgeschwindigkeit von 30m/s gemessen worden, bei 9m/s mittleren Windgeschwindigkeiten im zehn Minuten Intervall.

Wird aber von den 1-Sekunden Windmessdaten ausgegangen und in der einfachsten Variante von einer festen Abschaltschwelle von 12m/s so betragen die minimal erzielbaren Solarverluste 4.6% (wobei hier die typischen Einfahrzeiten berücksichtigt wurden).Andere wenige exponierte Standort wie jene im Föhntal, zeigen deutlich geringere Windlasten und damit auch deutlich geringere Solarverluste. So zeigen Standorte von denen Sekundenmessdaten des Windes vorliegen, wie Einsiedeln oder Seuzach, dass mit den gleichen Abschaltschwellen wie im Föhntal hier die minimal möglichen Verluste unter 1% liegen.

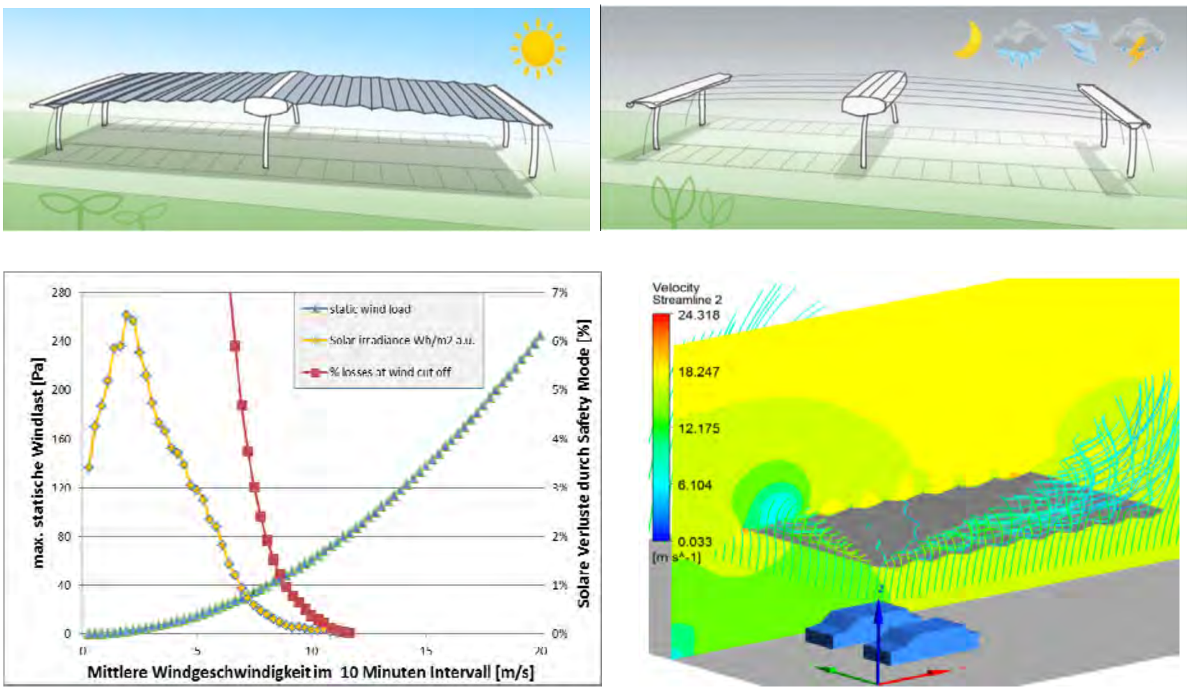

Abbildung 2 Oben links *ist exemplarisch der Standardbetriebsfall der Stromerzeugung bei ausgefahrenem Solarfaltdach dargestellt. Dagegen zeigt das* ***Bild oben rechts*** *die Urban Plant im Safety Mode um bei extremen Wetterbedingungen die Anlage mit den PV Modulen zu schützen.* ***Darunter links*** *sind drei Verläufe als Funktion der mittleren Windgeschwindigkeiten am Standort Vaduz im Zeitraum 2004 bis 2008 mit einer mittleren Windgeschwindigkeit von 2m/s dargestellt, die da sind: gelbe Raute- Häufigkeitsverteilung der eingestrahlten Solarenergie im jeweiligen Windintervall; rotes Quadrat – die mittleren Verluste der Solarstrahlung wenn alle Solarerträge mit höheren Windgeschwindigkeit als dieser Schwellwert als Verlust verbucht werden und der Verlauf des statischen Winddrucks (grünes Dreieck) als Funktion der Windgeschwindigkeit.* ***Unten rechts*** *sind die Ergebnisse einer CFD Simulation der Windströmungsverhältnisse dargestellt bei einer Windgeschwindigkeit von 18m/s und einer Antströmung unter 45 Grad von leicht unten, wobei die inhomogenen Geschwindigkeitsspitzen durch die Strömungshindernisse durch die unten parkenden Autos euch berücksichtigt wurden.*

Im Rahmen dieses Teilprojektes wurde ein Steueralgorithmus entwickelt, der nicht nur die lokalen Wind- sondern auch weitere lokal erfasste Wetterdaten in die Analyse einbezieht. Ein zusätzlicher Optimierungsparameter ist die Zahl der Ein- und Ausfahrten der Anlage zu minimieren. Die Wirksamkeit des Einbezugs überregionaler Wetterinformation, wie sie via Web von verschiedensten Diensten, meist aber sehr grobmaschig vorliegen und auch Windwarnungen von nahen Flughäfen, werden aktuelle in den Algorithmus einbezogen und bewertet.

Aktuell zeigt sich dabei, dass diese lokalen Wettermessungen an der Anlage die wesentlichen Auslöser für die Steuerbefehle bleiben werden.

Innovative Modulhalterungsvarianten

In einem weiteren wesentlichen Arbeitspaket, werden innovative Ansätze für die Unterkonstruktion der „Safety Box“ untersucht, auch was die Wahl alternativer Materialien anlangt. Zusätzlich wurden auch Fachwerkträger als Ersatz für die Tragseile evaluiert, die speziell für Urban Plant am Gebäuden relevant werden könnte. Da der Hauptteil der Arbeiten in diesem Arbeitspaket allerdings erst in 2014 geplant ist, liegen dazu noch keine abschliessenden Erkenntnisse vor.

Abbildung 3 *Urban Plant während der Ausfahrphase.(linkes Teilbild) Im rechten Teilbild ist ersichtlich, dass ein LKW unterhalb der Urban Plant (lichte Höhe 4.5m) passieren kann.*

Zusammenfassung - erster Zwischenbericht

Da die Einfahrzeit der Urban Plant in der Grössenordnung von einer Minute liegt, war in der Analyse verschiedener wirksamer Steueralgorithmen, das Arbeiten mit selten verfügbaren Sekundenmesswerten des Windes notwendig, um die Böen-Wirkung zu berücksichtigen. Eine Erkenntnis aus der CFD Analyse konnte dahingehend gewonnen werden, dass die am Prototypen gemessen Eigenresonanzfrequenzen der Solarmodule auf dem Tragseil mehr als um den Faktor zehn kleiner sind, als jene Frequenzen die von den aerodynamischen Lasten von Windböen mit 12m/s angeregt werden, wodurch geschlossen werden kann, dass das Risiko zu kritischem Schwingverhalten nicht gegeben ist.

Die aktuellen Arbeiten der Entwicklung des Steueralgorithmus zeigen, dass in windreichen Föhnstandorten mit Solarverlusten von etwa 5% zu rechnen ist, jedoch an den meisten übrigen Standorten in der Schweiz eher 2% oder weniger erreichbar ist. Generell muss beachtet werden, dass das Wetter keine einfache kausale Maschine ist und dass lokal erfasste Messwerte unerlässlich sind, aber die Modellierung und Prognose der Windböen immer mit wesentlichen Unsicherheiten verbunden bleibt.

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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

LANGZEIT-MESSUNG VON PV-ANLAGEN

Annual Report 2013

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Project- / Contract Number	PV-Langzeitmessung
Duration of the Project (from – to)	01.01.2012 – 31.12.2016
Date	05.02.2014

ABSTRACT

Since 1992 the PV LAB of BFH-TI in Burgdorf has carried out several analytical monitoring projects with a continuously increasing number of plants. At present 40 grid connected PV plants are monitored. The purpose of these long-term monitoring projects is to register all relevant influences on energy yield, degradation mechanism, reliability, and life expectancy of grid-connected PV plants which cannot be detected during initial monitoring campaigns of 1 or 2 years. For some of the plants, very long monitoring periods of 20 years without gaps are available.

The economy is investing a lot of money into the PV technology. Consequently, the reliability of this technology is very important. The data collection of the PV lab contains important information about the reliability of PV components during the whole life cycle of the plant.

The funding of a project of more than 20 years is difficult, because many financing partners cannot see the benefits of long term measuring data of PV plants. At the moment, the survival of the project is on the edge because of inadequate funding.

Einleitung

Investiert die Volkswirtschaft sehr hohe Summen in eine Technologie, so ist deren Zuverlässigkeit sehr relevant. Seit 1992 erfasst das PV LAB der Berner Fachhochschule für Technik und Informatik (BFH-TI) die Betriebsdaten von netzgekoppelten Photovoltaikanlagen. Insgesamt werden zurzeit über 40 PV-Anlagen in der Messkampagne erfasst. Davon sind 13 PV-Anlagen mit einer Feinmesseinrichtung nach Abbildung 1 ausgestattet, welche unabhängig vom Wechselrichter DC- und AC seitig die Leistung, sowie die Einstrahlung, Modul- und Umgebungstemperatur mittels Datenlogger aufzeichnet. Die Daten werden in einer Auflösung von 5 Minuten (Mittelwerte) abgespeichert. Bei den restlichen PV-Anlagen wird eine Grobmessung durchgeführt, welche die ins Netz eingespeiste Energie in 15-Minuten Intervallen aufzeichnet. Informationen zur Einstrahlung und Temperatur werden von einer nahegelegenen Referenzmeteostation entnommen.

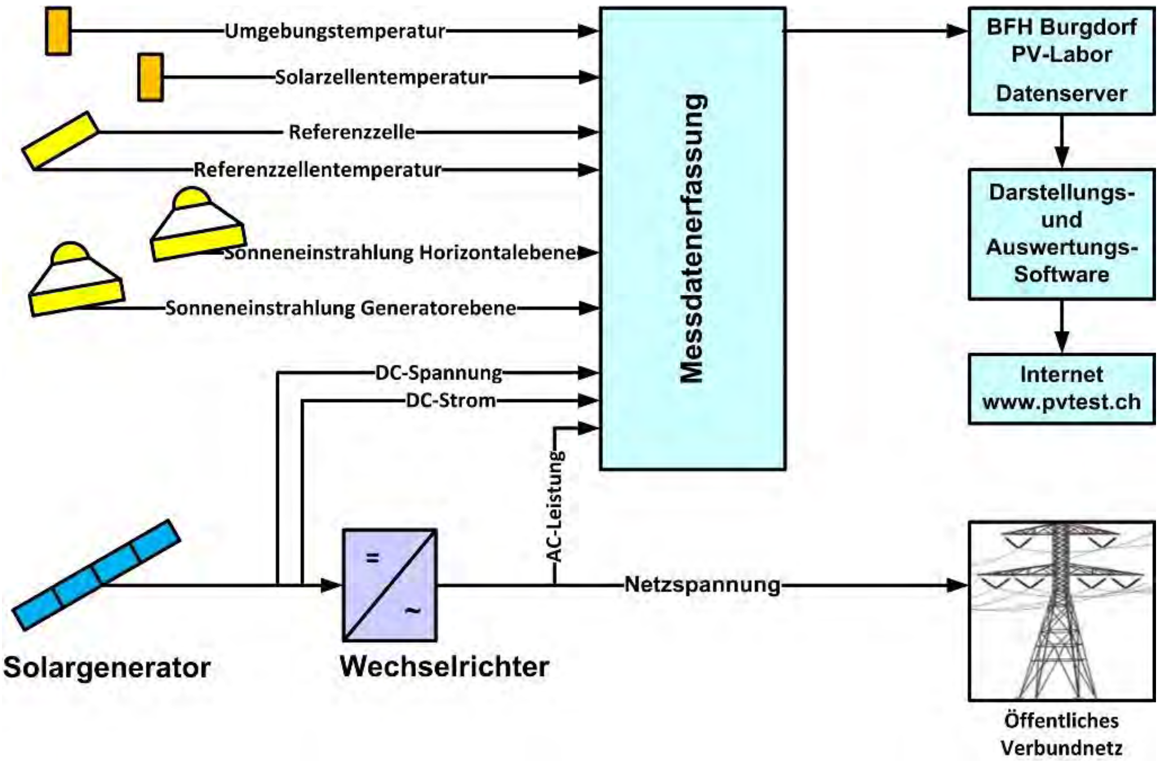

Abbildung 1: Allgemeine Darstellung der Feinmesstechnik einer PV-Anlage

Diese Langzeitkampagne wird seit Beginn unterbrechungsfrei geführt. Das Messprogramm gehört zu den weltweit am längsten und mit feiner Auflösung geführten Messkampagnen, so wird angenommen. Aus den Datenreihen des PV LABs können interessante Aussagen u.a. zur Zuverlässigkeit von PV-Anlagen gewonnen werden. Diese Messreihen beweisen auch den erfolgreichen Langzeitbetrieb von kristallinen PV-Anlagen, Probleme dieser Technologie wie Delamination, Verschmutzung sind daraus ersichtlich.

Die Finanzierung eines Projektes über einen Zeitraum von mehr als 20 Jahren sicherzustellen erweist sich als äusserst schwierig. In der Vergangenheit wurde die Messkampagne hauptsächlich durch das Bundesamt für Energie (BFE), der Gesellschaft Mont-Soleil (GMS) und Localnet finanziert. Seit dem Jahr 2010 hat die Messkampagne ernsthafte Finanzierungsschwierigkeiten. Einzig die Gesellschaft Mont-Soleil hat in den letzten zwei Jahren das Projekt finanziell unterstützt. Seit dem Jahr 2010 wurde mehrmals vergeblich ein Antrag zur Forschungsunterstützung beim BFE eingereicht. Im letzten Jahr wurde wegen den knappen finanziellen Ressourcen der Fokus auf die Akquisition von neuen Unterstützungsgeldern gelegt. Die Messinfrastruktur wurde regelmässig unterhalten, um die Qualität und Kontinuität der Messreihen sicherzustellen. Die Auswertung der Messdaten musste aufgrund der zunehmend prekären finanziellen Projektsituation auf ein Minimum reduziert werden.

Kurzbeschrieb der Messinfrastruktur

In der Abbildung 1 ist das gesamte Messnetz der Langzeitkampagne schematisch dargestellt. Die blau eingefärbten Rechtecke stehen für die PV-Anlagen aus der Feinmessung. Der Anlagename, sowie die wichtigsten Anlageinformationen sind in den Rechtecken, unter den Nummern 1 bis 5 aufgeführt. Im grün eingefärbten Rechteck sind die Namen aller PV-Anlagen aus der Grobmessung aufgeführt. Die Referenzmeteostation erscheint in Rot. Bei jeder PV-Anlage sind die vorhandenen Meteo- und Temperatursensoren eingezeichnet. Weiter ist in der Grafik enthalten, wie die Datenübertragung zum Server des PV LABs stattfindet. Dies geschieht entweder über eine Festnetzverbindung, über das Mobilfunknetz (GSM), Internetverbindung oder direkte Verbindung mit RS232-Schnittstelle zum Server. Die Messdaten von PV-Anlagen aus der Grobmessung müssen vor Ort ausgelesen und manuell in die Datenablage eingefügt werden. Die Daten aus der Feinmessung werden entweder über eine Internetverbindung alle fünf Minuten oder ein Mal pro Tag über eine Telefonverbindung an den Datenserver gesendet. Dieser speichert die Messdaten auf einem internen Laufwerk der BFH-TI ab.

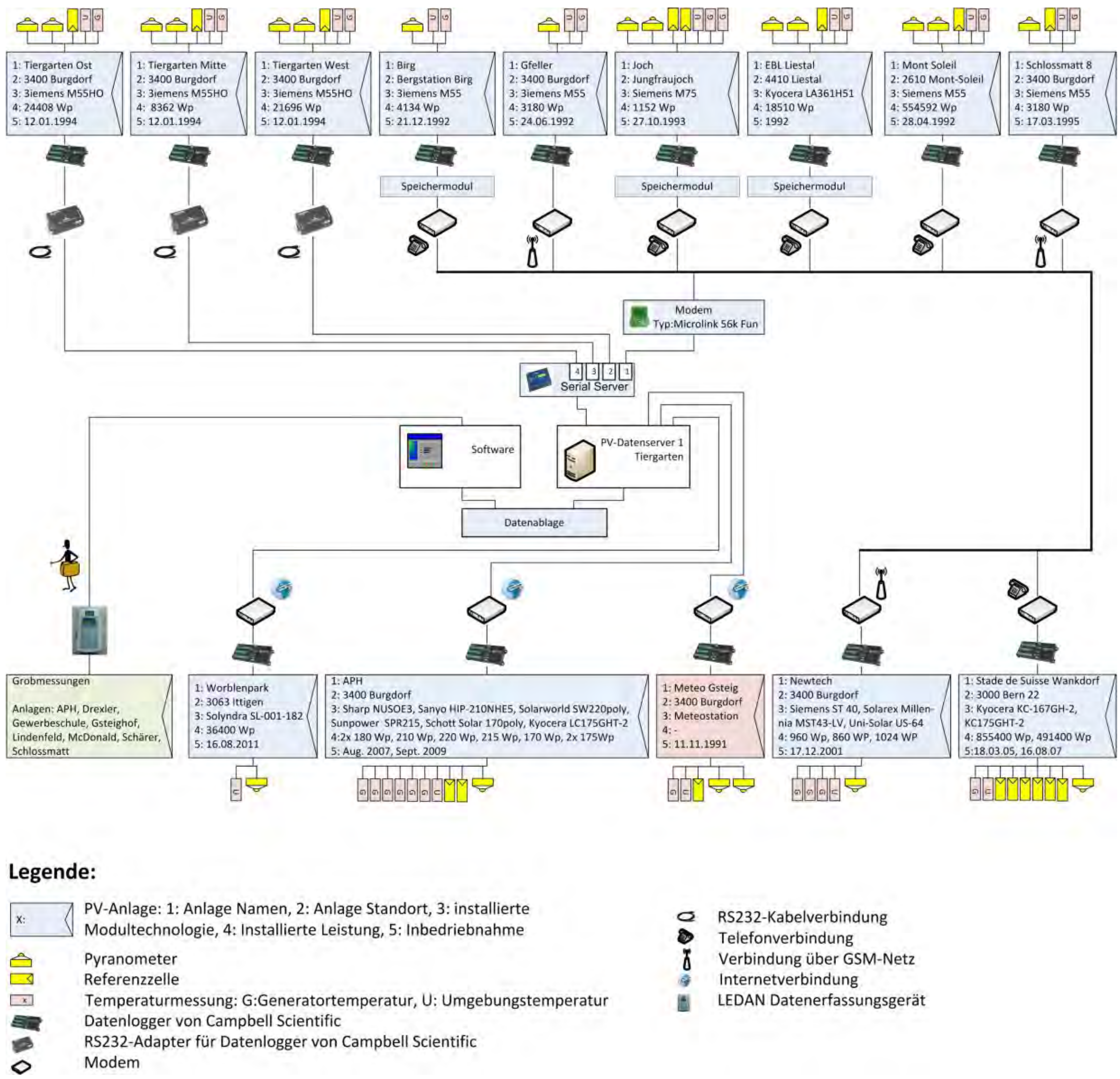

Abbildung 1: Übersicht Messinfrastruktur der Lanzeitkampagne des PV LAB

Durchgeführte Arbeiten und erreichte Ergebnisse

Neue PV-Anlage mit Feinmessung ausgerüstet

Die PV-Anlage APH besteht aus 8 Teilgeneratoren mit unterschiedlichen kristallinen Modultechnologien. Diese Anlage wurde in der Vergangenheit mit einem handelsüblichen Monitoringsystem gemessen. Dadurch war es unmöglich die verschiedenen Teilgeneratoren untereinander zu vergleichen. Aus diesem Grund entwickelte das PV LAB im letzten Jahr eine Feinmesstechnik speziell für diese PV-Anlage. Die Messtechnik konnte Mitte Jahr installiert werden und liefert seit dem 8. August 2013 die Betriebsdaten der einzelnen Teilgeneratoren. Die Messreihe lässt seither einen Vergleich der verschiedenen kristallinen Modultechnologien zu.

Kennlinienmessung der drei Teilgeneratoren von der „PV-Anlage Newtech“

Die visuelle Degradation der drei Teilgeneratoren ist stark fortgeschritten. Vor allem der Teilgenerator drei, welcher aus Modulen vom Typ Uni-Solar US-64 besteht, scheint von der visuellen Degradation stark betroffen zu sein. Die Abbildungen 2 und 3 zeigen den identischen Ausschnitt aus dem Teilgenerator Newtech 3, einmal im Mai 2011 aufgenommen und das andere Mal im September 2013.

Abbildung 2: Ausschnitt eines PV-Moduls (2 Modul v.l in der hinteren Reihe) des PV-Generator Newtech 3 aus dem Mai 2011

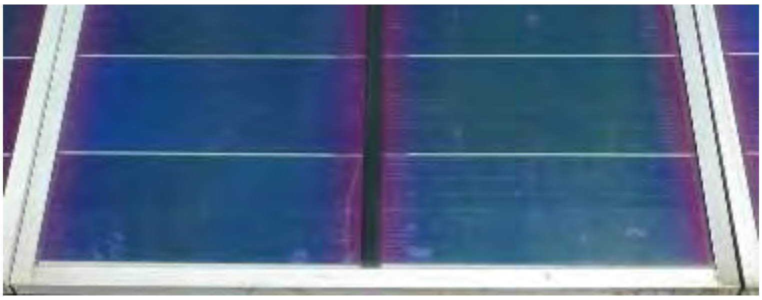

Abbildung 3: Ausschnitt eines PV-Moduls (2 Modul v.l in der hinteren Reihe) des PV-Generator Newech 3 aus dem September 2013

Unterhalt der Messinfrastruktur

Die Messinfrastruktur für die Monitoringkampagne wurde, wie in den vergangenen Jahren regelmässig gewartet. Ausserordentliche Wartungen der Messinfrastruktur fanden bei den Anlagen Mont Soleil, Newtech und Tiergarten Ost statt. Bei den Anlagen Tiergarten Ost und Mont Soleil wurde der Wechselrichter ausgetauscht. Aus diesem Grund musste die Messhardware entsprechend dem neuen Wechselrichter angepasst und wieder in Betrieb genommen werden. Ein Wechselrichter der PV-Anlage Newtech war im Juni ausgestiegen, konnte nach der Reparatur wieder eingesetzt werden.

Bewertung 2013 und Ausblick 2014

Im vergangenen Jahr stand die Akquisition von Projektgeldern zur Projektweiterführung im Zentrum. Werden genügend Unterstützungsgelder gesichert, kann die Messkampagne in Zukunft weitergeführt werden. Im August 2013 wurde die Feinmessung der PV-Anlage APH erfolgreich gestartet. Erste Auswertungen der Messdaten und Vergleiche der verschiedenen Modultechnologien werden nach Beendigung des ersten Messjahres, im September 2014 durchgeführt.

Es sind für das Jahr 2014 Erweiterungen des Messnetzes mit modernen PV-Anlagen geplant. So soll eine einachsig nachgeführte PV-Anlage und ein Carport im Raum Burgdorf mit Messtechnik ausgerüstet werden.

Auf dem Jungfraujoch soll neben der bestehenden PV-Anlage eine neue moderne PV-Anlage für die Forschung entstehen. Die Planung der Anlage wurde während mehreren Projektarbeiten von Studenten der BFH-TI erarbeitet. Im Sommer 2014 soll die Anlage nun erbaut und mit einem Feinmessystem ausgerüstet werden.

Das bestehende Datenablagesystem aus den 90-er Jahren ist für umfangreiche Messreihen und viele verschiedene PV-Anlagen ungeeignet. Einzelne Daten für eine Publikation können nur mit viel Aufwand aus dem Ablagesystem entnommen werden. Die bestehende Datensammlung soll in eine zeitgemässe Datenbank mit einer webbasierten Visualisierung integriert werden. Die Ergebnisse dieser Langzeit-Messkampagne werden durch die Webapplikation einerseits einer breiten Öffentlichkeit zur Verfügung stehen. Andererseits sollen vertrauliche Messdaten von laufenden Forschungsstudien nur für berechtigte Benutzer zugänglich sein.

PRÜFSTAND FÜR MULTISTRING-SOLARWECHSELRICHTER

Annual Report 2013

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Date	06.12.2013

ABSTRACT

The goal of this project is the development and the construction of a low EMI test bench for research and testing of multistring PV inverters. The test bench shall be able to simulate three independent sub arrays with open circuit voltage of up to 1'000V and maximum power of 11.52kW each. The thermal stability of the generated I/V characteristics shall be sufficiently high to allow measurements of the inverter's MPP tracking accuracy.

In preparation of this project, commercially available systems for the simulation of PV arrays were evaluated. Because none of the evaluated products matched our needs, it has been decided to self-construct the PV array simulator according to our requirements. The major component of this simulator is a powerful, liquid cooled, low drift, controllable linear current source based on latest generation linear power MOSFETs. To achieve good dynamic behaviour and high flexibility, the control and V/I curve generation is realised with a high speed digital circuit based on an FPGA and fast, high resolution data converters.

So far, the work included the development of a prototype of the linear current source and the V/I curve generation. Also, some groundwork for the liquid cooling system has been done. All of these components have been tested successfully. It is planned, that the test bench will be fully operational by beginning of 2015. Until then, the PV array simulators have to be built, the control and measuring software has to be written and the test location has to be set up. The test bench will then be a versatile research platform for development and testing of multistring PV inverters.

Einleitung

Im Rahmen des Projekts „Prüfstand für Multistring-Solarwechselrichter“ soll ein Testplatz aufgebaut werden, welcher es erlaubt, Solarwechselrichter mit bis zu drei MPP-Trackern vollumfänglich, normgerecht und realitätsnah zu prüfen. Herzstück des Prüfstands bildet ein Solargenerator-Simulator, welcher es erlaubt, drei voneinander unabhängige Solarkennlinien zu generieren. Im Vorfeld des Projekts wurde recherchiert, ob auf dem Markt verfügbare Solargenerator-Simulatoren den hohen Anforderungen für den Einsatz in einem Prüflabor gerecht werden. Keines der untersuchten Geräte vermochte jedoch vollumfänglich zu Überzeugen. Die wesentlichen Schwachstellen der kommerziell erhältlichen Simulatoren waren hohe EMV-Störungen, ungenügende Regelgeschwindigkeit, zu kleiner Spannungsbereich und zu hohe Erdkapazitäten. Deshalb wurde entschieden, den benötigten Solargenerator-Simulator selbst zu entwickeln.

Der geplante Simulator besteht aus drei Teilsimulatoren. Davon kann jeder eine Kennlinie mit einer Leerlaufspannung von bis zu 1‘000V und einem Kurzschlussstrom von bis zu 32A generieren. Wird eine Kennlinie gemäss EN50530 (Füllfaktor 72%) verwendet, beträgt die maximale MPP-Leistung 11.52kW. Bei höheren Füllfaktoren werden auch Leistungen von über 13kW möglich, womit der Prüfstand über 40kW Solarleistung simulieren kann. Um gute dynamische Eigenschaften zu erreichen und EMV-Störungen zu vermeiden, basiert der Solargenerator-Simulator auf einem linearen Design und verfügt über eine schnelle, FPGA basierte Regelung. Da im Betrieb beträchtliche Verlustleistungen auftreten können, werden flüssigkeitsgekühlte Leistungshalbleiter der neusten Generation (1‘500V Linear MOSFET) eingesetzt.

Für die Steuerung des Prüfplatzes im Allgemeinen und des Simulators im Speziellen wird eine Software geschrieben, welche es erlaubt, vollautomatische Messprozeduren gemäss EN50530 an Solarwechselrichtern durchzuführen. Daneben werden Programmroutinen implementiert, welche eine manuelle Steuerung der Simulatoren ermöglichen, wie sie beispielsweise bei für EMV-Messungen oder Sicherheitstest gemäss VDE 0126-1-1 und VDE-AR-N 4105 notwendig ist.

Die Arbeiten 2013 umfassten die Entwicklung des Leistungsteils und der digitalen Kennlinienerzeugung für die Simulatoren. Diese beiden Komponenten wurden mittlerweile erfolgreich getestet. Zudem wurden grössere Vorarbeiten für den Aufbau der Flüssigkeitskühlung getätigt und die Protokolle für die Kommunikation zwischen dem Steuercomputer und den einzelnen Teilsimulatoren festgelegt.

Kurzbeschrieb des Projekts

Der geplante Solargenerator-Simulator basiert im Wesentlichen auf einer Leistungsstarken, hochstabilen, steuerbaren Stromquelle, welche durch lineare Power MOSFET realisiert wird. Die Kennlinienerzeugung und die Regelung erfolgen durch eine schnelle FPGA basierte Digitalschaltung. *Fig. 1* zeigt das stark vereinfachte Prinzipschema eines Teilsimulators.

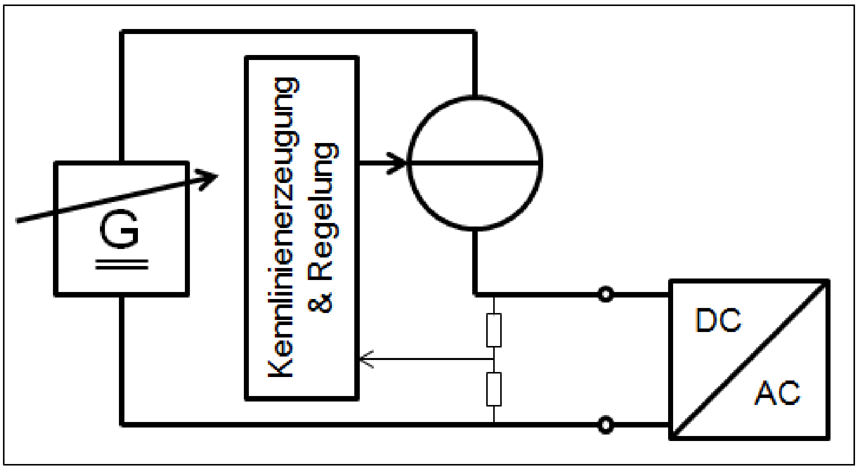

Fig. 1: *Prinzipschema eines Teilsimulators*

Die steuerbare Stromquelle ist die Komponente, welche die Qualität des Simulators am massgeblichsten beeinflusst. Die Quelle soll ein schnelles Regelverhalten zeigen, darf aber unabhängig von der angeschlossenen Last nicht schwingen. Damit diese beiden konkurrierenden Eigenschaften erreicht werden können, wird die Quelle ausgangsseitig mit einem ohmsch-kapazitiven Dämpfungsglied beschaltet. Eine Ausgangskapazität ist aber bei einem Solargenerator-Simulator grundsätzlich unerwünscht, weshalb dieses Glied so klein wie möglich gehalten wird. Ein weiteres qualitätsbestimmendes Merkmal der Stromquelle ist die thermische Stabilität des Ausgangsstromes, denn diese wirkt sich direkt auf die Stabilität der Kennlinie aus. Damit Messungen der Trackinggenauigkeit von Wechselrichtern überhaupt möglich sind, darf die Kennlinie des verwendeten Solargenerator-Simulators höchstens im Promillebereich driften. Die letzte grosse Herausforderung beim Bau der Stromquelle stellt die Kühlung der Linear MOSFET dar. Wird im Betrieb der Ausgang des Simulators kurzgeschlossen, fällt die gesamte Spannung über der Stromquelle ab. So können pro Teilsimulator kurzzeitig bis zu 16kW Verlustleistung entstehen. Selbst im Normalbetrieb kann die Verlustleistung etwa 1…2kW betragen. Aufgrund der kompakten Abmessungen der Stromquelle entsteht so eine beträchtliche Leistungsdichte. Deshalb erfolgt die Kühlung der Stromquelle mit einer Leistungsstarken Flüssigkeitskühlung.

Die digitale Kennlinienerzeugung und Regelung ist für die Qualität des Simulators ebenfalls sehr entscheidend. Damit ein schnelles Regelverhalten erreicht wird, darf die Reglerschaltung keine grosse Totzeit in den Regelkreis einbauen. Um dies zu erreichen, werden schnelle AD- und DA-Wandler (3 MSPS / 16 Bit) und eine Kennlinienberechnung ohne Pipeline-Delay eingesetzt. Die Totzeit der Regelung beträgt damit weniger als 1µs. Da eine Echtzeitberechnung in dieser kurzen Zeit nicht möglich ist, werden die Kennlinien vorgängig berechnet und in einem Flash-Speichermodul abgelegt. Dieses bietet Platz für 65‘536 Kennlinien, welche im Betrieb beliebig umgeschaltet und skaliert werden können.

Die Speisung des Simulators erfolgt über programmierbare Speisegeräte. Da die Teilsimulatoren unabhängig voneinander funktionieren sollen, ist pro Teilsimulator ein eigenes Speisegerät notwendig. Um die Verlustleistung der Stromquelle in Grenzen zu halten, wird die Spannung der Speisegeräte der Ausgangsspannung nachgeregelt, wozu eigens eine Schaltung entwickelt wird. Bei den vorgesehenen Speisegeräten handelt es sich um Schaltnetzteile. Damit die Messungen nicht durch EMV-Störungen der Speisegeräte verfälscht werden, müssen diese entstört werden. Dabei ist es jedoch entscheidend, dass keine nennenswerten Erdkapazitäten eingebaut werden, da ansonsten der Test von trafolosen Wechselrichtern verunmöglicht würde (Ansprechen der Fehlerstromdetektion).

Für die Steuerung der Simulatoren wird eine Steuerschaltung entwickelt. Diese übernimmt die Kommunikation mit dem Steuercomputer, die Konfiguration der Kennlinienerzeugung, die Fehlerüberwachung und sämtliche Schaltfunktionen. Das Herzstück der Steuerschaltung wird ein leistungsfähiger Cortex-M4 Microcontroller (32-Bit) sein.

Durchgeführte Arbeiten und erreichte Ergebnisse

Die bisherigen Arbeiten konzentrierten sich auf die Entwicklung der steuerbaren Stromquelle und der digitalen Kennlinienerzeugung. Die Prototypen dieser besonders kritischen Komponenten wurden mittlerweile erfolgreich getestet. Das Material für den Bau dieser Komponenten für den ersten der drei Teilsimulatoren ist grösstenteils vorhanden oder bestellt, so dass diese voraussichtlich noch vor Jahresende gefertigt und getestet werden können. Während die digitale Kennlinienerzeugung praktisch auf Anhieb funktionierte, erwies sich die Entwicklung der Stromquelle (verkleinerter Prototyp mit nur 4A Maximalstrom) als noch schwieriger als ohnehin angenommen. Die Probleme entstanden vor allem dadurch, dass die eingesetzten Linear-MOSFET über eine sehr hohe HF-Verstärkung und über beträchtliche, stark spannungsabhängige Eingangskapazitäten verfügen. Als Folge davon neigte der erste Prototyp je nach Arbeitspunkt zum Schwingen. Dies konnten durch ein grösseres Redesign der Schaltung in den Griff bekommen werden.

Um die Stromquelle unter realistischen Bedingungen testen zu können, wurden bereits umfangreiche Vorarbeiten für die Flüssigkeitskühlung durchgeführt. Da auf dem Markt verfügbare Flüssigkeitskühler entweder für unsere Zwecke ungeeignet oder nur zu exorbitanten Preisen erhältlich sind, wurde ein auf unsere Anwendung massgeschneidertes Produkt entwickelt. So ist ein Frässtück entstanden, welches sich mit Hilfe einer CNC-Fräse ohne grossen Aufwand aus einem Standardprofil fertigen lässt. Eine Messung mit dem Prototyp der Stromquelle und diesem Flüssigkeitskühler zeigte, dass bei einer Montagefläche von 153cm2 problemlos eine Verlustleistung von mehr als 1.4kW abgeführt werden kann. Das entspricht etwa der doppelten Leistungsdichte einer normalen Herdplatte. *Fig. 2* zeigt ein Bild des Prototyps der Stromquelle montiert auf dem Flüssigkeitskühler.

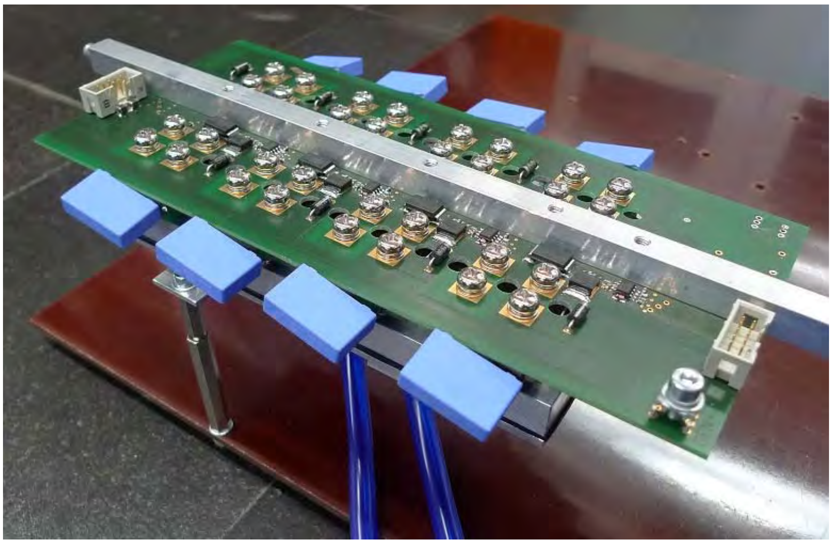
Fig. 2: *Ansicht des Stromquellen-Prototyps auf dem Flüssigkeitskühler*

Bewertung 2013 und Ausblick 2014

Die Projektziele für das Jahr 2013 wurden zum grössten Teil erreicht. Aufgrund der genannten Probleme bei der Entwicklung der steuerbaren Stromquelle gab es kleinere Verzögerungen. Da jedoch die Entwicklung der digitalen Kennlinienerzeugung sehr rasch voran kam, konnte dies teilweise wieder kompensiert werden. Das Wichtigste ist aber dass bewiesen wurde, dass das Schaltungsprinzip der Stromquelle funktioniert und dem Bau des Multistring-Prüfstandes mit den angestrebten Leistungswerten nichts mehr im Weg steht.

Das kommende Jahr wird durch eine Vielzahl von Entwicklungsarbeiten geprägt sein. Diese umfassen auf der Hardwareseite primär die Steuerschaltung. Dazu kommt ein umfangreiches Softwareprojekt zur Erstellung des Steuer- und Messprogramms für die Simulatoren und die Messgeräte. Nicht zu unterschätzen sind die ganzen mechanischen Arbeiten und der Aufwand für den Aufbau des Prüfplatzes, welcher unter anderem über einen AC-Anschluss von 70kVA verfügen muss. Der erste der drei Teilsimulatoren wird voraussichtlich im Frühsommer fertiggestellt und getestet werden. Spätestens im Frühjahr 2015 soll der Prüfstand in Betrieb genommen werden und als attraktive Forschungsplattform für die Entwicklung und den Test von Multistring-Solarwechselrichtern zur Verfügung stehen.

PHOTOVOLTAÏQUE ET NEIGE

Horizon des solutions pour l'installation sur les toits dans les régions enneigées

Annual Report 2013

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Date	15 November 2013

ABSTRACT

Winter 2012/2013 was marked by important snowfall and a long winter period. Despite the problems in the acquisition of data, measurement campaign conducted highlights the follow-ing points on the different studied technologies:

- Automatic snow clearing solution Eulektra:
  The data for the consumption of this solution are not available. However, the clearing solution was running very often during our various visits. This leads us to the conclusion that we had last year: The balance (production minus consumption) over the winter period is negative. To be effective, other parameters as snow depth, temperature, weather forecast should regulate the device. This year we were able to measure the temperature of the modules depending on the outside temperature. For -4°C, the panel temperature is 11°C. This allowed us to define the operating range of this solution,

- Manual snow clearing solution Solutronic:
  The data acquisition didn't work for this solution (production and consumption). Same conclusion as last year prevail: this is an interesting solution if someone is on site and takes into account the various parameters to have an efficient installation,

- Polymer application Freso:
  The measurement campaign has failed to highlight the effectiveness of this solution. We hope to have better results with a greater tilt,

- Double face modules Sanyo HIT Double:
  These panels allow a greater output per kWc, especially with a thin layer of snow (about 15-20% more efficient). In addition, a small thickness of snow is more rapidly cleared due to the heat lib-erate by the rear cells. With more substantial snowfall, the bottoms of the panels are on the snow forbidding the snow to be evacuate,

- Amorphous modules Flexcell:
  The modules are on the ground and the thick layer of snow not allowed them to produce.

Résumé

Globalement, l'hiver 2012/2013 a été marqué par des épisodes neigeux conséquent et une longue période d'enneigement ne permettant pas de réaliser des mesures sur la totalité de la saison (épaisseur de neige trop importante). Malgré les problèmes dans l'acquisition des données dont nous avons été victime, cette campagne a permis de faire ressortir les points suivants des différentes technologies étudiées:

- Inversion de courant automatique Eulektra:

  L'acquisition des données n'a pas fonctionné pour cette solution. Néanmoins, l'inversion de courant était en marche très souvent lors de nos différentes visites et ceci nous amène à la même conclusion que nous avions eu l'année dernière: Le bilan (production – consommation) sur la période hivernal est négatif. D'autres paramètres doivent être pris en compte avant d'enclencher cette solution aux moments judicieux: épaisseur de neige, température, météo des prochains jours,… Cette année nous avons pu mesurer la température des modules en fonction de la température extérieure: pour une température de -4°C, les modules ont une température de 11°C. Ceci nous a permis de définir la plage de fonctionnement de cette solution.

- Inversion de courant manuelle Solutronic:

  L'acquisition des données n'a pas fonctionné pour cette solution. La même conclusion que l'année dernière s'impose: c'est une solution intéressante si une personne est sur place et prend en compte les différents paramètres permettant un gain énergétique de l'installation.

- Polymère rendant les capteurs hydrofuge (solution FRESO):

  La campagne de mesure n'a pas permis de mettre en avant l'efficacité de cette solution. Une inclinaison supérieure des modules permettra potentiellement de la mesurer.

- Panneaux à modules en face arrière Sanyo HIT Double:

  Ces capteurs permettent un plus grand rendement par kWc, surtout lors de faibles chutes de neige (environ 15-20% plus efficace). De plus, une faible quantité de neige (10 cm) est plus rapidement évacuée grâce à la chaleur crée par les cellules en face arrière. Lors de chutes de neige plus conséquentes, le bas des capteurs se trouvent dans la neige empêchant une bonne évacuation de celle-ci.

- Modules amorphe Flexcell:

  Aucune mesure n'a pu être possible durant la période hivernale. Les modules étant au sol et l'épaisse couche de neige les recouvrant totalement.

Figure 1: Vue des installations après la première chute de neige, le 12.12.12

Description du projet

Le projet, en partenariat avec le canton de Neuchâtel, Viteos SA et Planair SA, se base sur une installation didactique sur les toits du Lycée Blaise Cendrars à La Chaux-de-Fonds.

Il est prévu de comparer la production de différentes technologies photovoltaïques dans les conditions d'enneigement. Les différentes technologies ainsi que les systèmes de déneigement étudiés sont répertoriés dans le paragraphe «technologies installées».

La conception, l'installation des capteurs et des systèmes de déneigement se sont déroulés durant l'année 2011. Les mesures de productions/consommations des différentes technologies se sont déroulées durant les hivers 2011-2012 et continueront durant l'hiver 2013-2014.

Technologies installées

Les technologies suivantes ont été installées sur le toit du Lycée Blaise Cendrars:

Technologie	Fabricant	Puissance de l'installation
Si Amorphe	Flexcell	1.35 kW_p
Si Monocristallin	Bosch	1.41 kW_p (x5)
HIT[1] Double	Sanyo	1.26 kW_p
Si Polycristallin	Trina	1.41 kW_p

Tableau 1: type de technologies des panneaux PV

La technologie amorphe a été choisie pour ses propriétés de sensibilité au rayonnement diffus, qui devrait lui permettre de chauffer même avec une faible épaisseur de neige.

La technologie HIT Double a été choisie pour sa double couche photovoltaïque, qui devrait lui permettre de fonctionner et de monter en température par la réflexion de la lumière sur la neige environnante.

Les modules du fabricant Trina permettront de comparer la production de panneaux chinois et de panneaux allemands de même puissance.

Les capteurs Flexcell (technologie amorphe) sont posés directement au sol et inclinés fai-blement. Tous les autres capteurs sont inclinés à 20°.

Les solutions de déneigement installées sur les différents champs de capteurs Bosch sont:

Type	Solution de déneigement	Remarques
Si Monocristallin, 1.41 kW_p	Sans déneigement	Installation de référence
Si Monocristallin, 2,82 kW_p	Solutronic (solution 1)	Inversion **manuelle** du courant dans les panneaux
Si Monocristallin, 1.41 kW_p	Eulektra (solution 2)	Inversion **automatique** du courant dans les panneaux
Si Monocristallin, 1.41 kW_p	FRESO (solution 3)	Application de polymère permettant de rendre les surfaces hydrofuge.

Tableau 2: type de solution active de déneigement

[1] HIT : Heterojunction with Intrinsic Thin layer

L'installation complète dispose de 8 champs d'environ 1.4 kWp chacun, soit une puissance totale d'environ 11 kWp. La solution de déneigement Solutronic nécessite deux champs de capteurs : il n'y a donc que 7 champs représentés.

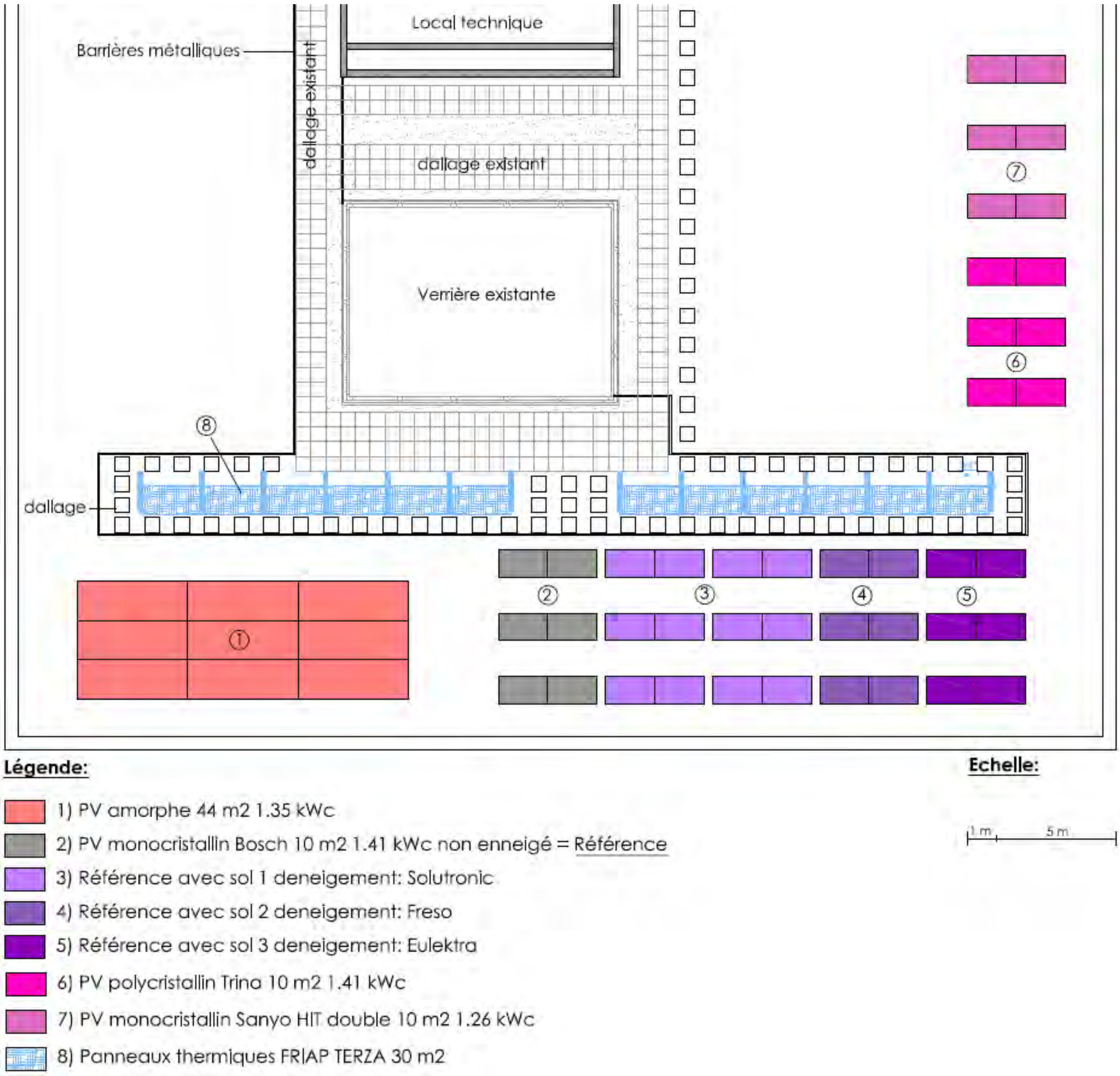


Figure 2: vue d'ensemble de l'installation sur le toit du Lycée

Chacun des 7 champs PV dispose de son propre onduleur et d'un équipement de supervi-sion (Solarlog) permettant d'enregistrer les différents paramètres (production d'électricité, T° extérieure, ensoleillement (W/m2)).
Les deux champs disposant d'un système d'inversion de courant possèdent un équipement de mesure de l'énergie consommée.

Remarque : dans notre rapport de l'année dernière, nous avions mentionné le changement suivant pour la solution Eulektra qui consistait à remonter le capteur de présence comme sur la photo ci-dessous:

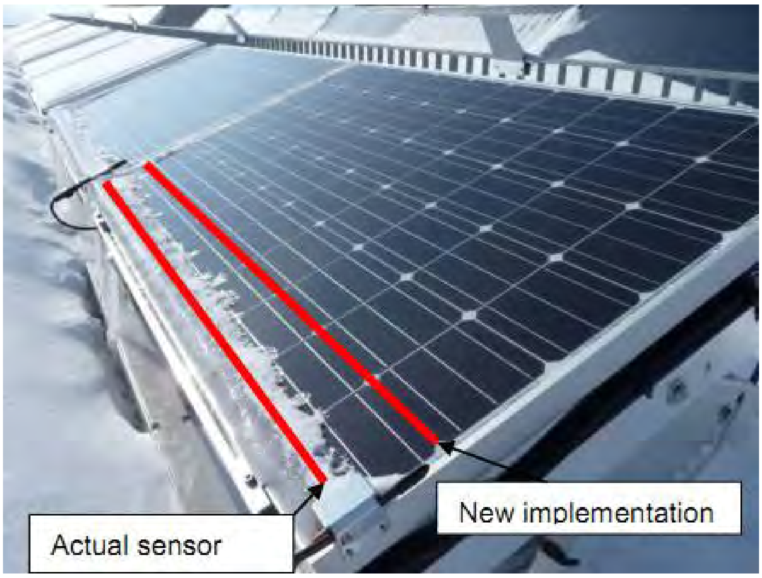


Figure 3: préconisation pour la modification de l'emplacement du capteur de présence

Finalement, lors du passage du fournisseur Eulektra et selon leur recommandation, un câble chauffant sur le cadre inférieur a été ajouté (voir photo ci-dessous). La raison invoquée est de dégager proprement la glace qui s'accumule en bas du module qui pourrait obstruer les cellules du bas.

Figure 4: modification du système par le fournisseur Eulektra. Ajout d'un câble chauffant sur la partie inférieure du cadre.

Cette solution rend encore moins attractif la solution Eulektra car des coûts additionnels sont à prévoir dans le cadre de ce type d'installation.

Bilan général hiver 2012/2013

Cet hiver 2012/2013 a été caractérisé par sa rigueur et par sa longévité. Au niveau des mesures, cela s'est traduit par une épaisseur de neige importante empêchant les panneaux de pouvoir se dégager. En effet, l'épaisseur de neige était plus haute que le bas des panneaux (voir Figure 1 et Figure 2). Une grande partie de l'hiver (mois de février et mars) les données acquises ne nous ont pas servi. Les graphiques ci-dessous comparent la production que nous avons eu en 2012 et celle que nous avons eu en 2013 et illustrent ce problème:

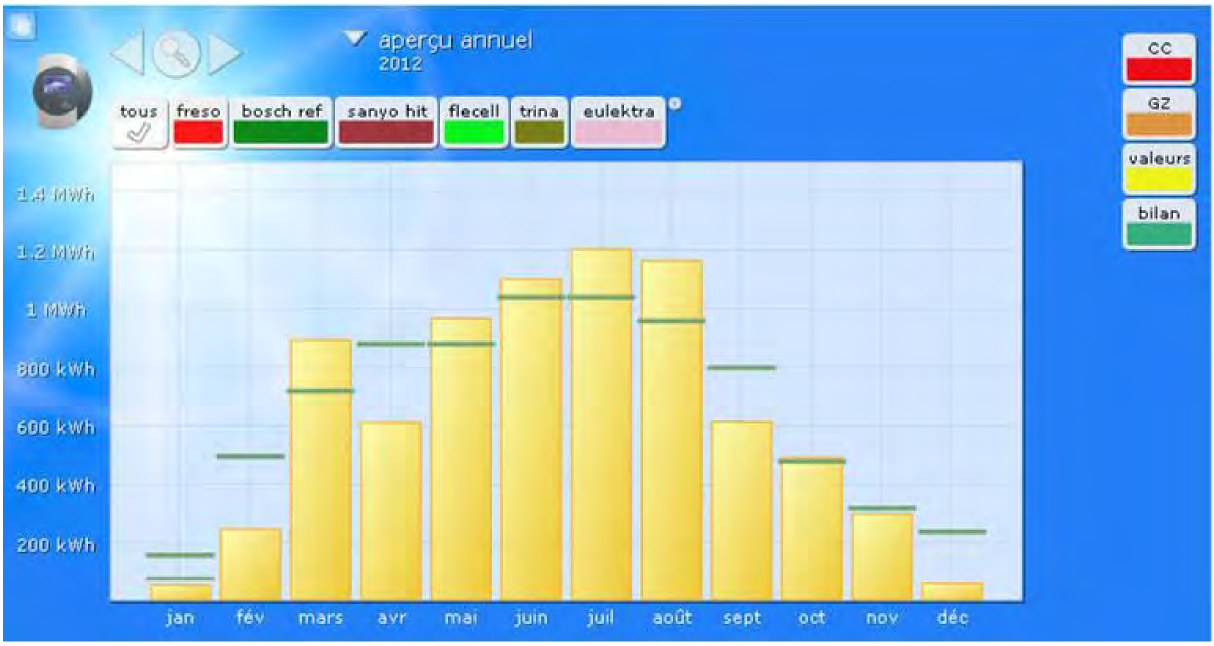


Figure 5: aperçu annuel 2012 de la production de l'ensemble des technologies (hormis Solu-tronic)

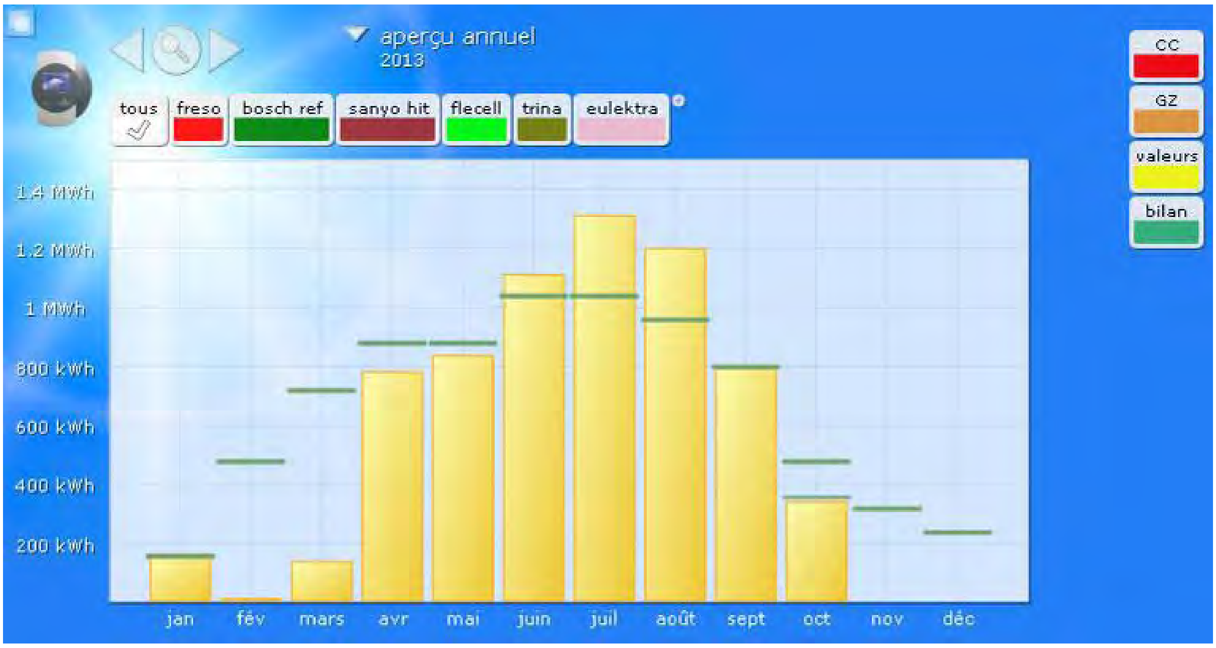


Figure 6: aperçu annuel 2013 de la production de l'ensemble des technologies (hormis Solutronic)

De plus, le système d'acquisition des données a connu un dysfonctionnement important cette année 2013 concernant:

- La consommation d'électricité pour les solutions Solutronic et Eulektra: aucune donnée disponible cette année, le problème étant survenu courant décembre et une solution corrective n'ayant pu être mise en place avant la fin de l'hiver par l'exploitant de la centrale.
- La production d'électricité pour la solution Solutronic: aucune donnée disponible cette année.

Mesures correctives réalisées:

- Données de production de la technologie Solutronic:
    - Système initial: acquisition des données avec un solarlog 500 spécifique.
    - Système modifié: acquisition des données avec les autres technologies soit directement sur le solarlog 1000.
- Données de production des autres technologies:
    - Système initial: acquisition avec un solarlog 1000 via le réseau du Lycée Blaise Cendrars et l'interface Solarfox.
    - Système modifié: acquisition avec un unique solarlog 1000.

Dès lors, et selon les points cités ci-dessus, le présent rapport a été réalisé à partir de données restreintes.

Bilan de l'hiver 2013

Le tableau ci-dessous présente la production des différentes solutions. Les données

	Janvier (du 10 au 31)	Février (du 1er au 28)	Mars (du 1er au 31)	Bilan 2013	Bilan 2012
Eulektra					
consommation [kWh/kWc]	*n.a*	*n.a*	*n.a*		
production [kWh/kWc]	*n.a*	*n.a*	*n.a*	***n.a***	*-291*
Solutronic					
consommation [kWh/kWc]	*n.a*	*n.a*	*n.a*		
production [kWh/kWc]	*n.a*	*n.a*	*n.a*	***n.a***	*185*
Bosch référence					
production [kWh/kWc]	*19.7*	*0.85*	*14.7*	***35.25***	*164*
Freso					
production [kWh/kWc]	*19.2*	*0.82*	*14.5*	***34.52***	*156*
Sanyo HIT D					
production [kWh/kWc]	*27.9*	*1.34*	*23.4*	***52.64***	*166*
Trina					
production [kWh/kWc]	*n.a*	*0.84*	*16.6*	***n.a***	*154*
Flexcell					
production [kWh/kWc]	*22.1*	*0.95*	*5.8*	***28.85***	*0*

Tableau 3: production et consommation des différentes solutions avec bilan sur la période janvier-mars 2013

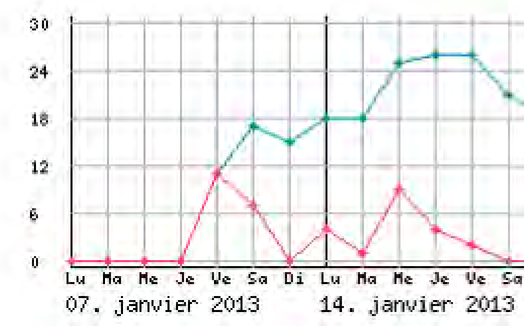
Bilan détaillé hiver 2013

L'analyse détaillée du fonctionnement des solutions a été réalisée sur deux périodes représentatives d'un fonctionnement hivernal avec chutes de neige:

Période 1 (du 9 au 13 janvier 2013)

Le vendredi 11 et le samedi 12 janvier, un épisode neigeux apporte 17 cm de neige. Le dimanche 13 janvier, la perturbation s'évacue et laisse place à une journée partiellement ensoleillée.

Le graphique ci-dessous montre les chutes de neige journalières (en rouge) et l'épaisseur du manteau neigeux sur une surface plane (en bleu).



Les graphiques ci-dessous montrent l'évolution de la production suivant les technologies:

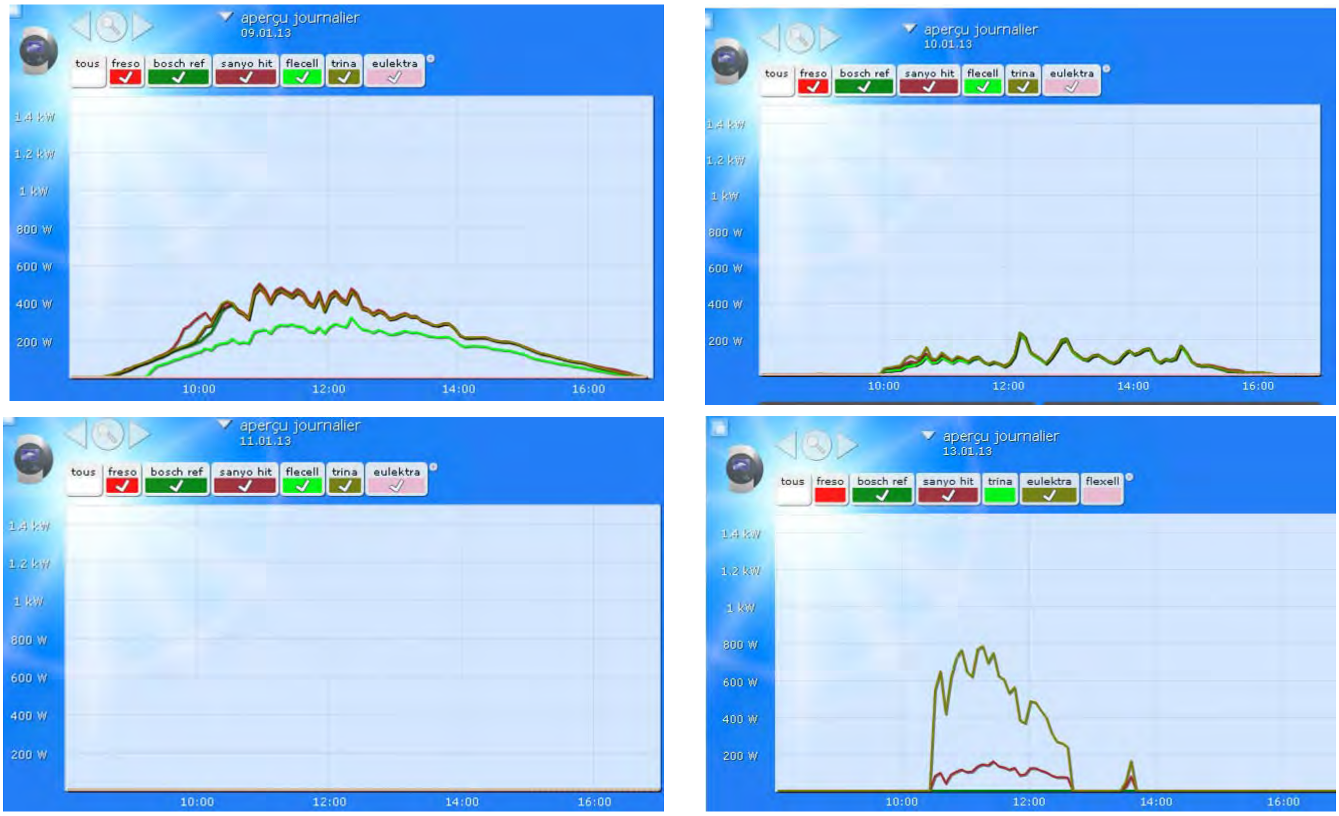


Figure 7: évolution de la production des différentes technologies et solutions du 9.01.13 au 13.01.13

Figure 8: évolution de la production des différentes technologies et solutions du 9.01.13 au 13.01.13

De cette période 1, nous pouvons en tirer les enseignements suivants:

- Avant l'épisode neigeux, le 9 janvier, toutes les technologies produisent de l'énergie.
- Nous pouvons identifier que la technologie **Flexcell** a une production inférieure aux autres car pas dans les mêmes conditions de test (capteurs à plat, voir les photos).
- Durant l'épisode neigeux aucune des technologies ne produit de l'électricité
- À l'issu de l'épisode neigeux, soit le 13 janvier, la solution **Eulektra** permet de produire environ 700Wh/kWc sur la journée. Aucune donnée chiffrée n'est disponible sur la consommation d'électricité nécessaire au dégagement des panneaux mais celle-ci est très probablement supérieure au gain réalisé cette journée du 13 janvier. Selon les données du bilan de l'hiver 2012, nous estimons cette consommation moyenne à environ 4'290 Wh/kWc par jour en janvier.
- les panneaux doubles de **Sanyo** ont permis une production d'environ 190Wh/kWc durant cette journée du 13 janvier. Une faible quantité de neige permet à cette solution de produire avec la face arrière.
- l'inversion de courant pour la solution **Solutronic** n'a pas été mise en marche. Les panneaux se sont comportés comme les Bosch référence.

Période 2 (du 1er au 2 avril 2013)

Le dimanche 31 mars, une chute de neige d'environ 6 cm a eu lieu suivie d'une période de temps ensoleillé qui débute en deuxième partie de journée de ce dimanche 31 mars permettant aux panneaux de commencer à se dégager.

Le graphique ci-dessous montre les chutes de neige journalières (en rouge) et l'épaisseur du manteau neigeux sur une surface plane (en bleu).

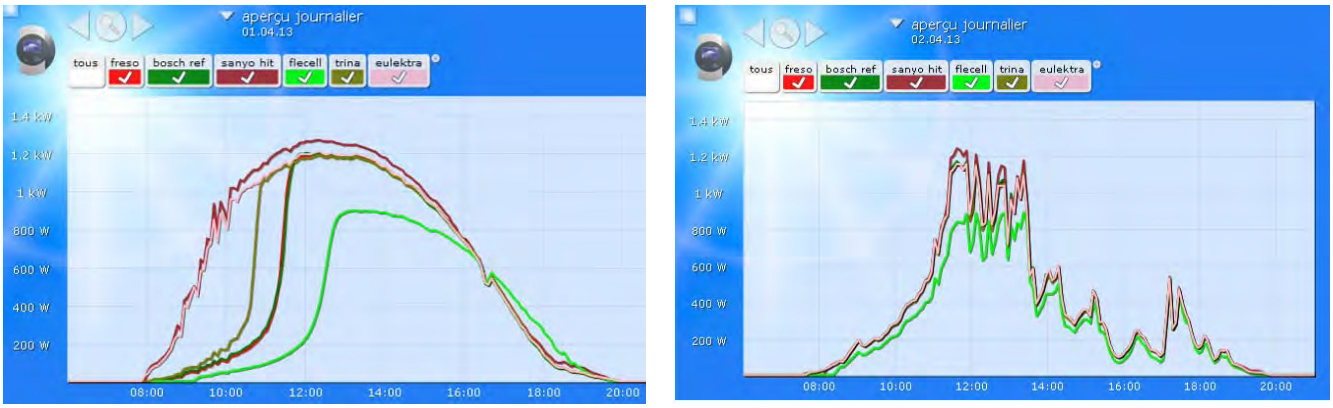


Figure 9: évolution de la production des différentes technologies et solutions du 1.04.13 au 2.04.13

Remarque: les données horaires pour la journée du 31.03 sont indisponibles.

De cette période 2, nous pouvons en tirer les enseignements suivants:

- Le 1er avril, la solution **Eulektra** est totalement dégagée et permet une production dès 8h00 du matin.
- La technologie **Sanyo** est directement dégagée elle aussi dès 8h00 du matin permet-tant aux panneaux de produire de l'électricité. La face arrière a permis à ces panneaux de se dégager durant la deuxième moitié de journée du 31.03. Nous pouvons égale-ment remarquer la production supplémentaire des panneaux Sanyo par rapport aux autres technologies : environ 15% de plus par kWc.
- Les panneaux **Trina** sont dégagés vers 10h30 du matin, soit environ une demi-heure avant la technologie de référence. Cependant, cet écart ne peut pas être considéré comme représentatif d'un meilleur dégagement des panneaux mais plutôt comme de conditions locales favorables à ce moment pour le dégagement de ceux-ci.
- Les solutions **Bosch référence et Freso** se dégagent en même temps vers 11h du matin. Nous n'observons donc pas d'amélioration de la solution Freso pour le dégage-ment de la neige.
- Les capteurs **Flexcell** se dégagent également en cours de journée vers 12h30.

Solution d'inversion du courant, étude de la température de fonctionnement

Des clichés réalisés avec une caméra thermique ont permis de connaitre la température de fonctionnement de la solution Eulektra inversant le courant dans les capteurs. Ces clichés datent du 14 février 2013. A chaque cliché thermographique de droite correspond la photo à gauche:

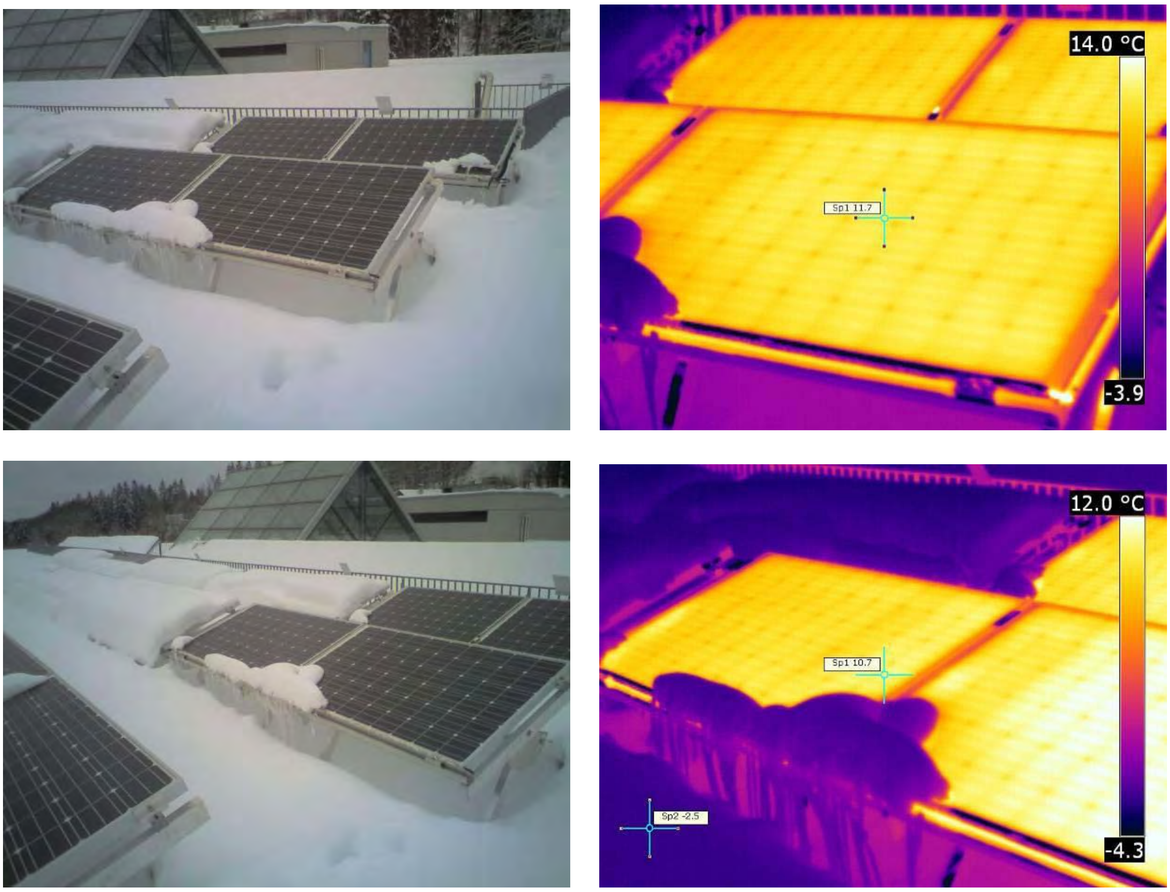


Figure 10: clichés thermographique de la journée du 14 février

L'étude de ces clichés nous a permis de déterminer la température des capteurs en fonction de la température extérieure. Celle-ci est d'environ 11°C pour une température extérieure de –4°C, soit une différence de température de 15°C entre l'air ambiant et la surface des cap-teurs. En dessous d'une température de -10°C à -15°C, le système devient inopérant.

Effet sur le rendement des panneaux pour l'inversion de courant

Au vu des contraintes que subissent les modules photovoltaïques avec la solution Eulektra (inversion automatique du courant dans les panneaux), il est intéressant de vérifier que le rendement après deux hivers n'est pas affecté.

Durant les mois de juin, juillet et août 2013, la solution de référence a produit 608.36 kWh. Quant à la solution Eulektra, elle a produit 611.54 kWh.

Nous pouvons donc considérer que l'inversion de courant ne provoque pas de pertes de rendements après 2 ans de fonctionnement.

Conclusion

Cette année a été marquée par deux incidents ne permettant pas de réaliser un suivi optimal:

- L'importance des chutes de neige qui a recouvert les capteurs sans permettre leurs dégagements.
- L'acquisition des données a connu d'importants dysfonctionnements.

Néanmoins, les conclusions suivantes ont pu être faites:

- Solution de déneigement Eulektra: nous n'avons pas pu suivre la consommation électrique de cette solution mais celle-ci a été en marche durant de longues périodes lors des importantes chutes de neige. C'est une solution séduisante si d'autres paramètres étaient pris en compte tels que:
    - Les prévisions météorologiques des journées suivant les chute de neige afin que la production photovoltaïque soit plus grande que la consommation nécessaire pour la fonte (gains>pertes).
    - Une température ambiante pas trop froide, sinon l'effet du déneigement électrique proposé ici est nul. Nous avons vu que pour des températures inférieures à -15°C, l'effet du déneigement n'est pas pertinent.
    - L'activation du déneigement quand une irradiation est déjà présente : le soleil poursuit l'action enclenchée, l'inversion de courant accélère les choses.
- Solution de déneigement Solutronic: bien que nous manquions de données, c'est une solution qui offre une bonne alternative quand la mise en marche est correctement effectuée.
- La solution Freso n'a pas permis d'obtenir de meilleurs résultats que la solution de référence. Une inclinaison supérieure pourrait éventuellement démontrer le contraire, mais aucune différence de glissement n'a été constatée.
- Les panneaux Sanyo ont montré encore une fois leur efficacité lors de faibles chute de neige. Avec une évacuation plus rapide que les autres solutions et avec un rendement au kWc environ 15% supérieur. Lors de chutes de neige plus importantes, les supports étant plus bas que les autres panneaux, les modules Sanyo se trouvent complètement ensevelis sous la neige.
- Le rendement des modules Trina sont comparables à la solution de référence.
- Les modules Flexcell ont été complètement recouverts par la neige une grande partie de l'hiver et n'ont donc pas produit durant cette période hivernale.

L'irradiation hivernale étant limitée, il est important de maitriser la dépense énergétique pour en bénéficier.

Les perspectives d'études pour l'année prochaine sont, en coordination avec les partenaires:

- Mesurer sur l'ensemble de la saison hivernale et analyser le gain/perte au niveau annuel (cette année ayant été marquée par un dysfonctionnement important de l'acquisition des données).
- Établir, en fonction de différents paramètres (neige récente, température, prévision météorologique), des recommandations pour la mise en route du déneigement pour la solution Solutronic
- Installer éventuellement une mise en marche par SMS de la solution Solutronic afin de gagner en flexibilité.
- Modifier l'inclinaison des modules pour l'hiver 2014-2015 afin de mettre en évidence les changements.

Comme pour l'optimisation du photovoltaïque dans les réseaux électriques, l'optimisation du fonctionnement d'une installation photovoltaïque en condition neigeuse requerra d'excellentes prévisions météorologiques afin de gérer son enclenchement raisonné aux moments opportuns.

DISTRIBUTION GRID ANALYSIS AND SIMULATION WITH PHOTOVOLTAICS (DIGASP)

SIMULATION APPROACH TO INVESTIGATE THE IMPACT OF DISTRIBUTED POWER PRODUCTION WITH PV ON A POWER GRID

Annual Report 2013

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Project- / Contract Number	SI/500549, SI/500549-01
Duration of the Project (from – to)	September 2010 – December 2013
Date	9th December 2013

ABSTRACT

The project “Distribution Grid Analysis and Simulation with Photovoltaics (DiGASP)” (former name “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?
- What effects can be expected, if certain modifications are applied to the distribution power grid (such as active / reactive power control, energy storage, tap changing transformers, active load control, …)

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.

In 2013, the project was finished. The technical report is published as a SFOE / PV ERA NET technical report. This document gives a short project summary.

Einleitung

Dieses Projekt wurde im Rahmen des PV+ Grid Calls des PV ERA NET mit den Projektpartnern *Austrian Institute of Technology* und der *Universität Oldenburg* 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 Hauptteil der Dissertation des Projektleiters. Die enge Zusammenarbeit mit dem Institut für *Elektrische Energieübertragung und Hochspannungstechnik (EEH)* der Abteilung für *Informationstechnologie und Elektrotechnik (D-ITET)* der *ETH* ist somit ein weiterer Pfeiler für das Projekt.

Der technische Schlussbericht liegt nur in Englisch als detaillierter Report vor. Verschiedene deutsche Kurzfassungen sind im Kapitel "Publikationen und Vorträge" aufgelistet.

Projektziele

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?

Die Beeinflussung der physischen Einspeisebegrenzungen ist dabei ein wichtiges Thema. Es soll untersucht werden, mit welchen Massnahmen welche Effekte erzielt werden können. Folgende Massnahmen stehen heute zur Diskussion:

- Berücksichtigung von Korrelation zwischen Last und Einspeisung
- Blindleistungsregelung am PV-Wechselrichter
- Wirkleistungsregelung am PV-Wechselrichter (Abregelung der Wirkleistung)
- Verwenden eines Stelltransformators als Ortsnetztransformator
- Ausrichtung der PV-Anlagen variieren
- Dezentrale Speicher
- Demand Side Management (Algorithmus von vorangehender Dissertation ETH)

Durchgeführte Arbeiten und erreichte Ergebnisse

Die Arbeiten Umfassen im Wesentlichen folgende Punkte

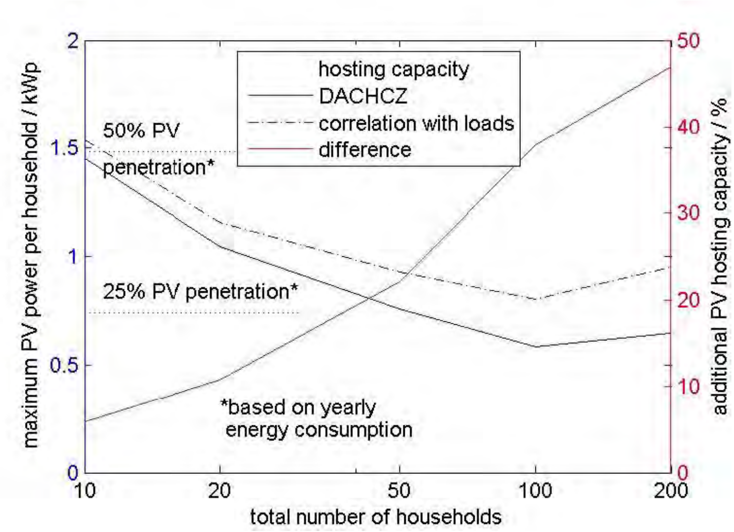
- Lastprofilgenerator: Eine Routine zur künstlichen Generierung von hochauflösenden Haushaltslastdaten.
- Meteodatengenerator: Eine Routine zur künstlichen Generierung von hochauflösenden Einstrahlungsprofilen sowie Temperatur- und Windprofilen.
- Simulation Framework: Eine Simulationsprozedur zu Lastflusssimulation verschiedener Szenarien und Regelungsalgorithmen.
- Resultate und Fallstudie: Eine systematische Zusammenstellung von Simulationsresultaten, deren Interpretation diverse grundlegende Aussagen zulässt.

WICHTIGSTE ERGEBNISSE IN DER ÜBERSICHT

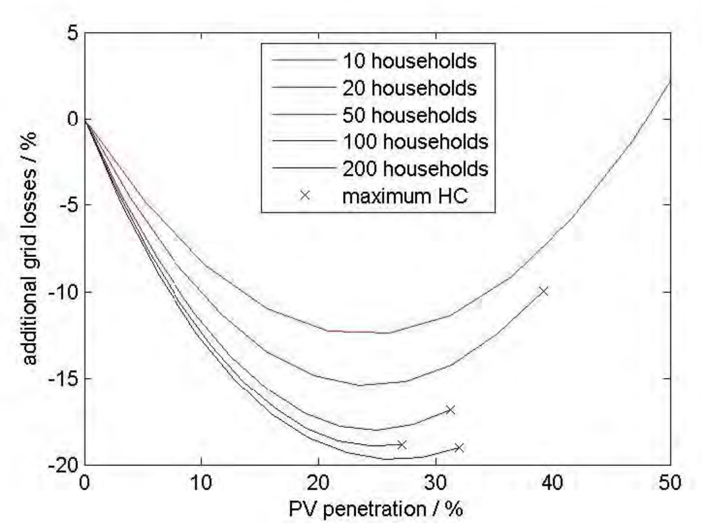
Für eine Stichleitung mit zehn Knoten à 1 bis 20 Haushalten wurde die maximale PV-Aufnahmefähigkeit (PV hosting capacity) untersucht. Dabei wurde das schwächste Stromnetz angenommen, welches die Lasten sicher versorgen kann. Der maximale Spannungsanstieg im Nieder-spannungsnetz wurde auf 3% limitiert.

Validiert mit einem 1-Knoten-Netz sowie einem Niederspannungsnetz in der Stadt Zürich haben die Resultate bis auf die Blindleistungsregelung einen "allgemeingültigen Charakter".

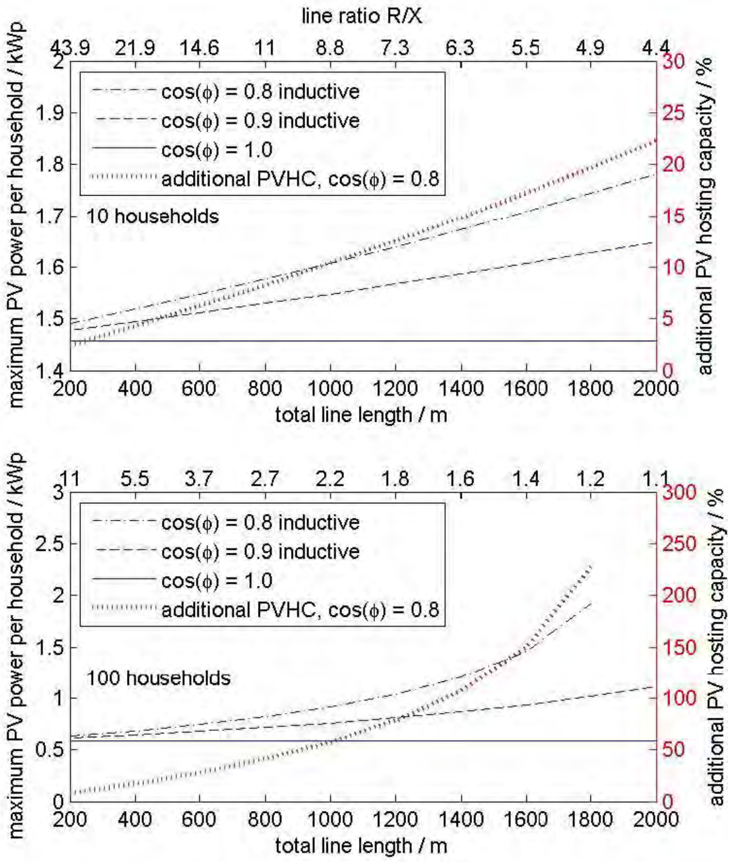
Keine Integrationsmassnahmen (DACHCZ) versus Berücksichtigung der Gleichzeitigkeit von Lasten und PV-Einspeisung: 20% bis 50% Solarstromanteil am Jahresverbrauch beträgt die PV-Aufnahmefähigkeit ohne Integrationsmassnahmen (DACHCZ). Wird die Gleichzeitigkeit mit den Lasten berücksichtigt, so können fast bis zu 50% mehr Solarstrom ans Netz abgegeben werden.



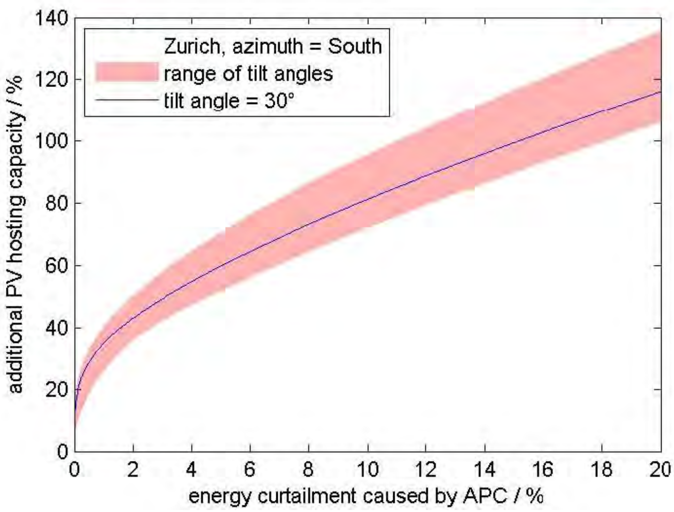
Die Netzverluste werden dank PV um ca. 10 bis 20% gesenkt. Die Verluste sind bei einem Solarstromanteil (PV penetration) von 25% am Jahresstrombedarf der Lasten minimal.



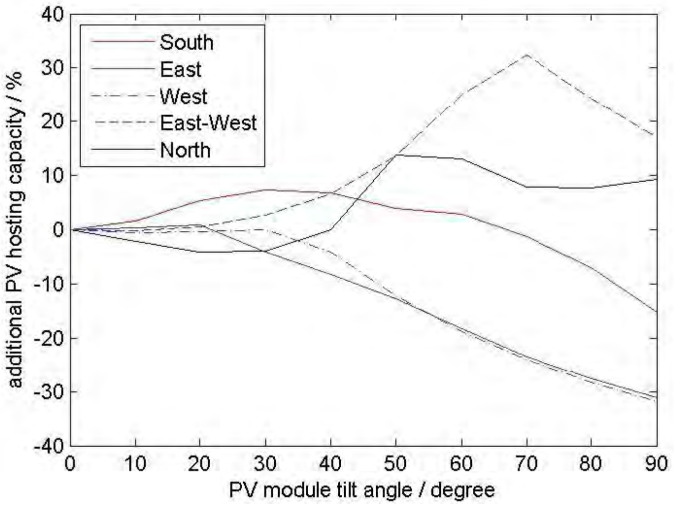
Blindleistungsregelung: Die Effekte der Blindleistungsregelung können ohne konkretes Netz nicht aussagekräftig verallgemeinert werden. Für die Stichleitung mit zehn Knoten ergibt sich die nachstehende Graphik.



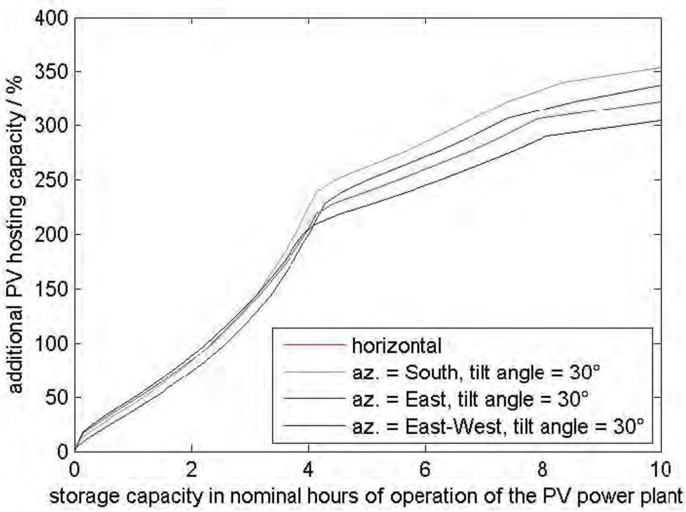
Wirkleistungsregelung: Wird auf die Leistungsspitzen verzichtet (Abregelung), so kann deutlich mehr Solarstrom ins Netz gespeist werden. Die Abregelungsverluste sind dabei zunächst sehr gering: Der Verzicht auf 2% der Energie ermöglicht eine zusätzliche PV-Aufnahmekapazität von rund 40%, wird auf 15% der Energie verzichtet kann der Solarstromanteil im Netz verdoppelt werden.



Ausrichtung der PV-Module: Werden die PV-Module nicht nach Süden, sondern z.B. nach Ost-Westen ausgerichtet, kann eine höhere PV-Leistung ins Netz eingespeist werden. Der Energieertrag der Module reduziert sich dadurch jedoch. Das Verhältnis von Energieertrag zu Leistungsspitze gibt einen guten Hinweis auf die zusätzliche PV Aufnahmekapazität. Es ist bei Ost-West-Anlagen am grössten, jedoch nur, wenn diese sehr stark geneigt sind (>50° Neigungswinkel).



Dezentrale Speicher: Ähnlich wie bei der Wirkleistungsregelung lassen sich durch dezentrale Speicher die PV-Aufnahmekapazität eines Netzes erhöhen. Der Zusammenhang zwischen Speicher-kapazität und erhöhter PV-Aufnahmekapazität wird in der nachfolgenden Grafik gegeben.



PUBLIKATIONEN UND VORTRÄGE

Ergebnisse und Teilergebnisse aus diesem Projekt wurden an folgenden Orten publiziert und vorgetragen:

- Paper: Christof Bucher, Göran Andersson, Generation of Domestic Load Profiles – an Adaptive Top-Down Approach, proceedings of PMAPS 2012, Istanbul, Türkei, 2012.
- Paper: Christof Bucher, Jethro Betcke, Göran Andersson, Benoît Bletterie, Lukas Küng, "Simulation of Distribution Grids with Photovoltaics by Means of Stochastic Load Profiles and Irradiance Data", in proceedings of the 27th European Photovoltaic Solar Energy Conference and Exhibition, Frankfurt, Deutschland, 2012, pp. 3795 - 3800.
- Paper: Christof Bucher, Jethro Betcke, Göran Andersson, "Effects of Variation of Temporal Resolution on Domestic Power and Solar Irradiance Measurements", Powertech 2013, Grenoble, Frankreich, 16-20 June 2013.
- Paper: Christof Bucher, Göran Andersson, Lukas Küng, "Increasing the PV Hosting Capacity of Distribution Power Grids – a Comparison of Seven Methods", in proceedings of the 28th European Photovoltaic Solar Energy Conference and Exhibition, Paris, Frankreich, 2013.
- Schlussbericht: Jethro Betcke, Jan Kühnert, Thomas Scheidtsteger, Development and Validation of the DiGASP Weather Generator, Technical report, Carl von Ossietzky University of Oldenburg Energy and Semiconductor Research Laboratory Energy Meteorology group, August 2013.
- Schlussbericht (noch nicht publiziert): Benoît Bletterie et al., Austrian Institut of Technology (AIT), Schlussbericht zum Projektbeitrag des AIT.
- Schlussbericht: Christof Bucher, Jethro Betcke, Benoît Bletterie, "Distribution Grid Analysis and Simulation with Photovoltaics", PV ERA NET, Schlussbericht 2013.
- Vortrag: "Auswirkungen eines hohen Photovoltaikanteils auf das Niederspannungsnetz", nationale PV-Tagung, 23. März 2012, Baden.
- Vortrag: "Wie viel Photovoltaik (PV) verträgt ein Verteilnetz ohne Netzausbau?", Energie-Apéro Aargau, Oktober 2013, drei Vorträge in Baden, Lenzburg und Aarau.
- Vortrag: "Distribution Grid Analysis and Simulation with Photovoltaics (DiGASP)", 22. Januar 2013, Oldenburg, Deutschland.
- Poster: "Leistungsreduktion bei PV-Anlagen. Energieverschwendung oder günstige Massnahme zur besseren Netzintegration?", nationale PV-Tagung, 11. März 2013, Basel.
- Vortrag: "Einbindung dezentrale Erzeugung – Wann muss ausgebaut werden?", Innovationsforum Energie, 15. März 2013, Zürich.
- Vortrag: Comparison of 7 measures to integrate PV in the low voltage grid, using stochastic irradiance data", IEA PVPS & SHC workshop, PVSEC 2013, 1. Oktober 2013, Paris, Frankreich.
- Vortrag: "Distribution Grid Analysis and Simulation with Photovoltaics (DiGASP) ", ewz, 22th October 2013, Zürich.
- Vortrag: "Methoden zur Erhöhung des Solarstromanteils im Niederspannungsnetz ", Elektrizitätswerke Schönau (EWS), 8th November 2013, Schönau, Deutschland.
- Fachartikel (noch nicht publiziert): "Wie viel Solarstrom verträgt das Niederspannungsnetz?", Bulletin VSE/electrosuisse, Frühjahr 2014.
- Dissertation (noch nicht publiziert): "Distribution Grid Analysis and Simulation with Photovoltaics (DiGASP) ", Frühjahr 2014, Zürich.

Nationale Zusammenarbeit

Nationaler Austausch und nationale Zusammenarbeit hat insbesondere mit der ETH Zürich und dem ewz stattgefunden.

ETH ZÜRICH

Die ETH übt mit Professor Andersson (Institut EEH - Power Systems Laboratory) die wissenschaftliche Betreuung der Arbeit aus. Intensiver Austausch besteht mit den Doktoranden des Instituts.

EWZ (ELEKTRIZITÄTSWERK DER STADT ZÜRICH)

Nebst der kontinuierlichen Unterstützung im Rahmen von Korreferaten und Rückmeldungen zu aktuellen Projektresultaten hat das ewz einer Messkampagne zur Charakterisierung von Haushaltslastdaten zugestimmt. Das angekündigte Messprojekt konnte im November 2012 gestartet werden. Die Verbrauchsdaten von 55 Haushalten werden in 1-Minuten-Schritten ausgelesen und künftig für die Netzsimulationen verwendet.

Internationale Zusammenarbeit

Internationale Zusammenarbeit besteht mit den Projektpartnern (Universität Oldenburg und Austrian Institut of Technology) sowie mit dem Konsortium des IEA PVPS Task 14.

UNIVERSITÄT OLDENBURG (PROJEKTPARTNER PV ERA NET)

Die Universität Oldenburg hat im Jahr 2012 einen Generator für stochastische Einstrahlungsdaten programmiert. Die Arbeiten sind weitgehend abgeschlossen und sollen im kommenden Jahr publiziert werden. Die generierten Einstrahlungsprofile werden in den Simulationen dieses Projekts verwendet.

AUSTRIAN INSTITUTE OF TECHNOLOGY AIT (PROJEKTPARTNER PV ERA NET)

Das AIT hat die Arbeiten rund um die Blindleistungsregelungen stark unterstützt. Der Schlussbericht des AIT wird Stabilitätsanalysen und Optimierungsansätze für Blindleistungsregelungen vorstellen.

Fazit und Ausblick

Mit einem Jahr Verspätung gegenüber dem ersten Terminplan konnte das PV ERA NET Projekt DiGASP Ende 2013 abgeschlossen werden. Zu den Hauptfragestellungen aus dem Projektantrag konnten verschiedene detaillierte Antworten und Ansätze aufgezeigt und präsentiert werden. Verschiedene weitere Fragestellungen aus dem Antrag wurden im Projektverlauf zu Gunsten der Haupt-Fragestellungen (z.B. das Thema Oberwellen) aus dem Scope von DiGASP entfernt.

Nach dem offiziellen Projektabschluss von DiGASP sind noch folgende Arbeiten zum Projekt vorgesehen:

- Publikation eines zusammenfassenden Berichtes im Bulletin VSE / electrosuisse
- Auswertung der Haushaltslastmessungen in Zürich
- Dissertation von Christof Bucher (zu grossen Teilen bestehend aus DiGASP)

Referenzen

Die Liste der Referenzen ist dem Kapitel "Publikationen und Vorträge" zu entnehmen.

DIGITALER LICHTBOGENDETEKTOR FÜR PV-WECHSELRICHTER

Annual Report 2013

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Project- / Contract Number	KTI-Nr. 13413.1 PFFLE-IW
Duration of the Project (from – to)	01.01.2012 – 30.06.2013
Date	05.02.2014

ABSTRACT

Due to the electrical characteristics in PV power plants (high voltages and DC currents), contact failures in the DC wiring may result in electrical arcs. Such arcs can reach temperatures of more than 1'000°C and are therefore a considerable fire hazard. There is already a record of a limited number of fires which have been caused because of arc faults in PV plants.

The goal of this project is the development of an arc fault detector which can be implemented into a PV inverter. This approach is probably the most cost effective solution, because some of the hardware required is already present inside the inverter (e.g. DC switch, power supply). The device shall detect the noise generated by an electrical arc and, in case of detection of an arc fault, turn off the inverter. If the inverter is turned off, the current inside the DC wiring is interrupted and the arc extinguishes.

Although it is rather simple to detect an arc in a test circuit inside a laboratory, the detection in real PV plants is very challenging. The main problem is that in the field there are numerous noise sources which might be mistaken for an arc. This can easily result in false positive detections which are very annoying for the owner of the PV plant. Another problem is that the few existing standards for arc fault detectors are still having teething problems, which make the test of such devices nearly impossible.

The prototype developed in this project has a very good detection rate for electrical arcs in both test circuits and in real PV plants. However, the immunity against false positive detection is not yet satisfying. At the moment, there are efforts being made for a follow-up project, whose goal will be to make the arc fault detector market-ready.

Einleitung / Projektziele

Aufgrund der elektrischen Eigenschaften von Photovoltaikanlagen – hohe Gleichspannungen mit Stromquellencharakteristik – können bei Kontaktdefekten in der DC Verkabelung der Anlage sehr leicht Störlichtbögen entstehen. Ein solcher Störlichtbogen kann eine Temperatur von weit über 1'000°C erreichen und stellt dadurch ein beträchtliches Brandrisiko dar. In der Vergangenheit gab es bereits eine begrenzte Zahl von Brandfällen, welche durch Störlichtbögen in PV-Anlagen ausgelöst wurden [1].

Das Ziel dieses Projekts ist die Entwicklung eines Lichtbogendetektors zur Integrierung in einem Solarwechselrichter. Dies ist vermutlich die kosteneffizienteste Lösung, weil im Wechselrichter bereits einige der benötigten Hardwarekomponenten vorhanden sind (z.B. DC-Schalter, Speisung). Dadurch sollte der Aufpreis für einen Wechselrichter mit integriertem Lichtbogendetektor nur wenige Franken betragen.

Kurzbeschrieb des Projekts

Der Lichtbogendetektor beruht auf der Detektion des Rauschens, welches von einem Störlichtbogen erzeugt wird und sich über die Verkabelung in der gesamten Anlage verbreitet. Dieses Rauschsignal wird durch einen Übertrager ausgekoppelt, verstärkt und in ein Digitalsignal gewandelt. Dieses Digitalsignal wird durch einen Mikroprozessor mit einem eigens entwickelten Detektionsalgorithmus analysiert. Wird ein Lichtbogen erkannt, wird dies derzeit lediglich durch eine LED signalisiert. Später soll dieses Detektionssignal dazu dienen, den Wechselrichter auszuschalten. Wenn dies geschieht, wird die DC-Verkabelung der PV-Anlage stromfrei und der Lichtbogen erlischt.

Durchgeführte Arbeiten und erreichte Ergebnisse

In einer ersten Projektphase wurden an verschiedenen PV-Anlagen Messungen von Lichtbogensignalen durchgeführt. Dazu wurden in den Anlagen jeweils künstliche Lichtbogen erzeugt und die entstandenen Störmuster am Eingang des Wechselrichters erfasst. Diese Messwerte wurden in einer Datenbank abgelegt, welche nun über 200 Lichtbogensignale umfasst. Anhand dieser Daten wurde ein Detektionsalgorithmus entwickelt, welcher in einer Prototypenschaltung auf einem Mikroprozessor implementiert wurde.

Der entstandene Prototyp ist in der Lage, Störlichtbögen sowohl in Testschaltungen als auch in richtigen Photovoltaikanlagen schnell und zuverlässig zu detektieren. Allerdings hat das Gerät im Feldeinsatz derzeit noch grosse Probleme mit der Selektivität. Bei einer Photovoltaikanlage kann es eine schier endlose Anzahl von potentiellen Störquellen geben (z.B. Radiosender, Schaltfrequenzen des Wechselrichters, Störungen auf der Netzspannung). Momentan führen solche Störer noch zu oft zu Fehlauslösungen des Detektors. Solche Fehlauslösungen sind für einen Anlagenbesitzer äusserst ärgerlich, denn dieser muss sich jedesmal versichern, dass das angezeigte Ereignis kein wirklicher Lichtbogen war und die Anlage danach manuell neu starten.

Ein unerwartetes Problem, das die Entwicklung des Detektors erschwerte, waren Mängel in der Normierung von solchen Geräten. Mit der UL1699B gibt es momentan weltweit nur eine einzige Testnorm für Lichtbogendetektoren für Photovoltaikanlagen. Diese stellt aber teilweise absurde Forderungen an den Prüfling. Zudem sind einige der geforderten Testprozeduren gar nicht durchführbar, weil der Lichtbogen in Prüfaufbau nicht zündet und folglich die Detektionsfunktion nicht überprüft werden kann.

Nationale Zusammenarbeit

Die Entwicklung des Lichtbogendetektors fand im Rahmen eines KTI-Projekts zusammen mit der Sputnik Engineering AG in Biel statt. Der Grossteil der Entwicklungsarbeiten wurde durch verschiedene Labors der Berner Fachhochschule durchgeführt. Die Sputnik Engineering AG beteiligte sich bei beim Bau einer Kleinserie von Testgeräten und bei den Feldtests.

Unsere negativen Erfahrungen mit der Testnorm UL1699B wurden an UL zurück gemeldet. Sie fanden aber bisher scheinbar noch wenig Gehör. Da es Bestrebungen für eine IEC Norm für PV-Lichtbogendetektoren gibt, werden die gewonnenen Erfahrungen durch unsere Mitarbeit in der TC82 auch dort eingebracht. Wir hoffen, dass nicht zuletzt durch unseren Beitrag auf internationaler Ebene so eine sinnvolle und anwendbare Norm zur Prüfung von Lichtbogendetektoren entsteht.

Bewertung 2013 und Ausblick 2014

Das KTI Projekt wurde Mitte 2013 formell abgeschlossen. Wie aber bereits erwähnt wurde, ist das entstandene Gerät noch zu empfindlich auf Fehlauslösungen und damit noch nicht marktreif. Es bestehen jedoch Ideen, wie das erarbeitete Detektionsprinzip verbessert werden kann. Deshalb laufen derzeit Bestrebungen für ein Folgeprojekt. Für ein solches konnte zwischenzeitlich ein Sponsor gefunden werden, womit die Arbeiten am Lichtbogendetektor innerhalb der ersten Jahreshälfte 2014 wiederaufgenommen werden sollten.

Referenzen

[1] **"Bewertung des Brandrisikos in Photovoltaik-Anlagen und Erstellung von Sicherheitskonzepten zur Risikominimierung"**, Gemeinschaftsprojekt des TÜV Rheinland, des Fraunhofer-Institut für Solare Energiesysteme ISE und weiteren Projektpartnern, http://www.pv-brandsicherheit.de.

Internationale Koordination

SCHWEIZER BEITRAG ZUM IEA PVPS PROGRAMM, TASK 1

Annual Report 2013

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Project- / Contract Number	SI/400735-02
Duration of the Project (from – to)	1.2.2013 – 2.2.2014
Date	23.1.2014

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
- 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.
- Providing information for government, industry and media about the global development of PV

The results of these activities include:

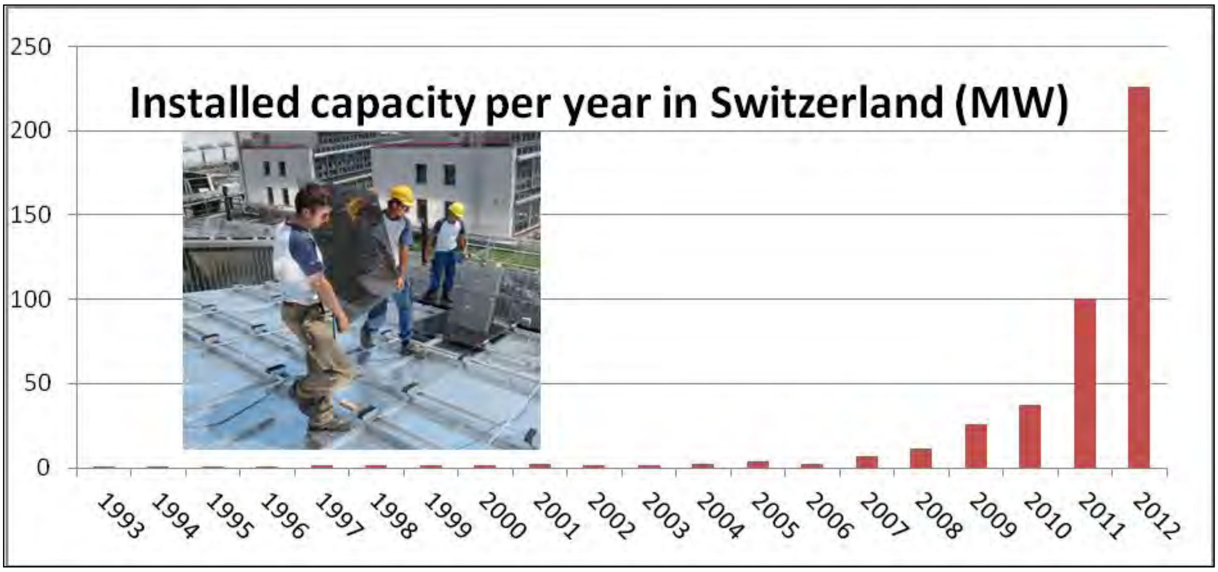
- National Survey Report (NSR) based on the statistics provided by the Swiss Association of Solar Professionals.
- 2 Task 1 meetings in Vienna (A) and Jeju (Rep. Korea)
- 2 Workshops in Paris and Taipeh (Taiwan)
- Webmastering support for www.iea-pvps.org until June 2013
- Contributions to subtask "New Business Models for PV"

Ongoing work:

- Workshop organization for the PV conferences in Amsterdam (Sept. 2014) and Kyoto (Nov. 2014)
- Participation at Task 1 Meetings in Tel Aviv (April) and Kyoto (November)
- Input for the new "Snapshot"-Trends Report
- National survey report 2013 / Contrib. to subtask "New Business Models for PV"

Einleitung / Projektziele

Innerhalb des IEA Implementing Agreements on Photovoltaic Power Systems kommt der Task 1 eine wichtige Bedeutung zu. Sie ist nicht nur der Kommunikationskanal für das gesamte Programm sondern seit 2013 berät sie auch das Executive Committee bei strategischen Fragen und macht Empfehlungen zu neuen Tasks.



Kurzbeschrieb des Projekts

Task 1 unterstützt die generelle Strategie des PVPS Programmes (Kostenreduktion, Potenzial erfassen, Barrieren beseitigen, Kooperation mit Nicht-IEA-Ländern) mit folgenden Produkten:

- Neu 2013: Snapshot of Global PV 1992-2012, erste Resultate der jährlich installierten Leistung. Publiziert im Frühjahr 2013
- Trends Report (Trends in Photovoltaic Applications, Survey report of selected IEA countries Between 1992 and 2012), 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.

Durchgeführte Arbeiten und erreichte Ergebnisse

Der Schweizer Beitrag innerhalb des PVPS Programms (Task 1) konzentriert sich auf folgende Schwerpunkte:

- Input-Daten Schweiz für den Snapshot of Global PV 1992-2012 [1]
- National Survey Report [2], eine Zusammenstellung der Marktentwicklung und des politischen Umfeldes in der Schweiz. Diese Daten werden im Trends Report [3] zusammengefasst und publiziert.
- 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
- Mitarbeit in der neuen Subtask „New Business Models for PV“

Daten für Snapshot of Global PV 1992-2012

In Zusammenarbeit mit Swissolar konnten bereits Anfang März 2013 erste Abschätzungen über die installierte Leistung erhoben werden.

National Survey 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.

TABELLE 1 NUMBERS OF PLANTS / BUILDING TYPE – AUSZUG AUS DEM NSR SWITZERLAND

Type of buildings	Numbers of PV Plants	average size of PV plant [kW]	Market share (installed capacity)
Single Family Houses	4000	7.5	13%
Multi Family Houses	1000	11.6	5%
Trade and Industry, Business	3600	24.4	39%
Agriculture/Farmer	1700	42.4	32%
Public buildings, public transport	1000	24.0	11%

Source: Markterhebung Sonnenenergie 2012

TABELLE 1 AUSZUG AUS DEM “NATIONAL SURVEY REPORT 1992-2012”: THE CUMULATIVE INSTALLED PV POWER IN 4 SUB-MARKETS

	Cumulative installed capacity as of 31 December 2011 (kW)																				
Sub-market	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Stand-alone domestic	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	4 100	4 200	4 MW
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	104 140	206 700	433 MWW
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	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	110 900	211 100	437 MW

WORKSHOPS

Anlässlich der Europäischen Photovoltaik-Konferenz in Paris organisierte Task 1 einen Workshop zum Thema Ensuring Robust PV Market Development with Limited Financial Support: the Role of New Business Models.

Dank guter Zusammenarbeit mit dem Konferenz-Organisator WIP wurde der Workshop sehr gut besucht.

An der asiatischen Photovoltaik-Konferenz in Taipeh (31. Okt. 2013) wurde vor allem das PVPS Programme vorgestellt sowie Marktberichte zu einzelnen Ländern.

Wie in den Vorjahren war die Schweiz hauptverantwortlich für den EUPVSEC-Workshop, Japan organsierte den asiatischen Workshop.

Konferenzen

Schweizer Photovoltaik-Tagung, Basel, April 2013: Referat zum globalen PV-Markt mit Daten aus dem Snapshot of Global PV – Report.

EUPVSEC Paris: Poster Präsentation der Resultate des Trends Reports 2012.

Zusätzlich wurden für den PVPS-Stand (innerhalb des EPIA-Standes) Flyer mit den neusten Resultaten des Trends Reports aufgelegt.

PVSEC23 in Taipei, Taiwan: *Oral Presentation* zum Trends Report 1992 – 2012.

Zusätzlich Workshop (siehe oben).

PR und Networking

Mit-Organisation der Schweiz. Photovoltaik-Tagung 2013 von Swissolar in Basel. Mitglied des Programm-Komitees. Referat mit Resultaten des Snapshot on Global PV.

Leitung der Kommission Photovoltaik des Branchenverbandes Swissolar

Der direkte Draht zu den Swissolar-Mitgliedern ermöglicht auch das direkte Abrufen von spezifischen Informationen zum PV-Markt in der Schweiz.

Mit Hilfe der Medienstelle von Swissolar konnte der Trends Report einer sehr grossen Zahl von Zeitungen und anderen Publikationen per Email zugestellt werden.

Bewertung 2013 und Ausblick 2014

Die Diskussion zur strategischen Ausrichtung wurde am Task 1 Meeting in Wien fortgesetzt.
Erste Resultate sind die Bildung von 2 Subtasks innerhalb von Task 1 (Business Models und PV as a Building Element)

Mit der Wahl eines neuen Operating Agents im Frühjahr 2013 wurden auch weitere neue Ideen und auch neue Aufgaben diskutiert und aufgegleist.

Positiv und Highlight war die erstmalige Publikation des Snapshop on Global PV fristgerecht im April 2013. Dafür verzögerte sich die Publikation des Trends Report bis in den November 2013. Die gedruckte Version wurde erst im Januar ausgeliefert.

2014 wird vor allem am Thema „Self Consumption“ und der Einbettung in die Geschäftsmodelle der Verteilnetzbetreiber (EW) gearbeitet werden – Subtask „New Business Models for PV“.

Referenzen

[1] **A Snapshot of Global PV 1992 – 2012**, IEA, PVPS, Task 1 – 22-2013

[2] P. Hüsser **National Survey Report on PV Power Applications in Switzerland 2012**, Mai/Aug. 2013

[3] Trends in Photovoltaic Applications in selected IEA countries between 1992 and 2012 IEA, PVPS, Task 1 – 23:2013

[4] ***Internet site www.iea-pvps.org***

[5] I. Kaizuka, G. Watt, P. Hüsser, R. Bründlinger, **Trends in Photovoltaic Applications - The Latest Survey Results on PV Market, Industry and Policies from the IEA PVPS Programme**
Poster Präsentation EUPVSEC, Paris, Okt. 2013,

IEA-PVPS TASK 12: Swiss activities in 2013

ÖKOBILANZEN VON SOLARSTROM

Annual Report 2013

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Project- / Contract Number	SI/500738 / SI/500738-02
Duration of the Project (from – to)	2013 – 2014
Date	September 22, 2014

ABSTRACT

In 2013 the leadership of the PVPS Task 12 changed. Subsequently, the work plan was redefined and reorganised. Secondly, the PVPS Task 12 team successfully applied for a three years pilot study within the Product Environmental Footprint activities of the European Commission. It involves global and European associations and US, European and Chinese manufacturing companies as well as research institutes and consultants.

Within the Swiss contribution to the *IEA PVPS Task 12, Subtask 2*, the existing data sets of the photovoltaic supply chain have been expanded to four world regions. The consideration of the actual markets shares results in a significant increase of the environmental impacts of solar electricity produced in Europe.

Furthermore, future key parameters of silicon-based single-crystalline and cadmium-telluride-based modules have been established and are under review by the other task members. They will be used for life cycle assessments of future PV electricity production based on three different scenarios. Data sets for future electricity mixes and future raw materials production have been established.

Contacts with Chinese experts have been established but the Chinese partners did not get the permission from the Chinese environmental authority to share the data with the PVPS Task 12 partners. Efforts will continue to establish detailed data sets of the Chinese supply chain. The LCA activities of PV recycling are postponed to 2015.

LCA activities in 2014 will focus on methodological aspects (energy return of investment), the EC pilot study, the continuation of analysing Chinese production and on the balance of system.

1. Einleitung / Projektziele

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 4'500 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. Im Jahr 2012 wurden im Auftrag des Bundesamtes für Energie aktualisierte Sachbilanzdaten zu Photovoltaik erarbeitet [5], welche öffentlich verfügbar sind[1], jedoch nicht im ecoinvent Datenbestand v2.2 enthalten sind.

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.

Im Rahmen der *IEA PVPS Task 12, Subtask 2* werden verschiedene PV-Ökobilanz-Projekte durchgeführt. Die Schweizer Projektpartner aktualisierten im Jahr 2008 die Sachbilanzdaten zu Cadmiumtellurid-Modulen [6]. Sie stellten im Jahr 2009 neue Datensätze zu Freiflächen- und Photovoltaik-Grossanlagen für eine Implementierung in der ecoinvent Datenbank bereit [7]. 2010 wurden die Solarstrommixe in 26 Ländern aktualisiert sowie verschiedene Chemikalien und Materialien, die in der PV-Industrie verwendet werden, bilanziert [8]. 2011 wurde der Methodik-Leitfaden der Task 12 zu Ökobilanzen von Solarstrom überarbeitet und die Sachbilanzdaten für Ethylen-Tetrafluor-Ethylen (ETFE) erstmals aktualisiert. Des Weiteren wurden im Jahr 2012 Sachbilanzdaten zur Herstellung von a-Si-Modulen und micromophen-Si-Modulen von Schweizer Firmen erarbeitet [9, 10].

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 zu etablieren und ein Recyclingsystem für die Photovoltaik-Module aufzubauen. Die Arbeiten der Schweizer Projektpartner der IEA PVPS Task 12 zum Anlagenrückbau und Recycling sind immer noch aufgeschoben aufgrund mangelnder Informationen und Daten.

Die Resultate des letzten Jahres [9, 10] haben gezeigt, dass das Produktionsland der Module einen deutlichen Einfluss auf die Umweltauswirkungen des Solarstroms hat.

Mit den von den Schweizer Projektpartnern der IEA PVPS-Task 12 geplanten Arbeiten wird beabsichtigt, dies mittels detaillierteren Chinesischen Produktionsdaten und der Modellierung der globalen Zulieferkette in den Ökobilanzdaten zu berücksichtigen.

Für das Jahr 2013 plante der Schweizer Projektpartner folgende Arbeiten durchzuführen:

- Erarbeitung von detaillierten Sachbilanzdatensätzen zur Chinesischen Produktion
- Erarbeitung von Sachbilanzdaten der globalen Zulieferkette von Photovoltaik-Modulen
- Erarbeitung von Sachbilanzdaten von zukünftigen Photovoltaik-Modulen mit dem Referenzjahr 2050
- Planung und Vorbereitung der nächsten 4-Jahresperiode der IEA-PVSP Task 12

Die Verantwortung über die Inhalte und Publikation der Sachbilanzdaten liegt bei *treeze GmbH.* Es ist geplant, dass die Daten im Rahmen einer Aktualisierung des ecoinvent Datenbestands publiziert werden (verantwortlich: *ecoinvent Centre*). Das Review der 2009, 2010, 2011 und 2012 neu erstellten und überarbeiteten Datensätze durch das ecoinvent Zentrum ist hängig.

[1] Bericht und Datenfiles sind auf www.lc-inventories.ch abrufbar, einer Webseite, die vom Bundesamt für Umwelt betreut wird und aktualisierte Ökobilanzdaten enthält, die (noch) nicht in den ecoinvent Datenbestand v3.0 integriert worden sind.

2. Kurzbeschrieb 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 und das Bereitstellen einer harmonisierten Methodik. In *Tab.1* sind die einzelnen Bereiche im Subtask 2 aufgelistet. Wesentliche Aktivitäten finden in den USA, Deutschland, der Schweiz, den Niederlanden, Frankreich sowie China und Japan (letztere vor allem im Bereich Safety) statt.

Tab.1 Neue Struktur der Aktivitäten im Subtask 2 des IEA-PVPS task 12

	Subtask 2. LCA	**Schweizer Beitrag**
2.1	LCA Methodology & Methodology Guidelines	Lead
2.1a	*3rd edition of LCA methodological guidelines*	*X (2015)*
2.1b	*Net energy methodological guidelines*	*R (2014)*
2.1c	*European Commission Product Environmental Footprint Pilot Project*	*X (3 years project)*
2.2	Life Cycle Inventories	
2.2a	*Global supply chain*	*X (2013-14)*
2.2b	*LCI of balance of system*	*X (2014)*
2.2c	*Water use in PV life cycle (manufacturing, panel washing)*	*X (2015)*
2.2d	*Changes in life cycle impacts of PV to 2050 (Average and best system characterization)*	*X (2013-14)*
2.2e	*LCI of module recycling*	*X (2015)*

3. Durchgeführte Arbeiten und erreichte Ergebnisse

Im Rahmen des Schweizer Beitrags zur IEA PVPS Task 12 wurden folgende Arbeiten im Jahr 2013 durchgeführt:

- Sachbilanzdaten zur globalen Zulieferkette unter der Berücksichtigung der vier wichtigsten Produktionsregionen der Welt
- Zukünftige Sachbilanzdaten zu siliziumbasierten monokristallinen und Cadmium-Tellurid-basierten Modulen
- Präsentation der neusten Ökobilanzergebnissen zu a-Si-Laminaten vom Typ Flexcell des Schweizer Herstellers VHF-Technologies SA. und zu µc-Si Modulen eines Schweizer Herstellers an der Europäischen Konferenz und Ausstellung zu Solarenergie (EU PVSEC) in Paris [11].

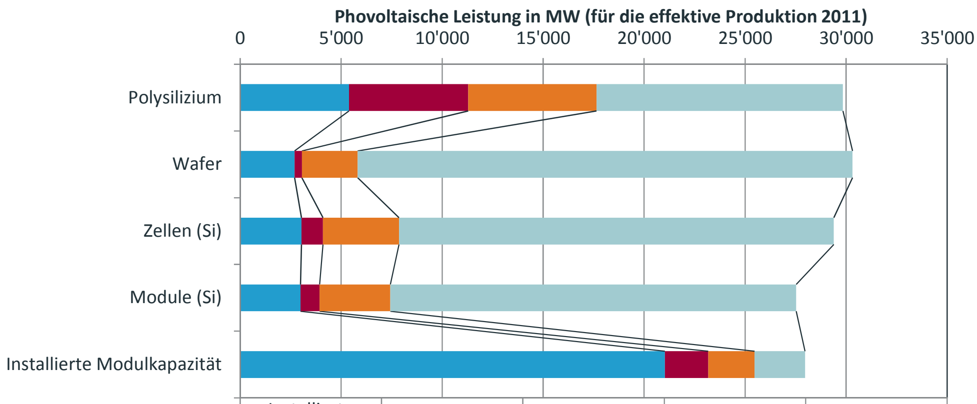
Sämtliche in den Jahren 2009, 2010, 2011, 2012 und 2013 erarbeiteten Sachbilanzdaten stehen Interessierten unter www.lc-inventories.ch kostenlos zum Download zur Verfügung. Die Daten werden in einem Datenformat zur Verfügung gestellt, welches den Import in alle gängigen Ökobilanz-Softwareprogramme erlaubt.

Aufgrund mangelnder Daten konnten keine detaillierteren Sachbilanzinventaren der Chinesischen Produktion erstellt werden. Die benötigten Daten wurden zwar von den Chinesischen Projektpartnern erhoben, die Publikation der Daten wurde jedoch durch das chinesische Umweltamt nicht bewilligt.

Die Erhebung von Sachbilanzdaten zum Modulrecycling wurde bis zum Jahr 2015 aufgeschoben, da die benötigten Daten noch nicht vorhanden sind.

SACHBILANZDATEN ZUR GLOBALEN ZULIEFERKETTE

Die globale Zulieferkette von kristallinen Silizium-Moduln wurde für die vier Weltregionen Europa, Amerika, Asien & Pazifik und China modelliert. Die Aufteilung des Marktes auf die vier Regionen wurde auf vier Ebenen berücksichtigt. Diese sind die Produktion des Polysiliziums, der Wafer, der Zellen und der Module sowie als fünfte Ebene die effektiv installierten Kapazitäten. *Fig. 1* zeigt die Anteile der vier Weltregionen auf allen Ebenen der Zulieferkette. Es zeigt die deutliche Dominanz chinesischer Hersteller bei den Wafern, den Zellen und den Moduln. Die Installation der Module findet nach wie vor überwiegend in Europa statt. Der Ausgangsrohstoff, das Polysilizium ist global gleichmässiger verteilt. China hat hier einen Produktionsanteil von weniger als 50 %.



	Installierte Modulkapazität	Module (Si)	Zellen (Si)	Wafer	Polysilizium
Europa	21'029	2'992	3'037	2'698	5'393
Amerika	2'151	944	1'066	360	5'902
Asien & Pazifik	2'290	3'501	3'760	2'761	6'352
China	2'500	20090	21528	24'500	12'194

Fig. 1 Marktanteile der vier Weltregionen an der Produktion von Polysilizium, Wafern, Zellen und Moduln und installierte Kapazität von siliziumbasierten Moduln im MW

Wie *Fig. 2* am Bespiel der Treibhausgasemissionen zeigt, ist er CO_2-Fussabdruck chinesischer Module deutlich höher als derjenige europäischer Module (siehe rote Balken). Der CO_2-Fussabdruck amerikanischer und asiatischer Module liegt etwa dazwischen. Werden die globalen Zulieferketten berücksichtigt und die in den Regionen installierten Module betrachtet (siehe blaue Balken), führt dies insbesondere für in Europa installierte Moduln zu einem deutlich höheren CO_2-Fussabdruck im Vergleich zu den Moduln europäischer Herkunft, da ein Grossteil der in Europa installierten Module in China hergestellt wird. Informationen über regionenspezifische durchschnittliche Wirkungrade der Module liegen nicht vor, weshalb derselbe Effekt auch beim CO_2-Fussabdruck der Stromproduktion aus Photovoltaik-Moduln zu beobachten ist.

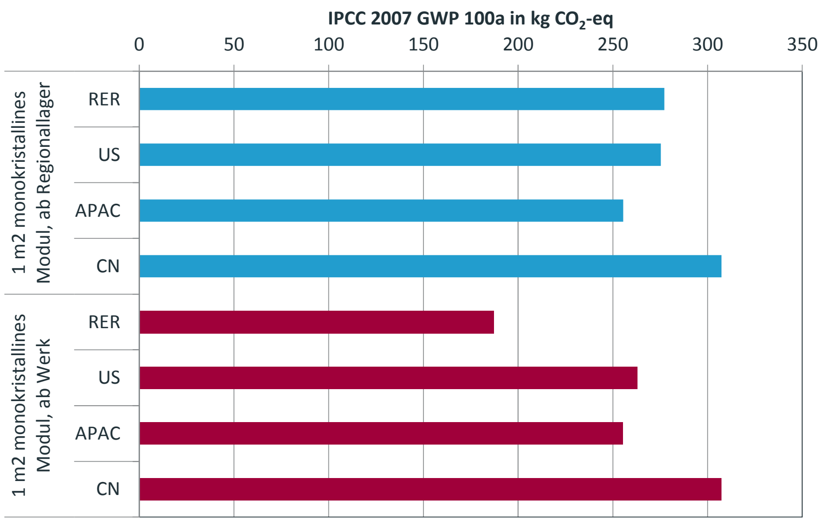


Fig. 2 Treibhausgasemissionen pro Quadratmeter siliziumbasiertes monokristallines Modul in kg CO_2-eq nach IPCC 2007 für Module ab Regionallager (d.h. in der genannten Region installiert, oben) und Module ab Werk (d.h. in der genannten Region hergestellt, unten)

SACHBILANZDATEN ZU ZUKÜNFTIGEN MODULEN

In Zusammenarbeit mit den Partnern im IEA Task 12 wurden szenarienabhängige Entwicklungen zentraler Parameter von siliziumbasierten monokristallinen und Cadmium-Tellurid-basierten Modulen erarbeitet. Die drei Szenarien (business as usual, realistic improvements, best available technologies) enthalten unterschiedlich ambitionierte Prognosen für 7 beziehungsweise 12 zentrale Parameter wie Zelleffizienz, Waferdicke oder Lebensdauer. *Tab.2* zeigt eine Liste der analysierten Parameter für die unterschiedlichen Modultypen.

Tab.2 Liste der zentralen Parameter für die beiden untersuchten Modultypen

Parameter	**Mono-kristallin**	**CdTe**	**Kommentar**
Zelleffizienz	Ja	Ja	Beschreibt die Effizienz der Zelle
Effizienzverlust Zelle zu Modul	Ja	Ja	Beschreibt den Effizienzverlust zwischen Zelle und Modul
Moduleffizienz	Ja	Ja	Beschreibt die Effizienz des Moduls
Wafer- und Schichtdicke	Ja	Ja	Beschreibt die Dicke des Wafer oder CdTe-Schicht
Zuschneide-verluste	Ja	Nein	Beschreibt die Zuschneideverluste des Wafers (nur für monokristallin, runder Kristall zu rechteckigem Wafer)
Sägeverluste	Ja	Nein	Beschreibt die Verluste durch das Sägen des Kristalls in Schichten (nur monokristallin)
Silberverbrauch	Ja	Nein	Beschreibt den Verbrauch von Silber für Kontakte (nur monokristallin)
FBR Anteil	Ja	Nein	Beschreibt den Anteil der FBR Produktion an der gesamten Polysiliziumproduktion (nur monokristallin)
Modulrahmen	Ja	Nein	Beschreibt den Aluminiumverbrauch für den Modulrahmen (nur monokristallin)
Aufständerung	Ja	Ja	Beschreibt den Materialverbrauch für die Aufständerung
Glasdicke	Ja	Ja	Beschreibt die Dicke des Glasschicht
Lebensdauer	Ja	Ja	Beschreibt die Lebensdauer der Module

Diese zukünftigen Parameterwerte werden dann verwendet, um Ökobilanzen für eine Solarstromproduktion im Jahr 2050 zu erstellen, in abhängigkeit der drei Szenarien.

4. Nationale / Internationale Zusammenarbeit

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 auch dieses Jahr nicht in der Lage, die bereitgestellten Daten zu validieren und in die neue Version des ecoinvent Datenbestands (v3.0) aufzunehmen.

Auf internationaler Ebene fanden insbesondere Diskussionen zu den zukünftigen Arbeiten der *IEA PVPS Task 12* statt. Unter der neuen Leitung von Garvin Heath wurden in zwei produktiven Projekttreffen die Ökobilanz-Aktivitäten in Subtask 2 neu strukturiert, ausgedünnt und gebündelt.

Trotz der Bereitschaft der Chinesischen Partnerinnen konnten sie die neu erfassten Daten zur Chinesischen Produktion den Projektpartnern und insbesondere uns nicht zur Verfügung stellen.

An der 11. nationalen Photovoltaik-Konferenz in Basel wurden von den Schweizer Projektpartnern Resultate zu den Ökobilanzarbeiten im Rahmen der Energiestrategie 2050 des Bundes gezeigt werden.

An der Europäischen Photovoltaik Konferenz (27th EU PVSEC) in Frankfurt wurden von den Schweizer Projektpartnern Ergebnisse zum Einfluss von Technologieentwicklungen und Marktverschiebungen auf die Ökobilanzresultate von Solarstrom präsentiert [9, 10]. Diese zeigen, dass die Treibhausgasemissionen von Solarstrom durch die Verwendung von neuen amorphen oder micromorphen Modulen reduziert werden können und dass der in der Fotovoltaikindustrie verwendete Strommix einen grossen Einfluss auf die Umweltbelastung von Solarstrom hat. Dies wurde durch den beachtlichen Unterschied zwischen europäischen und chinesischen Modulen verdeutlicht (siehe *Fig. 3*). Die Reduktion der Umweltbelastung und der Treibhausgas-Emissionen durch Effizienzgewinne aufgrund von technischen Fortschritten werden durch den vermehrten Import von Solarzellen und Modulen aus China deutlich überkompensiert.

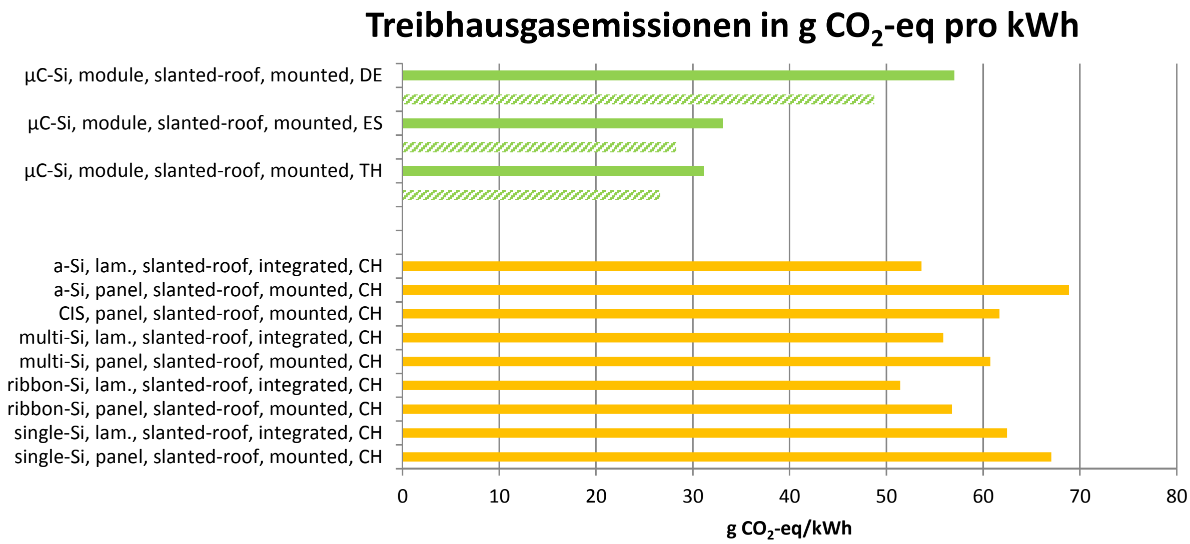


Fig. 3 Treibhausgasemissionen von Strom aus einer Schrägdachanlage mit Modulen montiert in Deutschland (DE), Spanien (ES) beziehungsweise Thailand (TH) und produziert mit Chinesischem Strommix (dunkelgrün) und produziert mit Europäischen Strommix (hellgrün) verglichen mit unterschiedlichen Schrägdachanlagen montiert in der Schweiz (CH, gelb) in g CO_2-eq nach IPCC 2007. Ertrag: Deutschland: 809 kWh/kWp; Spanien: 1394 kWh/kWp; Thailand: 1481 kWh/kWp; übrige Anlagen: 922 kWh/kWp.

Weiter nahm Rolf Frischknecht an zwei Projekttreffen des *IEA PVPS Task 12* in Boulder, Colorado und in Paris teil. Dabei ging es um die Neudefinition und Strukturierung der einzelnen Arbeiten und um deren Koordination.

5. Bewertung 2013 und Ausblick 2014

Die Erstellung von detaillierten Sachbilanzdatensätze zur Chinesischen Produktion konnte nicht abgeschlossen werden, da die benötigten Daten nicht zur Publikation freigegeben worden sind. Wir werden auf anderen Wegen versuchen, detaillierte Daten zur Chinesischen Produktion zu erhalten.

Die Sachbilanzdatensätze zu den globalen Zulieferketten sind erstellt und ausgewertet. Prognosen zur Entwicklung der zentralen Parameter von siliziumbasierten, mono-kristallinen und Cadmium-Tellurid-basierten Modulen sind abgeschlossen und befinden sich derzeit im Review bei den übrigen Projektpartnern. Sachbilanzdatensätze zur zukünftigen Stromproduktion in drei der vier modellierten Weltregionen sowie zur Aluminiumproduktion wurden erstellt.

Der PVPS Task 12 hat sich bei der Europäischen Kommission erfolgreich um das Durchführen einer Pilotstudie zum Umweltfussabdruck von Photovoltaikstrom beworben. Diese Pilotstudie wird drei Jahre dauern und durch Projektpartner des PVPS Task 12 und weitere Organisationen und Firmen durchgeführt.

Die Durchführung der geplanten Modellierung der Modul-Take-Back-Systeme und des Modul-Recyclings ist aufgeschoben auf das Jahr 2015. Wir werden zu jenem Zeitpunkt diese Arbeiten wieder aufnehmen und zu Ende zu führen.

Für 2014 sind folgende Arbeiten geplant:

- Weiterführung: Erstellung von detaillierten Sachbilanzdatensätzen zur Chinesischen Produktion (Task 2.2a)
- Mitarbeit am Methodikpapier zu energetischen Payback Time (Task 2.1b).
- Zuarbeit zur Pilotstudie „Product Environmental Footprint of Photovoltaic electricity production" (Task 2.1c)

- Sachbilanzdaten zu Balance of System, insbesondere Inverter (Task 2.2b).
- Abschluss der Ökobilanzen zur zukünftigen Stromproduktion mittels Photovoltaik in der Schweiz für das Jahr 2050 und Dokumentation in IEA-Bericht (Task 2.2d).

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 (weiterhin v2.2) aufzubereiten.

6. Referenzen

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SCHWEIZER BEITRAG ZUM IEA PVPS PROGRAMM, IEA PVPS TASK 13

Annual Report 2013

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Project- / Contract Number	2012.01
Duration of the Project (from – to)	2010 - 2013
Date	04.03.2014

ABSTRACT

Switzerland takes part in the Photovoltaic Power Systems (PVPS) program of the International Energy Agency (IEA), Task 13: Performance and Reliability of Photovoltaic Systems, 2010 – 2013. The overall objective of Task 13 is to improve the operation, reliability and, thus, electrical and economic output of photovoltaic power systems and subsystems.

Task 13 is focusing on:

- Providing reliable statistical data for any kind of decision makers for different PV applications and system locations (e.g. different countries, regions, climates).
- Technical issues such as adapting test methods and reliability assessments of PV modules, comparing the long-term behavior of systems and components, as well as performance analysis and optimization of PV systems

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 Consulting AG is the responsible Subtask 1 leader and also the activity leader 1.1 Database and Analysis of PV Systems.

In the year 2013 the 'Input Tool' for the collection of plant- and operational data was used by the experts. The collected information and performance data was evaluated and controlled by TNC, imported into the database. It is now available in the internet for the PV community and other interested parties worldwide. By the end of 2013 annual datasets of 100 PV systems with a total capacity of 8’500 kW, representing more than 330 years of operational data, was collected, approved and made available in the online database. The installations representing Italy 31, USA 24, Switzerland 11, Sweden 10, France 7, Germany 7 and 6 other countries.

Introduction/Aims of the project

2013 Task 13 has launched and published public access to the developed performance database of PV systems. The process of normalized data collection with high quality has been successfully established with the help of the task experts.

Description of the project

The database contains information on the technical performance and reliability of Photovoltaic (PV) systems and subsystems located worldwide. The information is gathered and presented by means of standard data collection formats and definitions. The database user can select PV system data, read monitoring data and calculated results. This tool can be used to check the operational behaviour of existing PV plants and to get a PDF on its performance results in standard quantities allowing cross-comparison between the systems.

Work carried out and results achieved

2013 we have participated on two expert meetings:

1. March 18th – 20th 2013 in Rotterdam, The Netherlands
2. October 22nd – 24th 2013 in Kuala Lumpur, Malaysia
3. Additionally in 2013 Task 13 has held a special parallel event as a workshop at the occasion of 28th European Photovoltaic Solar Energy Conference and Exhibition in Paris, September 30th – October 4th 2013. On the workshop under the Title: “ Analysis of PV System Performance” the online database was made public available to the PV community through the internet. The database was explained and demonstrated in a presentation “Gathering PV performance data worldwide: the current state-of-the-art” by Th. Nordmann.

The following chapter is explaining the process and database of analysing PV systems in more details:

Database and Analysis of PV Systems

1. Introduction

Talking about efficiency in photovoltaics (PV) the focus often lies on efficiency of cells or modules. However, it is worthwhile to devote at least equal attention to the overall efficiency of the entire photovoltaic system in order to make this technology a competitive and reliable alternative to conventional energy sources. Losses in inverters and cables, losses due to reflection and temperature effects as well as losses due to system outages can greatly affect the overall energy yield and thus the economic efficiency of a photovoltaic installation.

In recent years, great progress in terms of the overall efficiency of PV systems has been made, which is reflected for instance in a clearly measurable increase of the performance ratio. The performance ratio (PR) as an important indicator of PV systems efficiency is explained in more detail further on. Typical ranges of the PR rose from 50% - 75% in the late 1980s via 70% - 80% in the 1990s to typically >80% nowadays, with some systems reaching 90% [REF1]. Nevertheless the PR bandwidth of newly installed PV still varying from 70% - 90% shows the necessity of evaluating the performance of entire PV systems.

2. Concept / Terms

In order to measure and compare the efficiency of entire PV systems it is necessary first to describe the whole energy conversion chain from solar irradiation input to electricity fed into the grid by suitable and normalized quantities. The normalized evaluation and presentation of the operational data in the IEA PVPS Performance Database is based on the Standard IEC 61724, "Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange and Analysis". Because the database comprises grid-connected PV-systems only some adaptions were implemented. [1], [2].

Figure 2 shows a schematic illustration of grid-connected PV-systems along with the most important parameters

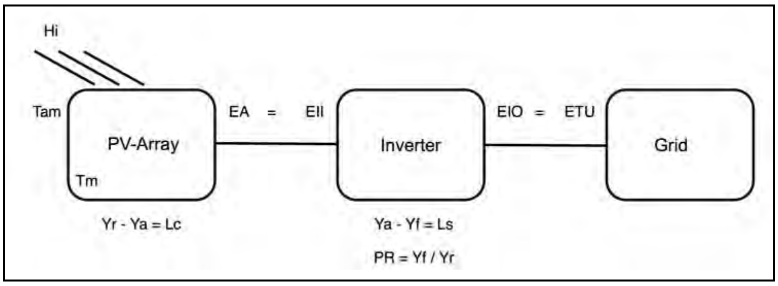

Figure 2: Normalized evaluation of a grid-connected PV-system

Hi represents the incoming solar irradiation onto a PV-Array. EA describes the DC-energy output of the array, for the purpose of simplicity,we assume this to be equal to energy EII which is fed into the inverter. As the cell temperature has a significant influence to the efficiency of PV-modules ambient temperature Tam and module temperature Tm are important for the complete description of the PV system.

Knowing reference yield Yr and array yield Ya, generator losses Lc can be calculated. Besides mentioned temperature effects there are several more factors that can contribute to generator losses, such as partial shading, soiling, reflection, MPP-tracking-errors, conductor losses, (MPP=Maximum power point) or mismatch.

The inverter transforms DC-energy EII into AC-energy EIo, which is fed into the grid (ETU). System losses of the inverter are calculated as the difference between Ya and the normalised final yield Yf.

The performance Ratio PR calculated from Yf (ac side) and Ya (dc side) is the ratio between the energy actually generated to the energy an ideal lossless PV plant would have produced with the same amount of irradiation energy and at a module temperature of 25°C. The PR is one of the most useful key figures to determine the efficiency of PV-systems regardless of module efficiency.

In Annex A further recorded and derived parameters used for the PV Performance Database are listed. This standardization of parameters is crucial to allow a profound analysis and comparison of PV systems.

3. Using the IEA PVPS Performance Database

The IEA PVPS Performance Database is basically open to everybody after registration. The database is available under the following address in the internet:

http://www.iea-pvps.org

With a web browser the data of PV plants from different countries, sizes, and years of construction acquired and evaluated during the Task 2 (1993-2007) and Task 13 (after 2010) , can be accessed with an easy to use graphical interface.

A search function allows for access to the data of a registered plant. In the overview the most important project specific data such as nominal power, number of modules or geographic location can be viewed. In further menus more detailed information such as type of the inverters and modules or the combination of the modules to strings can be accessed. The recorded data on a monthly base and in an annual overview is evaluated and displayed in tables and graphs, such as shown in Figure 3. The exemplary graph shows the monthly data from 2012 of a PV plant at Bolzano airport in Italy.

Figure 3: Yield of a PV plant at Bolzano airport (Italy)

The 12 bars in the Figure 3 show the monthly average of the normalized yield per day. The normalization shows the average full operational hours per day. The overall height of the bar represents the Reference Yield Yr. The yellow part represents the array capture losses Lc, while the green part stands for the system losses Ls. The blue part represents the final yield of the plant. The green line symbolises the Performance Ratio PR. It is not a staight line, due to different influences such as temperature effects or snow coverage of the modules. Additional information such as the outage fraction is shown with a red line. Outage can be caused by an outage of the inverters or of the overall system.

Another important function is the possibility to sort the available data within in database. This allows a comparison of the different plant data within the sorted arguments. Pre-defined filter criteria are (Figure 4):

- Year of construction
- Type of plant (i.e. flat roof, sloped roof, facade, etc.)
- Installed nominal power
- Country
- Cell technology

Within the filtered data, there is still the possibility to display the data on a monthly or annual base in form of tables. Additionally, there are five normalized and pre-defined graphical displays of the data available which can be applied to the filtered data.

Analysing single PV systems

The first chart in Figure 5 shows the annual Performance Ratio of a single PV system in Switzerland (Jungfraujoch) for 16 years of operation. It can be seen that the PR of this system stays almost constant at about 0.8 over this time period.

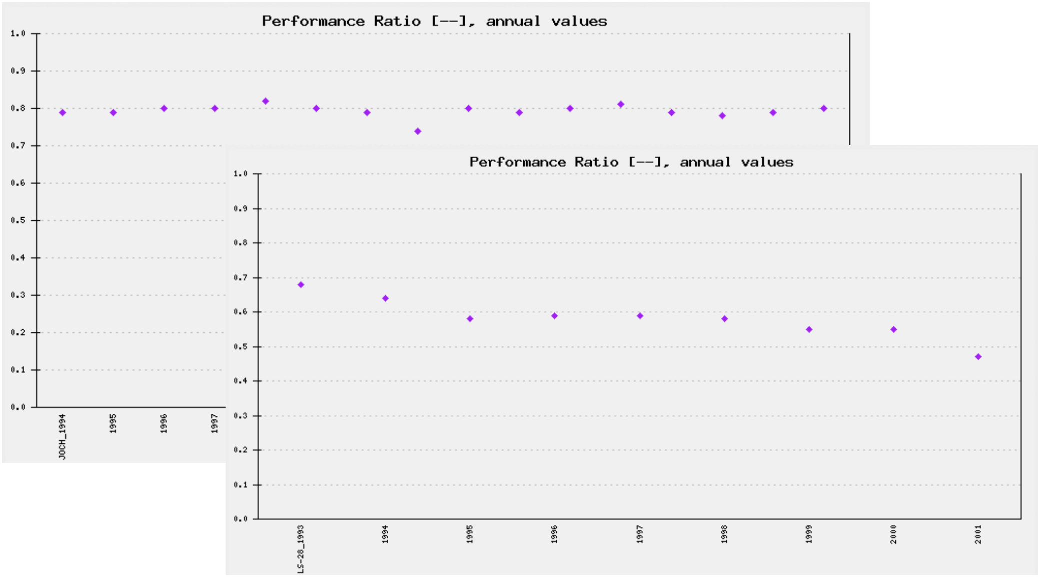

Figure 5: Annual Performance Ratio of a PV system in Switzerland

Figure 6: Annual Performance Ratio of a PV system in Germany

In comparison, Figure 6 shows the same type of chart for a selected PV system in Germany. The annual PR decreases significantly over the monitored time of 9 years. Possible reasons for this decrease are degradation effects of the PV cells.

The annual PR of a third PV system located in Italy is shown in Figure 7. The PR of this system is varying noticeably over the monitoring period of 13 years. This indicates that the system experienced several outages since being installed.

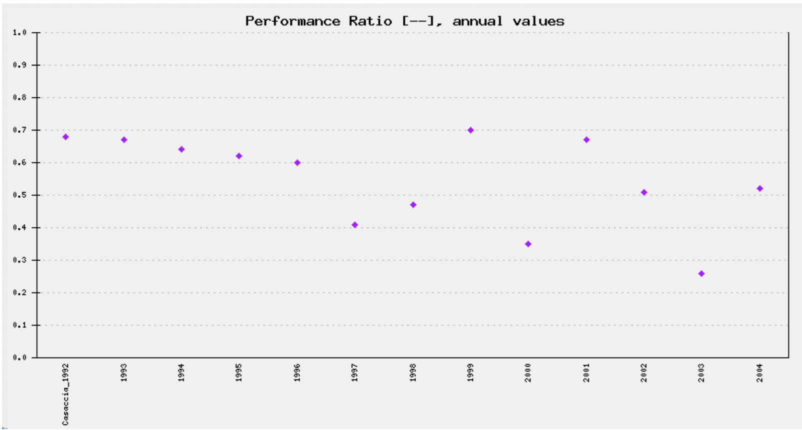

Figure 7: Annual Performance Ratio of a PV system in Italy

Analysing groups of PV systems using filter criteria

Using the filter options it is not only possible to analyse single PV systems but to draw graphs for a whole group of plants.

Figure 8 and Figure 9 show two charts of operational data from PV systems filtered by year of installation. Figure 8 shows the annual PR for PV systems installed between 1983 and 1990. Figure 9 shows the annual PR for PV systems installed between 2005 and 2012 (with the installation year on the x-axis). Comparing the two graphs it is visible that more operational data is available for the more recent years. Furthermore it can be seen that the PR of the PV systems installed in the 80s vary around a value of 0.7 whereas the PR of the newer plants show typical values of 0.8. Values of zero represent incomplete datasets (e.g. datasets with less than 12 months operational data).

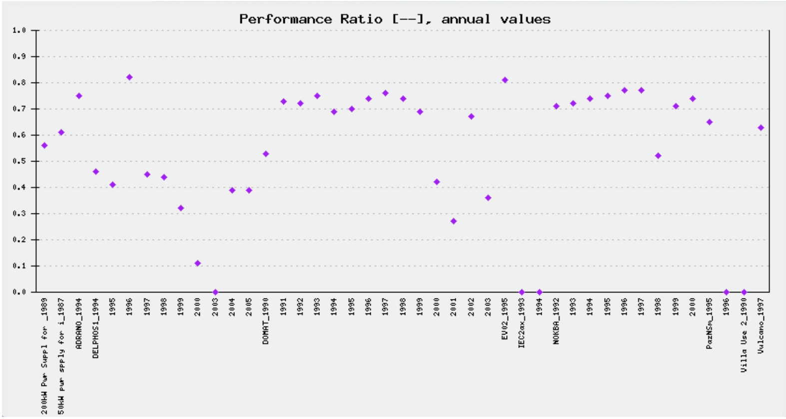

Figure 8: Performance Ratio of PV systems installed between 1983 and 1990

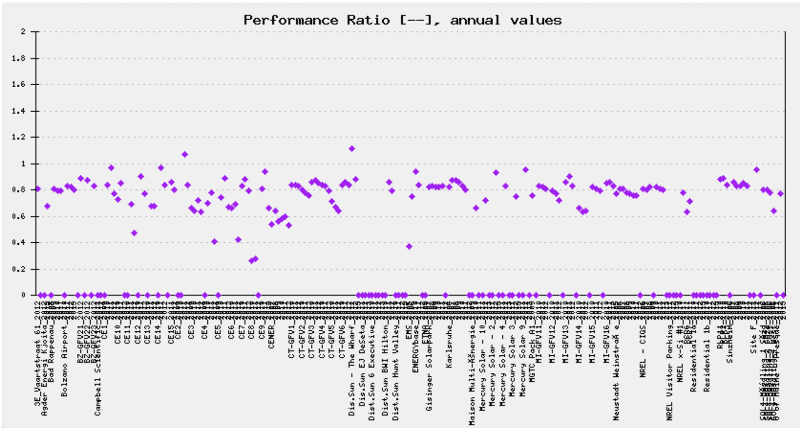

Figure 9: Performance Ratio of PV systems installed between 2005 and 2012

Figure 10 and Figure 11 show two more graphs of the same PV systems discussed above. Here the final yield is plotted versus the reference yield. Figure 10 shows data for systems installed from 1983 – 1990, Figure 11 shows data for systems installed between 2005 and 2012. The blue line represents a PR of 1, i.e. an ideal PV system without losses under standard test conditions. A constant PR <1 would be represented by a line starting at 0 with slope corresponding to the PR. The further a data point, i.e. the annual final yield is away from the blue PR=1 line the lower the PR of the PV system for the respective year of operation. Comparing the cloud diagrams the data points in Figure 11 are closer to the blue line indicating a higher PR for the more recent PV Installations.

This way of illustrating system performance is useful to compare a great amount of datasets graphically in order to analyse the influence of different factors such as cell technology, mounting type or others.

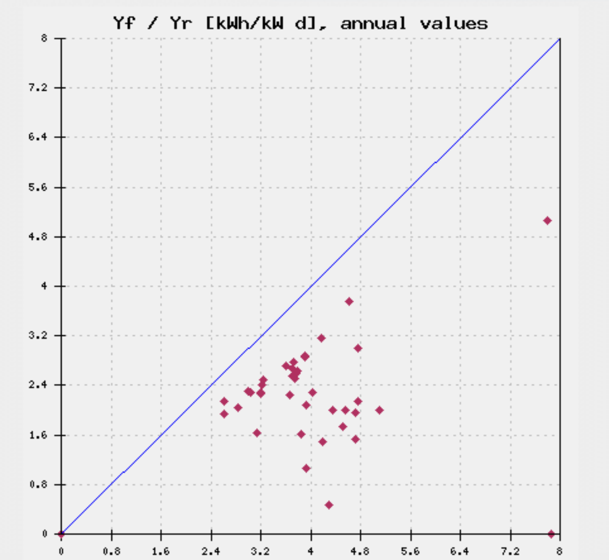

Figure 10: Final yield vs. reference yield for PV systems installed between 1983 and 1990 (Task 2)

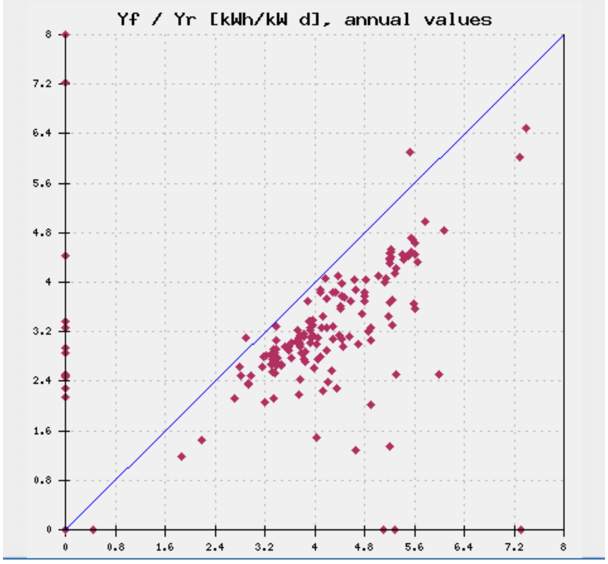

Figure 11: Final yield vs. reference yield for PV systems installed between 2005 and 2012 (Task 2 & 13)

Figure 12 shows the fourth pre defined type of graph of the database web application for PV systems in Switzerland (left) and Italy (right). In this graphs the array efficiency etaA is plotted vs. the theoretical array efficiency etaA STC at standard test conditions. Standard test conditions (STC) are defined by a irradiation of 1000 W/m2 in the module plane, a module temperature of 25°C and a light spectrum at air mass (AM) of 1.5. As the charts are based on monthly data it is possible to illustrate and compare the range of the array efficiencies within the monitored years for selected PV systems. A major influence to the array efficiency is the seasonal change of the ambient temperature, which affects directly the temperature of the cells and therefore the cell efficiency. The red lines in the diagrams represent a etaA / etaA STC ratio of 1. Although data values above this line are possible for some sites (e.g. a cold and sunny alpine location), the datasets need to be verified carefully to avoid having datasets based on measurement or calculation errors in the database.

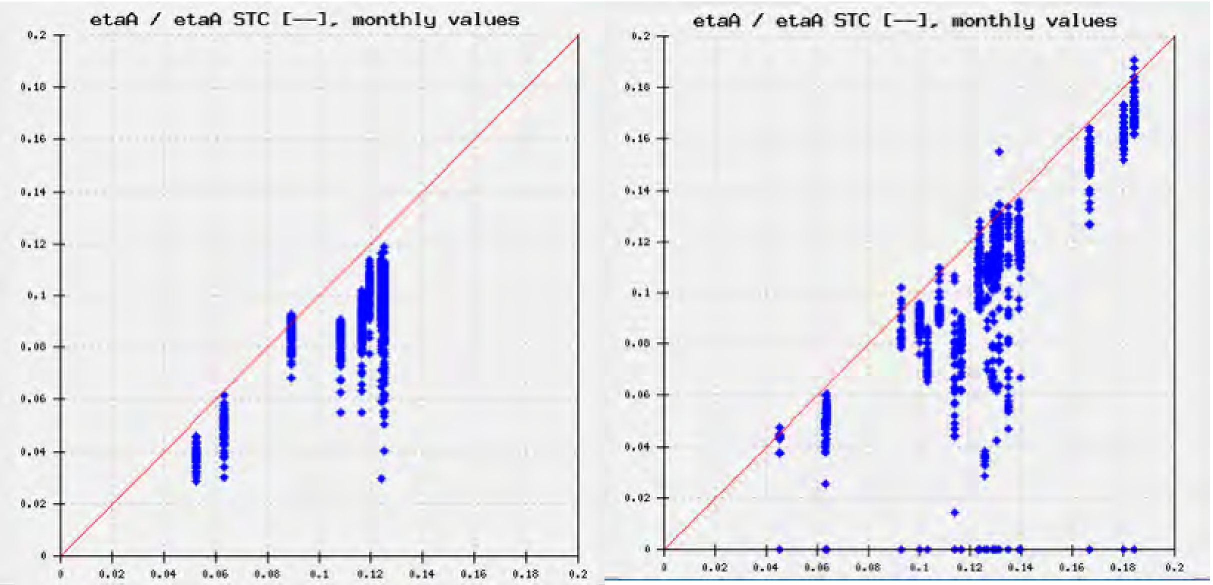

Figure 12: Array efficiency vs. theoretical array efficiency at standard test conditions STC; left: selected PV systems in Switzerland, right: PV systems in Italy

Figure 13 shows an example of the last pre-defined chart type. Annual irradiation in the module plane is plotted versus the latitude of the respective PV system. Operational data of all participating PV plants of Task 13 are included in this chart. This illustrates the bandwidth of irradiation that is available for the different sites and gives an impression of the geographical distribution of the PV systems included in the database.

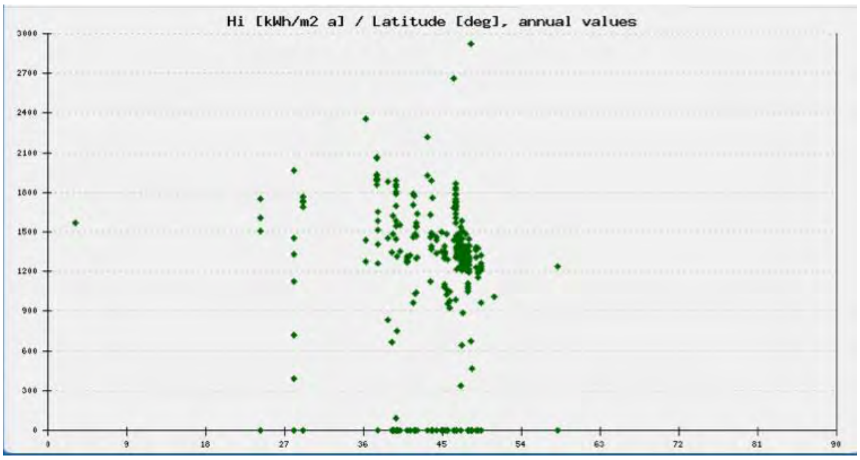

Figure 13: Annual irradiation in module plane. PV plant data Task13

Beside these pre-configured filter and display options any variant of filters and graphs are feasible in principle. A simple and effective way of using the database individually is to list annual or monthly operational data in a table and subsequently export it to a spreadsheet application like Microsoft Excel. With that it is possible to create own graphs and to analyse the data in more detail.

National and international cooperation

The activity of Task 13 as part of the photovoltaic power system implementing agreement of the international energy is by itself a form of international cooperation. Presently, the following IEA PVPS countries and institutions are participating in Task 13: Austria, Belgium, China, Cyprus, EPIA, France, Germany, Israel, Italy, Japan, Malaysia, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, UK and USA.

Evaluation 2013 and Outlook 2014

The process of collecting high quality performance data in a standardized form has been successfully established in Task 13 Subtask 1. The webbased database is online and accessible for interested parties in the PV community with proper login and identification through the internet. The amount of the available project data is still behind the initially plan. We hope to reach these targets in phase 2 of Task 13.

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IEA PVPS TASK 14 – HIGH PENETRATION OF PV SYSTEMS IN ELECTRICITY GRIDS

SWISS CONTRIBUTION

Annual Report 2013

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Project- / Contract Number	IEA PVPS Pool II No. 2011.01	
Duration of the Project (from – to)	March 2010 – March 2014	
Date	December 15, 2013	

ABSTRACT

The main purpose of Task 14 is to analyze the role of grid connected PV as an important source in electric power systems on high penetration level where additional efforts may be necessary to integrate the dispersed generation in an optimum manner. The aim of these efforts is to reduce the technical barriers to achieve high penetration levels of distributed renewable systems on the electric power system.

Cross-cutting subtask (Information Gathering, Analysis and Outreach) objective is to review and document worldwide implementations of high penetration PV scenarios into electric power systems and based on subtask work, to generalize and refine them to generate a set of convincing cases of safe and reliable implementation.
Subtask 1 (PV generation in correlation to energy demand) objective is to show and determine how with better prediction tools an optimized local energy management, PV penetration level can be improved in grid.
Subtask 2 (High penetration PV in local distribution grids) objective is to identify and evaluate the role of PV in distribution grids, to analyze the impact of high penetration and to make recommendations (Grid Codes, incentives, regulation).
Subtask 3 (High penetration solutions for central PV generation scenarios) objective is to envision the future power system with the integration of system-wide PV integration through the review of PV generation output variation and its predictability, the power system operation and the power system increase.
Subtask 4 (Smart inverter technology for high penetration of PV) objective is to highlight and define inverter technology requirements for successful smart integration of a high penetration of PV (technology, technical requirement, standards and system integration aspects).

Switzerland is responsible of subtask 1 and contributes to other subtasks.

Purpose of the project

The project aims to analyse the impact of a high penetration of photovoltaic (PV) especially the integration in electricity grid. The high penetration of renewable energy systems (RES) is a real challenge to maintain reliability and stability in electricity grids. The objective is so to analyse and reduce the technical barriers restricting PV penetration in following fields: local energy management (load profiles and weather's effect) → subtask 1, local distribution grids (optimized load management) → subtask 2, central PV generation → subtask 3, inverter technology → subtask 4.

Short description of the project

The task 14 results from a workshop on the role of photovoltaic in Smart Grids.

What are the opportunities and needs for an electricity grid with a high penetration of PV? In a number of countries the PV has been grown rapidly with some problems and issues associated to a question more and more current.

As the initiative and responsibility of the task were taken over by Austria, the following countries announced their interest to participate to the task: Australia, Canada, Switzerland, Germany, Israel, Italy, Japan, Korea, Portugal, USA, China and Thailand.

The main purpose of this task is to promote the use of grid connected PV as an important source in electric power system on a high penetration level. However, these dispersed generators require additional efforts and a great collaboration to be integrated in an optimum manner. It will only be possible when the technical barriers will be reduced. To achieve this objective the task 14 will focus on working with utilities, industry and other stakeholders to develop the technologies and methods enabling the widespread deployment of distributed PV technologies into electricity grids.

The objectives are:

1. develop and verify mainly technical requirements for PV systems and electric power systems to allow high penetrations of PV systems interconnected with the grid
2. discuss the active role of PV systems related to energy management and system control of electricity grids

To achieve these objectives the project was divided into five parts: four subtasks and a cross-cutting subtask (Fig. 1).

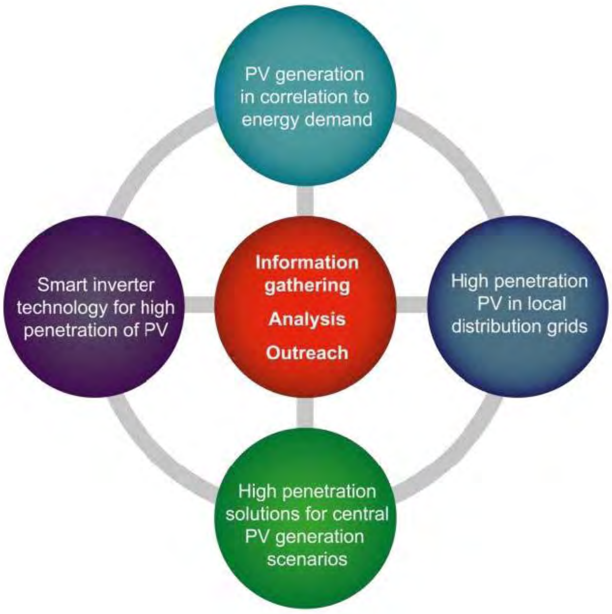

FIG. 1: PARTS OF THE IEA-PVPS T14 PROJECT

Subtasks description, work done and results

CROSS-CUTTING SUBTASK (NEW SUBTASK LEADER: USA)
« INFORMATION GATHERING, ANALYSIS AND OUTREACH »

The objective of this subtask is to collect, standardize and share existing information on high penetration PV into electric power systems, based on other subtasks needs.

SUBTASK 1 (SUBTASK LEADER: SWITZERLAND)
« PV GENERATION IN CORRELATION TO ENERGY DEMAND »

The objective of this subtask is to show and determine how with better prediction tools an optimized local energy management, PV penetration level can be improved in grid.

Activity 1.1 (Switzerland)

The analysis of the questionnaire *"Use of solar and PV forecasts for enhanced PV integration"*, which was made in the year 2011, has been integrated in an official IEA report about "Photovoltaic and Solar Forecasting: State of the Art" (IEA PVPS T14-01:2013), which has been published in October 2013 [2].

Meteotest is continuing their research on the combination of cloud and radiation fields from satellite images with wind fields from the NWP (numerical weather prediction) model WRF (weather research and forecasting). This shortest term solar forecasting algorithm for 0.5 - 6 hours ahead which is updated every 15 minutes (Figure 2) has been evaluated for more than 20 sites in Switzerland, including low lands, alpine and high-alpine stations.

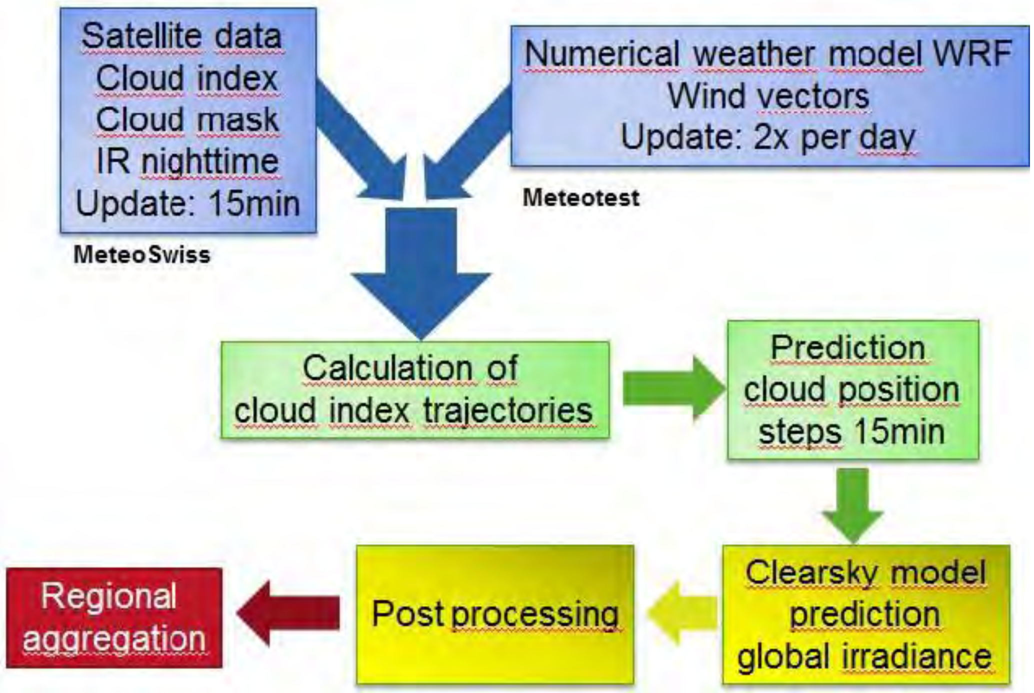

FIG. 2: THE SHORTEST TERM FORECAST MODEL OF METEOTEST.

The RMSE ranges between 75 – 200 W/m^2 (20 - 60%), depending on season, station and forecast horizon (Fig. 3). The uncertainty is low in flatland and much higher in the Alps. The improvement of this approach over NWP WRF direct models output for 3 – 6 hours is about 40%. A particular focus during the reporting period has been on the investigation of Kalman filters to improve the forecasts. It has been found, that this post-processing approach is useful to correct for clear sky days (but not for cloudy).

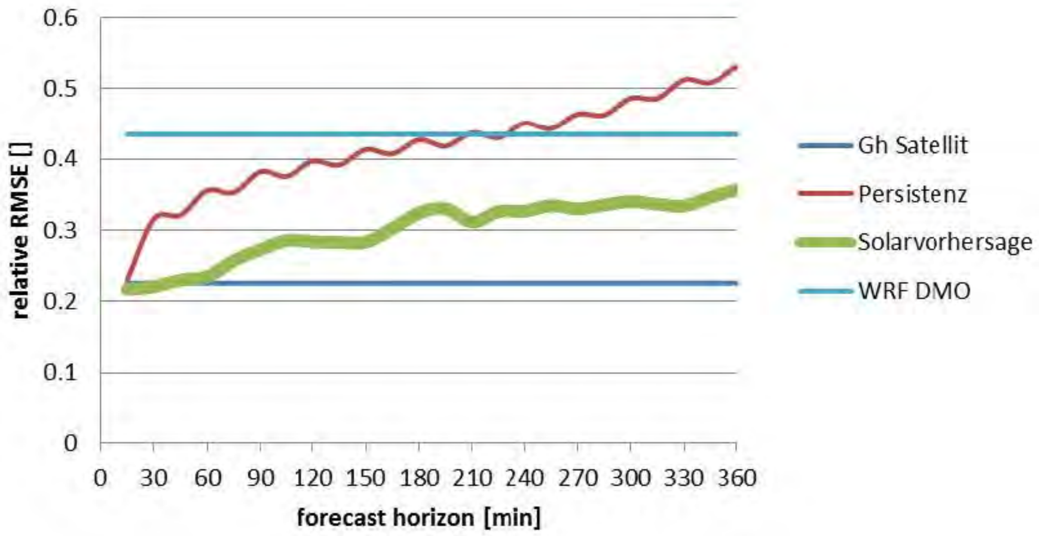

FIG. 3: RELATIVE RMSE IN DEPENDENCE ON FORECAST HORIZON FOR FORECASTS BASED ON CLOUD ADVECTION WITH NWP WIND FIELDS ("SOLARVORHERSAGE"). FOR COMPARISON THE RMSE OF WRF BASED FORECAST ("WRF DMO") AS WELL AS SATELLITE DERIVED IRRADIANCE ("GH SATELLIT") AND PERSISTENCE ("PERSISTENZ") IS GIVEN. DATABASE: IRRADIANCE OF A SINGLE STATION (BERN-ZOLLIKOFEN) IN SWITZERLAND, JULY – SEPTEMBER 2012.

The results of Meteotest are in accordance with those found by Univ. of Oldenburg [3]:

- the altitude of the wind vectors is not sensible; the altitude of 2.5 – 3.5 km shows the best results
- the forecast errors for the first hour are up to 50% lower than for NWP models
- the results of the method are better or equal than those from NWP up to 4 (summer) – 6 hours (winter) ahead

During the last months of the project the regional aggregation model and the validation with ground stations (during two months a dense network of ground stations was installed) will be made.

The project is supported by the BKW FMB AG and is going on until April 2014. After the end of the project an operational service is planned.

<u>Activity 1.2</u> (Switzerland)

The basis case study was improved with a typical theoretical solar curve simulated with the Polysun® software

	Power	Generation		Of 4'000 kWh Yearly consumption
Basis	550 W	495 – 550 kWh		12 – 14 %
DSM	800 W	720 - 800 kWh	(+45%)	18 – 20 %
Storage	1'470 W	1'323 - 1'470 kWh	(+167%)	33 – 37 %
DSM + storage	1'580 W	1'422 - 1'580 kWh	(+187%)	36 – 40 %

TABLE 1: RESULTS OF BASIS CASE STUDY

The test site in Cernier (CHE) (smart meters in households, data transmission and remote consultation) will offer the possibility to study and analyse PV local energy management with storage. The project has started in 2013 in 300 household. A detailed survey of household indicated the theoretical level of DSM. The real shifting potential of demand around PV peak (11-15h) is investigated through an economical experimentation.

The IMT, Institute of Microengineering in Neuchâtel (CHE) works on a project for PV local storage. A meeting took place on January to introduce the task 14 to IMT and to discuss a possible collaboration.

Collaboration with IWES has been defined for storage scenario definition and potential of demand side management.

Activity 1.3 (Portugal)

The scope of activity has been redefined in order to make a literature review and analysis about PV variability, with the involvement of international partners. Under the supervision of Planair, EDP (Portugal) has analysed and summarised relevant information to define standards to analyse variability of large PV systems (monitoring standards). Three different models are analysed in details, and a Portuguese case study is described. The report is currently under review.

SUBTASK 2 (SUBTASK LEADER: GERMANY)
« HIGH PENETRATION PV IN LOCAL DISTRIBUTION GRIDS »

The objective of this subtask is to identify and evaluate the role of PV in distribution grids and to make a cost-benefit analysis for ancillary services. Especially this subtask focuses on the analysis of impact of high PV penetration in distribution grids in order to make recommendations on Grid Codes, incentives and regulation.

Methods and results of the project DiGASP [1] have been discussed on the Task 14 meeting in Kassel (Spring 2012) and will be integrated in the conclusions of Subtask 2.

Activity 2.1 (USA)

The questionnaire *"Survey of high penetration scenarios on distribution feeders"* has been sent to SIG, ewz and swissgrid (see activity CC2).

A short report addressed to the topic *"review of extension/operation rules of grid operators"* was written by Basler & Hofmann and will be included in Activity 2.1.

Activities 2.2 and 2.3 (Germany) and Activity 2.4 (Canada)

A summary of the case study "Luchswiesenstrasse" is presented in Subtask 2:

Case Study Zürich, Switzerland

With an energy share of only 0.55 % in 2012 solar electricity plays only a minor role in the Swiss electricity mix. Large scale high penetration scenarios do not exist yet. In this case study, a high penetration scenario in the area "Luchswiesenstrasse" of Zurich was investigated using load flow simulations with high resolution irradiation profiles and load patterns.

Definitions:

- **PV penetration in %**: Yearly electric energy produced by PV power plants divided by yearly energy consumption in the same area.
- **PV hosting capacity**: Maximum possible PV penetration.

Grid overview

The following table gives an overview over the most important facts and figures of the grid.

Number of energy meters (corresponds roughly to the number of households)	1’550
Number of grid connections	111
Number of main cables	28
Maximum load	1’300 kW
Average yearly energy consumption	5’200 MWh
Rated transformer power	2 x 1’000 kVA
Grid voltage	230 V / 400 V

TABLE 2: FACTS AND FIGURES OF THE GRID

The grid topology is shown in Figure 1.

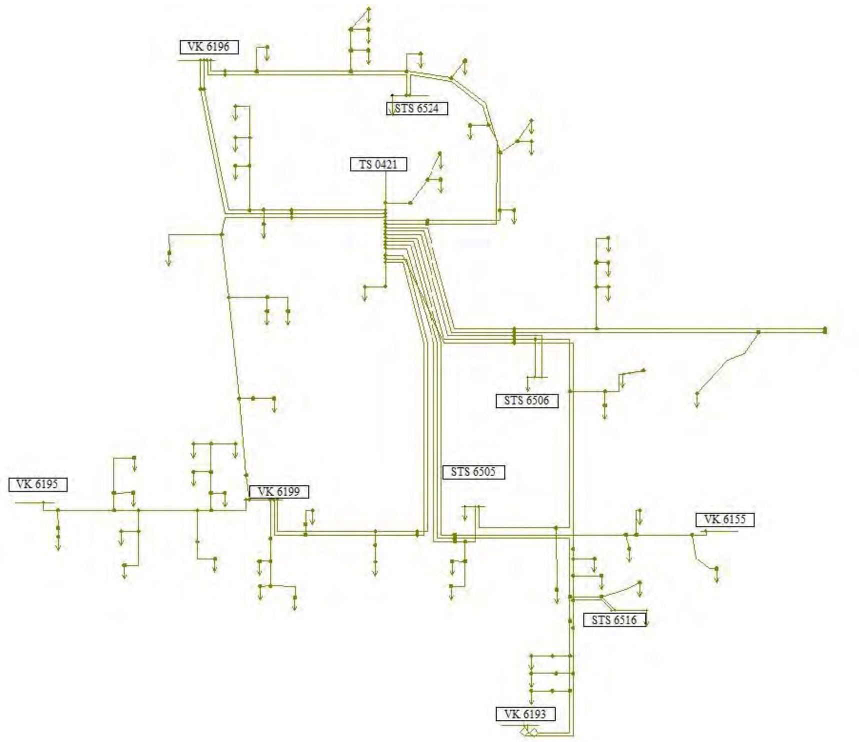

FIG 4: GRID TOPOLOGY OF THE INVESTIGATED GRID AREA "LUCHSWIESENSTRASSE".

Roof Capacity for PV systems

The roof capacity of the investigated area is roughly 3'600 kWp, resulting in an energy yield of 3'270 MWh per year. This corresponds to 67% of the annual electricity consumption of the area. In order to reach this amount of PV, every roof needs to be completely covered with PV panels. From today's perspective, this seems to be unrealistic. However it gives an upper limit, which is used as the maximum PV penetration in this study.

Simulation method

As most of the loads in the grid are domestic households, the loads are modelled using high resolution load profiles (Source: Distribution Grid Analysis and Simulation with Photovoltaics (DiGASP), Christof Bucher et al., PV+Grid, PV ERA NET). The output of the PV systems is modelled using stochastic irradiance profiles developed in the same project as the load profiles.

The load flow computation is done using MATLAB and the Matpower toolbox. The temporal resolution of the simulation was chosen between 1 and 15 minutes, depending on the type of simulation. For different grid integration measures, the PV hosting capacity of the grid was computed. The grid voltage rise was thereby the major restriction for a further increase of the PV penetration.

Results

The results are summarised in Table 2.

	Simulation Method	**Remark**	**Result**
1	DACHCZ: no measures	Standard method to calculate if a particular PV system can be connected to the LV grid (max 3% relative voltage rise in LVDG)	PV hosting capacity = 370 kWp (6%), voltage limit. Thermal current limit allows 965 kWp (26.8 %)
2	Correlation with load	Similar to 1. Not the relative but the absolute voltage investigated. PV rises the voltage, loads lower the voltage.	PV hosting capacity = 1000 kWp (17%), voltage limit. Thermal current limit allows 1200 kWp (33.5 %)

3	RPC: Reactive power control	Cos(phi) is reduced to 0.9 (cos(phi) fix)	The PV hosting capacity can be increased with 20% to 450 kWp (simulation method 1) and 1200 kWp (simulation method 2).
4	APC: Active power curtailment	Two curtailment scenarios: a) 70% AC/DC-ratio, energy loss of 3% b) b) 50% AC/DC -ratio, energy loss of 15%	a) 41% more PV hosting capacity b) b) 85% ore PV hosting capacity
6	Storage	Every power plant gets an energy storage of a) 1h rated PV power b) b) 4h rated PV power	a) Ca. 50% more PV hosting capacity b) Ca. 200% more PV hosting capacity
7	DSM: Demand side management	Assumption: Hot water Boilers can be switched on during midday.	30% - 70% more PV, depending much on the design.
8	OLTC: On Load Tap Changer trans-former	Reducing the voltage at the trans-former by 3%	100% more PV hosting capacity. Thermal current limit reached in some cases.

TABLE 3: RESULTS SUMMARY OF THE CASE STUDY.

Figure 5 show the voltage histogram for one year, using a temporal resolution of 5 minutes. The first voltage violation occurs between scenario 3 (PV pen. = 13.4%) and scenario 4 (PV pen. = 20.1%), while the first line overload occurs only with scenario 6 (PV pen. = 33.5%).

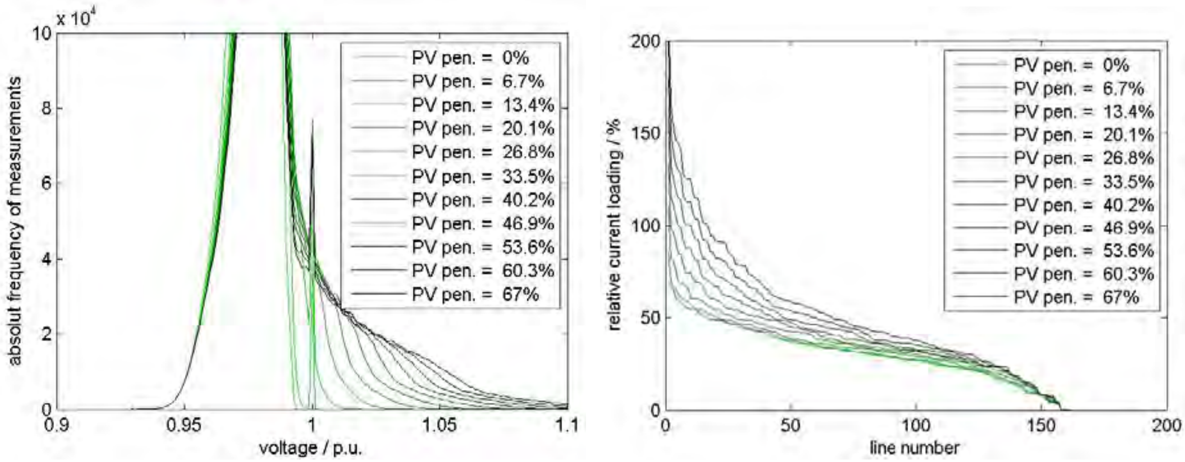

FIGURE 5: VOLTAGE HISTOGRAM AND MAXIMUM CURRENT LOADING FOR DIFFERENT PV PENETRATION SCENARIOS.

SUBTASK 3 (SUBTASK LEADER: JAPAN)
« HIGH PENETRATION SOLUTIONS FOR CENTRAL PV GENERATION SCENARIOS »

The subtask will envision the future power system with the integration of system-wide PV integration through the review of PV generation output variation and its predictability including smoothing effect, power system operation planning, and power system augmentation planning.

As for the questionnaire of activities CC2 and 2.1 the questionnaire *"Use of solar and PV forecasts for enhanced PV integration"* has been sent to EWZ and swissgrid.

Activity 3.1 (Canada)

Due to collaboration between activities 1.1 and 3.1 the Swiss group is strong involved in this activity (especially Meteotest, see activity 1.1).

Activities 3.2 and 3.3 (Japan)

Meteotest delivered a case study for the report “Power system operation planning with PV integration”. Daily and seasonal storage needs for four renewable energy scenarios for four different scenarios till 2050 have been calculated.

This report examines the electricity storage needs for four renewable energy scenarios in Switzerland. The background of this report is the decision of the Swiss government and parliament in 2012 to phase out nuclear power stations in Switzerland and to replace them until 2050 mainly with renewable energies.

Two scenarios are driven by the available natural resources and the target to limit the worldwide climate change to 2°C. The other two scenarios are based on one of the official scenarios of the Swiss government. All scenarios show PV as the main new and additional source of energy, which will deliver between 15 – 25% of the electricity.

Input to the storage model are hourly load data, hourly renewable production and measured hydro power data. Several assumptions had to be made to lower the complexity of the model. The transmission grid has not been modelled, but is assumed to be a copper plate, whereas climate change is taken into account. PV production has been varied with different values for peak shaving and different distributions of the orientation of the modules in order to find optimal strategies for the grid integration.

The result shows that the daily and seasonal storage needs are rising. The scenarios with higher PV penetration (25%) have clearly higher needs. The need for daily and seasonal storage can be covered by relatively small extensions of the pumped and conventional hydro storage capacity and therefore with existing technologies with known and relatively low costs in Switzerland.

The consideration of climate change is important and can’t be neglected. It changes the seasonal variations of the input to the hydro storages and lowers the additional seasonal storage need.

Peak shaving is shown to be useful to lower daily storage power on a national level, whereas a forced installation on east and west looking roofs seems not to be a purposeful strategy.

SUBTASK 4 (SUBTASK LEADER: AUSTRIA)
« SMART INVERTER TECHNOLOGY FOR HIGH PENETRATION OF PV »

This subtask will highlight and define inverter technology requirements for successful smart integration of a high penetration of PV: technology, technical requirements and standards, and system integration aspects.

As funding of Austria has been delayed deliverables of this subtask are not defined yet. At Swiss level, reports will be sent to Sputnik Engineering for validation.

Activity 4.1 (Austria)

No Swiss contribution in this activity at the moment.

Activity 4.2 (Germany)

Generic inverter models are currently collected by the activity leader. Basler & Hofmann takes part in the discussion and contributes its experience with active and reactive power control algorithms in simulations.

Activity 4.3 (China)

Related to activity 4.3 and to interest of some Swiss grid operators Planair SA had established a short inventory of existing monitoring system for PV inverter communication.

National and international collaboration

For Swiss participation to IEA-PVPS task 14 Planair SA allied with Basler & Hofmann AG and Meteotest in order to provide quality services, Swiss developments and knowledge for task 14.

At an international level the collaboration with other participating countries is constructive and efficient as we can see it in various activities.

Planair SA (subtask 1 leader) represented Switzerland during the international meetings in Brussels, and Basler & Hofmann AG represented Switzerland during the meeting in Sydney, Australia.

A Swiss meeting with PVPS Pool (Swiss electrical society) took place on October 30th for technical dissemination.

The dissemination of the results of Task 14 to the IEC / CENELEC committees is under discussion. Basler & Hofmann is involved in the IEC TC82 and maintains the communication between Task 14 and IEC. The IEC has though a rather weak position in grid standards and is therefore not a primary dissemination platform for Task 14.

Year 2013 evaluation and outlook for future work in 2014

Swiss team is subtask 1 leader and especially develops activities 1.1 (joined with 3.1) and 1.2. The subtask is well-advanced in its results and deliverables.

Swiss team will ensure the Swiss dissemination of work and results in task 14.

The spring meeting in 2014 will take place in Switzerland from March 31th to April 2nd, including a workshop with Swiss utilities. This meeting will be a very good opportunity to disseminate the results of the task in Switzerland.

Activity 1.2

The report will be completed in 2014 to be published by the end of the year. Issues regarding DSM and storage will be included in.

Activity 1.3

The report will be reviewed and published.

Switzerland also contributes to other activities:

CC subtask

Normative work, update of wiki, participation to questionnaire, simulation tools and settings of project DiGASP, participation to workshop

Subtask 2

The DiGASP-project and its results will be disseminated in Task 14. Work on active and reactive power control algorithms is continued and will be used to extend the knowledge position of Task 14 in grid control aspects. Specific cases will be simulated with the DiGASP-approach. The report will include a Swiss chapter including the DiGASP project and an additional project in Geneva to be determined.

Subtask 3

Meteotest will deliver a high penetration case study for Switzerland.

Subtask 4

The focus of the Swiss contribution in Subtask 4 will be to evaluate the state of the art in communication between utilities and PV power plants, as well as to define requirements based on utility demands. This shall mainly be based on the questionnaire for utilities which is under development.

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IEA SHC TASK 46

SOLAR RESOURCE ASSESSMENT AND FORECASTING

Annual Report 2013

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Project- / Contract Number	8100072 / SI/500184-05
Duration of the Project (from – to)	1.1.2011 – 30.6.2016
Date	9.12.2013

ABSTRACT

From Switzerland University of Geneva and Meteotest are taking part in the IEA SHC Task 46. The goal of this task is to provide the solar energy industry, the electricity sector, governments, and renewable energy organizations and institutions with the means to understand the “bankability” of data sets provided by public and private sectors.

A major component of the task is to provide this sector with information on how accurately solar resources can be forecasted in the near future (sub-hourly, 1-6 hours, and 1-3 days) so that utilities can plan for the operation of large-scale solar systems operating within their systems. Another major component of the task is understanding short-term (1-minute or less) resource variability associated with cloud passages that cause power “ramps”, an important concern of utility operators with large penetrations of solar technologies in their system.

For the second annual report two topics concerning solar forecast are picked out. First the ongoing work on forecast for the next 15 minutes based on sky cameras is described. Second the work of Univ. of Oldenburg and Meteotest about forecast models for the next 6 hours based on satellite images and wind vectors from numerical weather predication models are presented.

Introduction / project goals

The goal of IEA Task 46 "Solar Resource Assessment and Forecasting" is to provide the solar energy industry, the electricity sector, governments, and renewable energy organizations and institutions with the means to understand the “bankability” of data sets provided by public and private sectors. A major component of the task is to provide this sector with information on how accurately solar resources can be forecasted in the near future (sub-hourly, 1-6 hours, and 1-3 days) so that utilities can plan for the operation of large-scale solar systems operating within their systems. Another major component of the task is understanding short-term (1-minute or less) resource variability associated with cloud passages that cause power “ramps”, an important concern of utility operators with large penetrations of solar technologies in their system.

Based on the outcomes of precedent Task 36, the objectives of Task 46 are to:

- Evaluate solar resource variability that impacts large penetrations of solar technologies
- Develop standardized and integrating procedures for data bankability
- Improve procedures for short-term solar resource forecasting
- Advance solar resource modeling procedures based on physical principles

Achieving these objectives would reduce the cost of planning and deploying solar energy systems, improve efficiency of solar energy systems through more accurate and complete solar resource information, and increase the value of the solar energy produced by solar technologies.

Task 46 focuses on

1) the development, validation, and access to solar resource information derived from surface-based observations, satellite-based platforms, and numerical weather prediction (NWP) models
2) solar resource variability and forecasting issues pertinent to grid-tied or large-scale penetrations of solar technologies into a national energy system
3) data bankability issues, especially those related to solar resource measurement practices and merging of measured and modeled data sets
4) exploring means by which to improve the modeling of the solar resource using satellite-based platforms or other weather observations

As with Task 36 the audience for the results of the Task includes the technical laboratories, research institutions and universities involved in developing solar resource data products. More importantly, data users, such as energy planners, solar project developers, architects, engineers, energy consultants, product manufacturers, and building and system owners and managers, and utility organizations, are the ultimate beneficiaries of the research, and will be informed through targeted reports, presentations, workshops and journal articles. Key results of this task will be posted to the IEA SHC Task 46 Publications web site.

Task definition

SUBTASK A: SOLAR RESOURCE APPLICATIONS FOR HIGH PENETRATIONS OF SOLAR TECHNOLOGIES

This Subtask will develop the necessary data sets to allow system planners and utility operators to understand short-term resource variability characteristics, in particular up and down ramp rates, to better manage large penetrations of solar technologies in the grid system. Although this work is primarily focused toward PV systems, which react almost instantaneously to cloud passages over individual panels, the information is also useful for solar thermal and CSP systems where intermittency due to variable solar resources can impact their ability to meet load demands. Subtask A consists of three main activities:

- Activity A1: Short-Term Variability
- Activity A2: Integration of solar with other RE
- Activity A3: Spatial and Temporal Balancing Studies of the Solar and Wind Energy Resource

SUBTASK B: STANDARDIZATION AND INTEGRATION PROCEDURES FOR DATA BANKABILITY

This task addresses data quality and bankability issues related to both measurement practices and use of modeled data. Subtask activities are:

- Activity B1: Measurement best practices
- Activity B2: Gap-Filling, QC, Flagging, Data Formatting
- Activity B3: Integration of data sources
- Activity B4: Evaluation of Meteorological Products
- Activity B5: Data Uncertainties over Various Temporal and Spatial Resolutions

SUBTASK C: SOLAR IRRADIANCE FORECASTING

Solar irradiance forecasting provides the basis for energy management and operations strategies for many solar energy applications. Depending on the application and its corresponding time scales different forecasting approaches are appropriate. In this subtask forecasting methods covering time-scale from several minutes up to seven days ahead will be developed, tested and compared in benchmarking studies. The use of solar irradiance forecasting approaches in different fields will be investigated, including PV and CSP power forecasting for plant operators and utility companies as also irradiance forecasting for heating and cooling of buildings or districts. Subtask activities are:

- Activity C1: Short-term forecasting (up to 7 days ahead)
- Activity C2: Integration of solar forecasts into operations

SUBTASK D: ADVANCED RESOURCE MODELING

Although most of the work in Task 36 involved the testing and evaluation of existing solar resource methodologies, some specific new methodologies have been identified that could be developed within a new task. These methodologies are driven by specific information requests from energy developers and planners. They can include new data sets required for the control and heating and cooling in buildings, solar resource forecasting for CSP plant operations, and the impact of climate change on solar resources, both from an historical perspective as well as estimates of future impacts. Subtask activities are:

- Activity D1: Improvements to existing solar radiation retrieval methods
- Activity D2: Development of global solar resource data sets for integrated assessment of global and regional RE scenarios modeling, with a special focus on CSP and solar heating technologies
- Activity D3: Long term analysis and forecasting of solar resource trends and variability (up to now only very few work could be done in this activity due to missing funding).

The team has started the work in autumn 2011. In 2013 two project meetings were held in Nice (France) and Oldenburg (Germany).

In October 2014 Meteotest organized a common workshop between IEA SHC 46 and IEA PVPS 14 in form of a parallel event at the EU PVSEC 2014 (http://www.iea-pvps.org/index.php?id=255).

Work done and results

Two examples of ongoing work are described from activity C, where Meteotest is mostly involved.

The forecast horizon of 1 minute – 6 hours is strongly investigated, as within this time period the possibility to forecast the exact position of clouds is much better than for longer time frames. Two types of forecasts are picked as example: the first one is based on sky cameras and the second based on satellite images.

ACTIVITY C

Forecast with sky cameras

The analysis and forecast with sky cameras (Figure 1) or total sky imagers is a popular topic, in which many groups are currently involved. With two cameras the cloud position and height can be detected and forecasted for the next 10 – 20 minutes.

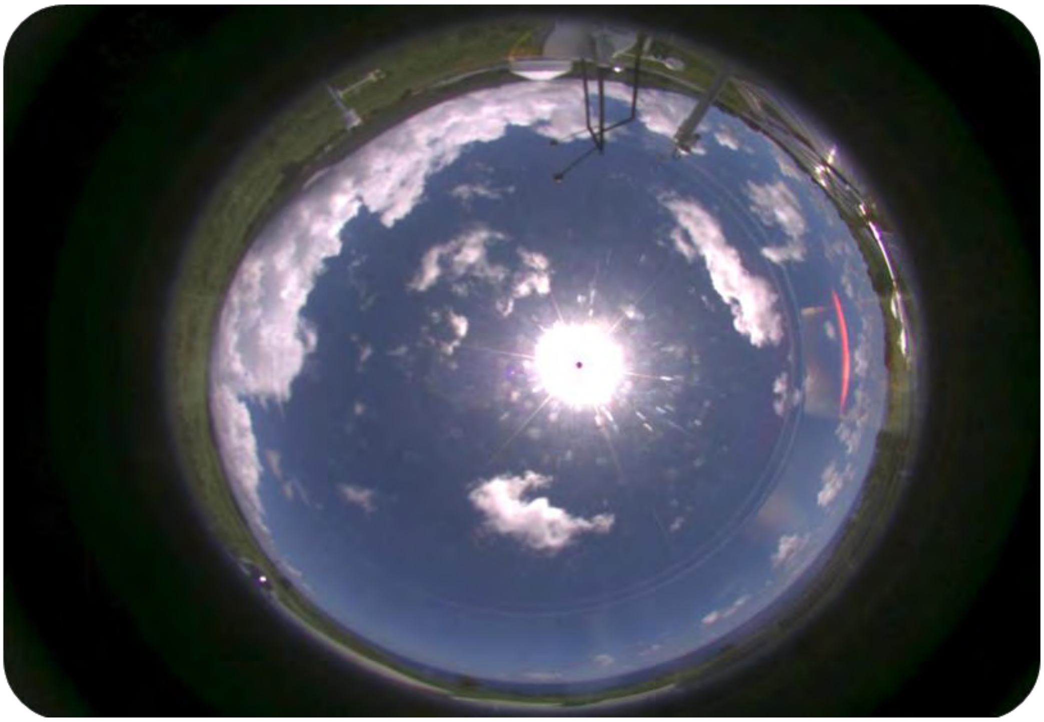

Figure 1: *Picture from cloud camera (La Reunion, Source: EDF / Mines Paristech).*

Univ. California at San Diego (UCSD) is continuously working on improving cloud detection from ground based sky imagers as a basis for very short term forecasting with high resolution. The new UCSD prototype produces high-quality sky imagery with a high dynamic range, allowing for more accurate cloud fields and more reliable thin cloud detection. No shadow band is necessary, leading to 10% more imagery available and interpolation errors eliminated. The state-of-the-art sky imager forecasting device with algorithms for 15 minute ramp forecasting has a high temporal and spatial resolution, a reasonable coverage of approx. 15 km^2 and is applicable for short time-horizon up to 20 minutes. Fig. 2 gives an evaluation of the sky imager forecasts for an example afternoon and reveals a superior performance compared to persistence for 4 – 15 minutes ahead.

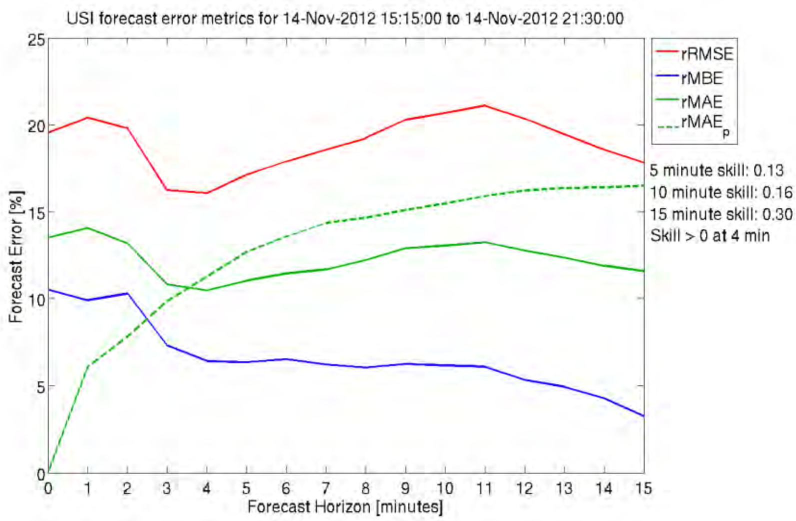

Figure 2: *Forecast errors metrics for sky imager forecasts in comparison to persistence for the afternoon of 14-Nov-2012 for a location in the US.*

MinesParisTech - in cooperation with EDF R&D- is working on 3D reconstruction of cloud motion and corresponding shadow on the grounds from stereoscopic and optical flow analysis of hemispherical images from 2 fish-eye cameras. The stereoscopic analysis with correlation-based cloud matching to assess parallax and therefore 3D position is combined with a Kalman filter to detect cloud heights. First results are encouraging and the value of the application of a Kalman filter has been shown.

Also Univ. of Oldenburg has started with the development of forecasts of solar radiation and PV power using a sky imager. The measurements devices at Univ. of Oldenburg currently include the sky imager, a spectrometer, PV modules, and global horizontal and tilted, diffuse and direct measurements. They will be complemented by several photodiode pyranometers, distributed in the area around the sky imager. An approach for cloud classification for daylight conditions will be applied to infer cloud information from the sky images in a first step. Further topics are the projection of cloud information from the sky images onto the surface for approximation of shading, cloud-motion-vectors from sky imagery, and finally analysis and modeling of radiative fluctuations.

Forecast with a combination of satellite cloud position and wind vectors from weather models

This group of forecast models has a forecast horizon of 15 minutes to 6 hours.

Univ. of Oldenburg is working on evaluation and further development of their cloud motion vector (CMV) forecasting algorithm based on Meteosat satellite images [1]. Images from Meteosat Second Generation (MSG) satellites provide valuable information for forecasting clouds and solar irradiance several hours ahead by using cloud motion vectors (CMV). An approach to derive irradiance information from MSG images and of predicting the cloud situation by applying CMV is described and an evaluation of the irradiance forecast for single sites and regional averages on basis of a one year data set is presented. The CMV forecast shows a superior performance in comparison to forecasts with numerical weather prediction (NWP) models up to 5 hours ahead.

In the reporting period, the research on satellite based irradiance forecasting at Univ. of Oldenburg has been extended to the use of wind fields from NWP model forecasts as an alternative to satellite derived CMVs to advect clouds, as proposed also by Meteotest (see below).

At Univ. of Oldenburg wind fields from the IFS model operated at the ECMWF are used for this purpose and a first study for May 2012 was performed. A particular focus was on the analysis of the forecast accuracy in dependence on the NWP model level of the applied wind fields that ideally should match the actual cloud heights. Fig. 3 shows – as a first result - a very similar performance of forecasts based on cloud advection with NWP wind fields and satellite derived CMVs for the investigated period.

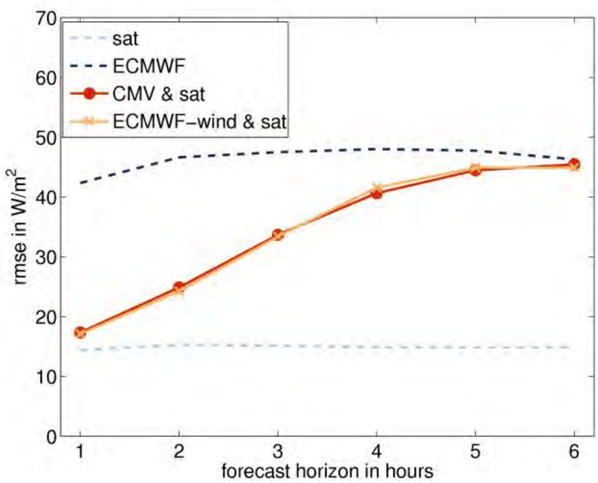

Figure 3: *RMSE in dependence on forecast horizon for forecasts based on cloud advection with NWP wind fields (orange) and satellite derived CMVs (red). For comparison the RMSE of ECMWF based forecast as well as satellite derived irradiance is given. Database:* ***average*** *irradiance for 290 stations in Germany, May 2012.*

The conclusion of this work is, that the method using cloud vectors from NWP shows the same quality, but with much less computer resources and is therefore interesting for the operational service.

Also Meteotest is continuing their research on the combination of cloud and radiation fields from satellite images with wind fields from the NWP (numerical weather prediction) model WRF (weather research and forecasting). This shortest term solar forecasting algorithm for 0.5 - 6 hours ahead which is updated every 15 minutes (Figure 4) has been evaluated for more than 20 sites in Switzerland, including low lands, alpine and high-alpine stations.

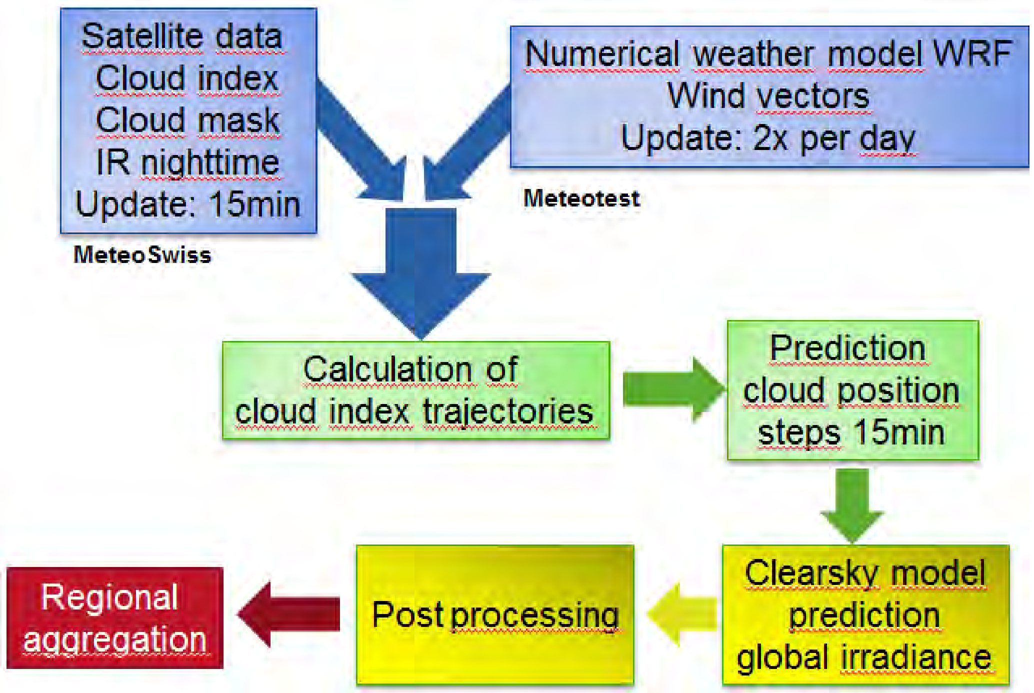

Figure 4: *The shortest term forecast model of Meteotest.*

The RMSE ranges between 75 – 200 W/m^2 (20 - 60%), depending on season, station and forecast horizon (Fig. 5). The uncertainty is low in flatland and much higher in the Alps. The improvement of this approach over NWP WRF direct models output for 3 – 6 hours is about 40%. A particular focus during the reporting period has been on the investigation of Kalman filters to improve the forecasts. In has been found, that this post-processing approach is useful to correct for clear sky days (but not for cloudy).

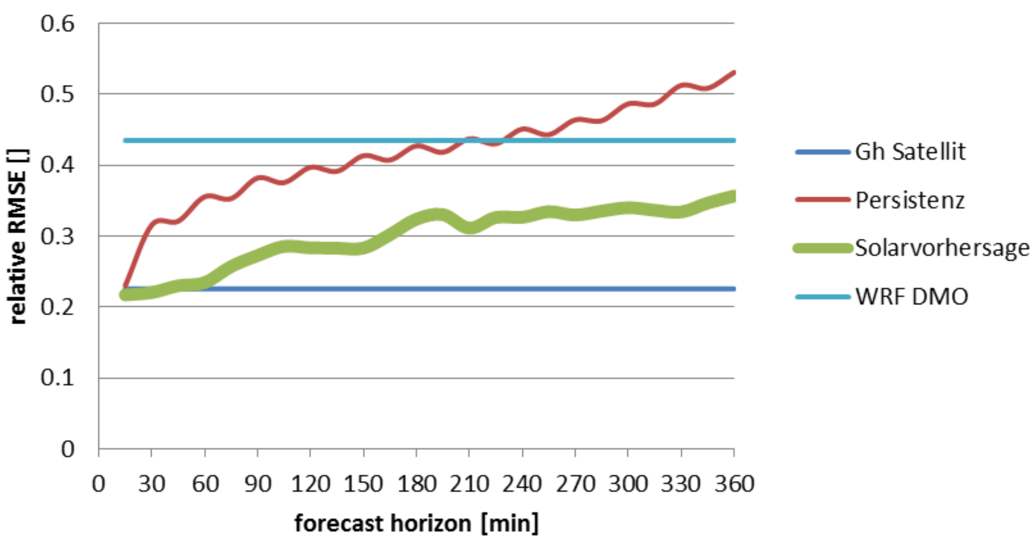

Figure 5: *Relative RMSE in dependence on forecast horizon for forecasts based on cloud advection with NWP wind fields (“Solarvorhersage”). For comparison the RMSE of WRF based forecast (“WRF DMO”) as well as satellite derived irradiance (“Gh Satellit”) and persistence (“Persistenz”) is given. Database: irradiance of a* ***single*** *station (Bern-Zollikofen) in Switzerland, July – September 2012.*

The results of Meteotest are in accordance with those found by Univ. of Oldenburg:

- the altitude of the wind vectors is not sensible; the altitude of 2.5 – 3.5 km shows the best results
- the forecast errors for the first hour are up to 50% lower than for NWP models
- the results of the method are better or equal than those from NWP up to 4 (summer) – 6 hours (winter) ahead

During the last months of the project the regional aggregation model and the validation with ground stations (during two months a dense network of ground stations was installed) will be made.

The project is supported by the BKW FMB AG and is going on until April 2014. After the end of the project an operational service is planned.

National / international cooperation

The work was done in the framework of IEA Solar Heating and Cooling task 46. From Switzerland there is also University of Geneva part of the task team. The results are exchanged with the COST action ES1002 (“wire”). Task 46 will continue with a level of minimal collaboration with SolarPACES. Task 46 is closely related to Task 14 in the PVPS (Jan Remund of Meteotest serves as task liason).

Task 46 also maintains collaboration with the Global Earth Observation System of Systems (GEOSS) Programme, and the IRENA Global Atlas.

Outlook

The task will go on next year. The team will meet presumably twice with a first meeting in April.

References

[1] J. Kühnert, E. Lorenz, A. Hammer D. Heinemann: Satellite Based Short Term Prediction of Photovoltaic Power for the Application at the Energy Market; Presentation at ICEM 25.-28.6.2013, Toulouse, France;

NORMIERUNG FÜR PV-SYSTEME

IEC-TC 82 / CENELEC TC 82 UND NATIONALES TK 82 FÜR PV-SYSTEME

Annual Report 2013

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Project- / Contract Number	SWISSOLAR - 17967
Duration of the Project (from – to)	2008 - …..
Date	January 2014

ABSTRACT

PV standardisation is a continued process producing updated and new standards, technical reports and specifications. As usual there were two national TK 82 meetings, one at Meyer Burger in Thun and one in Zürich. Also two IEC-TC 82 committee meetings took place. The spring meeting was in Sydney and the autumn meeting in Delhi. The TC 82 published three new standards and three new TS (Technical Specifications). The European Committee for Electrotechnical Standardization (CENELEC) has published one new standard about Ammonia corrosion testing for PV modules and three documents in collaboration with IEC TC 82. IEC and CENELEC together have currently more than 40 documents under revision or in preparation as new publications. Still the lack of resources is a big problem and causes severe delays for the publication of standards.

The effort in 2013 focused on national activities like the transformation of international standards to the local requirements, update of the NIN (Niederspannungs-Installationsnorm / Standard for Low Voltage Electrical Installations) regarding the PV section and various issues such as cabling, fire safety, module level converters and fault current protection. A new document about overvoltage and lightning protection was published as supplement to the existing lightning protection specifications.

Due to more questions with utility interconnection the national committee IEC-CES-TK 8 was established. This will enable more know how transfer between users and developers of standards. Beside the smart grid activities there is a new subcommittee SC8A launched on "Grid Integration of Large-Capacity Renewable Energy (RE) Generation". Peter Toggweiler is a Liaison Member of IEC-TC- 82 and IEC-TC 8.

Einleitung / Projektziele

Normierung für PV-Systeme gilt als übergeordnete Zielsetzung gleich wie jedes Jahr. Das IEC passt dazu regelmässige den strategischen Businessplan an. Die wesentlichen Projektziele aus nationaler Sicht lauten wie folgt:

- PV und Brandschutz: Anpassung der Empfehlungen an die neuen Brandschutzvorschriften
- Umsetzung der neuen Bestimmungen zu Blitz- und Überspannungsschutz
- Umsetzung der NIN 2015 betreffend PV in Zusammenarbeit mit Electrosuisse
- Revision der Norm für die Systemdokumentation und Inbetriebnahme
- Normen für Inselanlagen
- Testverfahren für Lichtbogendetektor
- Test- und Produktenormen für Moduldosen mit integrierter Elektronik
- Informationsveranstaltungen für die Fachleute in der Schweiz

Kurzbeschrieb des Projekts

Normen und technische Regeln für die Photovoltaik sind erforderlich für die Sicherheit von Personen und Material, für die zweckmässige Funktion und für einen fairen und gut funktionierenden internationalen Handel. 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 CES-TK 82 und der schweizerischen Vertretung im IEC-TC 82 und CENELC TC 82, welche zuständig sind für die PV-Normen. Die IEC- und CENELEC-Normen fokussieren auf die Elektrotechnik und zugehörige Themen wie Sicherheit, Brandschutz und generelle Aspekte zur Qualität. Sie decken einen weiten Bereich ab, angefangen vom Sonnenlicht, über Solarzellen, Solarmodule, Systemkomponenten, Installationstechnik, Netzanschluss, Abnahme und den Betrieb von Anlagen. Entsprechend gliedern sich die Aufgaben in einen internationalen und nationalen Teil. Im Jahr 2013 dominierten die nationalen Aufgaben. Neu wird die Zusammenarbeit mit dem SIA (Schweizerischer Ingenieur- und Architektenverein) verstärkt.

Seit mehreren Jahren ist die Arbeit des IEC-TC 82 in 5 Arbeitsgruppen (Working Groups, WGs) aufgeteilt plus eine gemeinsame Arbeitsgruppe (Joint Working Group, JWG 1) mit Delegierten aus mehreren IEC-TCs.

WG 1 Glossary

WG 2 Modules, non-concentrating

WG 3 Systems

WG 6 Balance-of-system components

WG 7 Concentrator modules

JWG 1 Decentralized Rural Electrification(JWG TC 82/TC 88/TC 21/SC 21A)

Durchgeführte Arbeiten und erreichte Ergebnisse

Auch im 2013 bildete die Überarbeitung und Aktualisierung von bestehenden Normen den Schwerpunkt. Insbesondere die Revision des Teils 712 der NIN erforderte zahlreiche Besprechungen und Diskussionen. Im Berichtsjahr sind folgende Normen neu erschienen:

CENELEC	
EN 50530:2010/A1:2013	Overall efficiency of grid connected photovoltaic inverters
EN 61730-1:2007/A2:2013	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction

EN 50548:2011/A1:2013	Junction boxes for photovoltaic modules
EN 62716 :2013	Photovoltaic (PV) modules - Ammonia corrosion testing
EN 62109-1:2010	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements

IEC	
IEC 61730-1:2004/A2:2013	Amendment 2 - Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
IEC/TS 62257-9-5:2013	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-5: Integrated system - Selection of stand-alone lighting kits for rural electrification
IEC 62716:2013	Photovoltaic (PV) modules - Ammonia corrosion testing
IEC/TS 62548:2013	Photovoltaic (PV) arrays - Design requirements
IEC 62670-1:2013	Photovoltaic concentrators (CPV) - Performance testing - Part 1: Standard conditions
IEC/TS 62257-1:2013	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 1: General introduction to IEC 62257 series and rural electrification

Dazu kommen über 40 Dokumente gemäss Anhang 1, welche aktuell in Arbeit sind.

Viele Diskussionen drehten sich um das "Array-Dokument", welches die Montage und Verdrahtung der Solarmodule und der übrigen DC-Installation beschreibt. Es wurde als IEC/TS 62548: PHOTOVOLTAIC ARRAYS – DESIGN REQUIREMENTS (Technical Specification) publiziert. Vorläufig wird es nicht auf Deutsch übersetzt, weil der Hauptteil in die neue Hausinstallationsnorm einfliessen wird. Dazu wurde folgendes Dokument als Entwurf vorgelegt: IEC 60364-9-1: Low-voltage electrical installations - Part 9-1: installation, design and safety requirements for photovoltaic systems (PV). Als Folge der vielen Kommentare ist das Publikationsdatum noch unbestimmt. Sobald es in Kraft tritt, wird der Inhalt in der Schweiz in die NIN aufgenommen. Leider war es für die laufende NIN-Revision nicht verfügbar. Trotzdem wurden einige unbestrittene Forderungen übernommen.

Das nationale TK 82 hatte wie gewohnt zwei Sitzungen mit jeweils etwa 12 Teilnehmern, eine davon bei Meyer Burger in Thun und die andere in Zürich. Das Sekretariat vom TK 82 wird neu von Reinhard Düregger, Leiter des CES geführt. Die Übergabe funktioniert problemlos und ohne Unterbruch.

Brandschutz und Prävention

Die Vereinigung der Kantonalen Feuerversicherungen hat neue allgemeine Brandschutzvorschriften in die Vernehmlassung geschickt. Weil diese in verschiedenen Aspekten auch die PV-Anlagen betreffen, musste aus Sicht Photovoltaikanwendung eine Stellungnahme ausgearbeitet werden. Unter anderem ist ein wichtiger Aspekt, dass bei einem Solarmodul als Bedachungsmaterial eine einseitige Brandprüfung genügt. Dachoberflächen dürfen nicht brennbar sein. Ein handelsübliches Solarmodul mit Glas auf der Frontseite und einer mehrlagigen Rückseitenfolie erfüllt diese Anforderung bei einem nur einseitigen Brandtest. Für die typischen Dachanwendungen mit dem geforderten Schutz gegen Flugfeuer genügt ein solcher Test.

PV in Buildings (BIPV)

Auf den CENELEC-BIPV-Normenentwurf (prEN 50583 “Photovoltaics in Buildings”) gab es zahlreiche Kommentare und Änderungsanträge. An mehreren Meetings haben Vertreter aus der Schweiz teilgenommen. Neu wurde der CENELEC-BIPV-Vorschlag auf zwei separate Dokumente aufgeteilt:

1. BIPV Module
2. BIPV Systeme

Das Ziel für beide Dokumente ist das Abstimmungsverfahren im Jahr 2014 abzuschliessen. Der Schweizer Beitrag zur BIPV-Norm wird im Auftrag Swissolar von Thomas Hostettler vom Ingenieurbüro Hostettler in Bern geleitet und koordiniert.

Die Erarbeitung des IEC-BIPV Dokuments hat sich weiter verzögert. Möglicherweise wird das CENELEC-Dokument anschliessend in einem Harmonisierungsverfahren auch zum IEC-Dokument.

Blitzschutz

Blitz- und Überspannungsschutz ist in der Schweiz einerseits in der NIN aber vor allem in den Leitsätzen 4022 geregelt. Für PV-Anlagen wurden von einer Arbeitsgruppe, bestehend aus Mitgliedern vom TK 64, TK 81 und TK 82, ergänzende Erläuterungen in Form eines Merkblatts verfasst, welches von der Electrosuisse im Oktober 2013 publiziert wurde.

Photovoltaikanlagen

Überspannungsschutz und Einbindung in das Blitzschutzsystem
Erläuterungen zu den Leitsätzen 4022 Blitzschutzsysteme

Damit wurden die bis dahin bestehenden Unsicherheiten bezüglich dem Überspannungsschutz beseitigt. Wenn die PV-Anlage auf einem Gebäude mit Blitzschutz steht, benötigt es im Gleichstromkreis einen blitzstromtragfähigen Überspannungsableiter vom Typ1. Der Nachteil dabei ist, dass solche Ableiter in einem separaten Gehäuse montiert sein müssen. Wegen zu hohen Transienten können sie nicht direkt im Wechselrichtergehäuse eingebaut werden. Für ein Gebäude ohne Blitzschutzanlage genügt ein Typ2, welcher oft im WR eingebaut ist. Andere Lösungen bleiben weiterhin möglich, sie sind aber im Rahmen eines Blitzschutzkonzeptes zu begründen. Swissolar hat an einer Veranstaltung umfassend über das neue Dokument informiert und es sind vertiefte Schulungskurse geplant.

Revision des Teils 712 zu PV in der Hausinstallationsnorm (NIN)

Ursprünglich erhofften alle, das ein neues, internationales IEC-TC 64 Dokument inklusive den Teil 712 als Basis für die Revision zur Verfügung steht. Leider war auch auf den letztmöglichen Zeitpunkt zum Teil 712 kein Dokument verfügbar. Deswegen wurde das IEC-TS 62548 soweit als möglich als internationale Referenz benutzt. Neu wird in der NIN für die Dokumentation und Abnahme auf die EN 62446 verwiesen. Das neue Merkblatt für den Blitzschutz wird möglicherweise in die NIN integriert. Offen bleibt noch wie die fertig steckbaren Netzverbundanlagen behandelt werden sollen. Die Marktüberwachung des Starkstrominspektorates wird dazu in absehbarer Zeit informieren.

Abnahme, Inbetriebnahmeprüfung und Systemdokumentation (EN 62446)

In Anlehnung an die EN 62446 wurde in Zusammenarbeit mit den involvierten Verbänden VSEI, Electrosuisse, SUVA, Swissolar und VSE das neue PV-DC-Mess- und Prüfprotokoll erarbeitet und von der SiNa-Kommission freigegeben. Damit ist es ein offizieller Teil der Abnahmedokumente gemäss NIV. Es kann bei den beteiligten Verbänden gratis als ausfüllbares PDF bezogen werden.

Bild 1: Auszug aus dem neuen Mess- und Prüfprotokoll Photovoltaik

Das entsprechende IEC-Dokument "Mindestanforderungen an Systemdokumentation, Inbetriebnahmeprüfung und Prüfanforderungen", IEC 62446 wird gegenwärtig revidiert. Swissolar begrüsst das und setzt sich dafür ein, dass die Kurzschlussmessung nicht mehr zwingend Bestandteil der Abnahme- oder Kontrollmessung ist. Es genügt, wenn ersatzweise der Betriebsstrom gemessen wird. Zudem soll es ein vereinfachtes Verfahren für Kleinanlagen geben.

Netzanschluss

Das Thema Netzanschluss von kleinen und grossen Stromerzeugungseinheiten betrifft diverse TC sowohl bei IEC wie auch bei CENELEC. Fokusiert behandelt wird es im TC 8 "Systems aspects for electrical energy supply". In der Schweiz gab es bisher wenig Interesse beim IEC-TC 8 mitzuarbeiten. Die Mitarbeit im CENELEC TC 8X und die ENTSO-E Belange waren den Netzbetreibern wichtiger. Dank der Gründung eines nationalen TK 8 soll die Zusammenarbeit mit dem IEC verstärkt werden.

Zukünftige Tätigkeiten des IEC TC 8 welche für die Schweiz von besonderem Interesse sind:

- Grid Integration of Large-Capacity Renewable Energy Generation, Generic Smart Grid Requirements
- Power Quality aspects from the energy supplier point of view
- Guidelines for the General Planning and Design of the Micro-Grids

Kommunikation, Publikationen

An verschieden Veranstaltungen wurde über die aktuellen Normen und Vorschriften informiert. Publikationen gab es in diversen Fachzeitschriften und Swissolar informiert die Branche regelmässig über Neuerungen im monatlichen Newsletter.

Zusammenarbeit mit anderen Normengruppen

Mit folgenden **IEC-TCs** besteht eine regelmässige Zusammenarbeit:

TC 8	Systems aspects for electrical energy supply
SC 17B	Low-voltage switchgear and control gear
TC 21	Secondary cells and batteries
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	Power systems management and associated information exchange
TC 64	Electrical installations and protection against electric shock
TC 77 / SC77A	EMC Low frequency phenomena
TC 81	Lightning protection

D-A-CH-CZ

Unter diesem Titel arbeiten die drei deutschsprachigen Länder und CZ eng zusammen, vor allem im Bereich Stromverteilnetze. Neu wird diese Zusammenarbeit über das nationale TK 8 koordiniert.

IEA PVPS Task 14 (High Penetration of PV Systems in Electricity Grids)

Die Zusammenarbeit mit dem Projekt IEA PVPS Task 14 der Internationalen Energieagentur (IEA) wird weiter geführt.

SIA-Normen

Zur SIA 261 (Einwirkungen auf Tragwerke) beim Schweizerischen Ingenieur- und Architektenverein (SIA) wird an einer Ergänzung für PV-Anlagen gearbeitet.

Neu wirkt Peter Toggweiler in der KGE (Kommission Gebäudetechnik und Energie) mit.

Auch international sind im Baubereich mehr Normen in Vorbereitung, unter anderem gibt es bei der europäischen Normenorganisation (CEN) eine Arbeitsgruppe, welche sich mit Solarenergie am Gebäude beschäftigt (CEN/TC 128, Roof covering products for discontinuous laying and products for wall cladding).

Bewertung 2013 und Ausblick 2014

Die wesentlichen Ziele konnten erreicht werden und die Zusammenarbeit funktioniert gut. Betont und verdankt sei hier das effiziente und konstruktive gemeinsame Schaffen von Mitgliedern aus den TK 64, TK 81 und TK 82, dem ESTI, der Electrosuisse und Swissolar. Erfreulicherweise entstanden daraus neue Publikationen, welche viele offene Fragen klären und hilfreiche Anwendungsempfehlungen liefern.

Zur Tätigkeit im 2014 sind noch nicht alle Details bekannt, weil der Zeitplan bei wichtigen Dokumenten noch ungenau ist. Bestimmt werden weitere Bemühungen notwendig sein, um die Richtlinien für die Vorsorge bei Brandereignissen und Brandverhütung zu vereinheitlichen und zu vereinfachen. Die Bearbeitung der neuen CENELEC- und CEN-BIPV-Norm wird ebenfalls ein Schwerpunkt bilden.

Neben den beiden nationalen Meetings sind aktuell folgende internationale Meetings mit Teilnehmern aus der Schweiz geplant:

- Südkorea, Juni 2014, TC 82 General Meeting plus WG 3 & WG 6
- Der Ort für das Meeting im Herbst 2014 ist noch offen, möglicherweise in Wien
- Diverse Meetings zur Bearbeitung der BIPV-Norm

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IEC programme of work, some are in collaboration with Cenelec	
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IEC 60904-11 Ed. 1.0	Photovoltaic devices - Part 11: Measurement of initial light-induced degradation of crystalline silicon solar cells and photovoltaic modules
IEC 60904-2 Ed. 3.0	Photovoltaic devices - Part 2: Requirements for reference solar devices
IEC 60904-8 Ed. 3.0	Photovoltaic devices - Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device
IEC 60904-8-1 Ed. 1.0	Photovoltaic devices - Part 8-1: Measurement of spectral response of multi-junction photovoltaic (PV) devices
IEC 61215 Ed. 3.0	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval
IEC 61683 Ed. 2.0	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
IEC 61730-1 Ed. 2.0	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
IEC 61730-2 Ed. 2.0	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
IEC 61829 Ed. 2.0	Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics
IEC 61853-2 Ed. 1.0	Photovoltaic (PV) modules performance testing and energy rating - Part 2: Spectral response, incidence angle and module operating temperature measurements
IEC 62109-3 Ed. 1.0	Safety of power converters for use in photovoltaic power systems - Part 3: Particular requirements for PV modules with integrated electronics
IEC 62109-4 Ed. 1.0	Safety of power converters for use in photovoltaic power systems - Part 4: Particular requirements for combiner box
IEC 62116 Ed. 2.0	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures
IEC 62446 Ed. 2.0	Grid connected PV systems - Minimum requirements for system documentation, commissioning tests and inspection
IEC 62670-2 Ed. 1.0	Concentrator photovoltaic (CPV) performance testing - Part 2: Energy measurement
IEC 62688 Ed. 1.0	Concentrator photovoltaic (CPV) module and assembly safety qualification
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IEC 62787 Ed. 1.0	Concentrator photovoltaic (CPV) solar cells and cell-on-carrier (COC) assemblies - Reliability qualification
IEC 62788-1-2 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 1-2: Encapsulants - Measurement of volume resistivity of photovoltaic encapsulation and backsheet materials
IEC 62788-1-3 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 1-3: Encapsulants - Measurement of dielectric strength
IEC 62788-1-4 Ed. 1.0	Measurement procedures for materials used in Photovoltaic Modules - Part 1-4: Encapsulants - Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off frequency
IEC 62788-1-5 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 1-5: Encapsulants - Measurement of change in linear dimensions of sheet encapsulation material under thermal conditions

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IEC 62790 Ed. 1.0	Junction boxes for photovoltaic modules - Safety requirements and tests
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SOLAR-ERA.NET

ERA-NET ON SOLAR ELECTRICITY FOR THE IMPLEMENTATION OF THE SOLAR EUROPE INDUSTRY INITIATIVE

Annual Report 2013

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Duration of the Project	01.11.2012 – 31.10.2016
Date	December 2013

ABSTRACT

SOLAR-ERA.NET is a network that brings together more than 20 RTD and innovation programmes in the field of solar electricity technologies (photovoltaics and concentrating solar power) in the European Research Area.

The network of national and regional funding organisations has been established in order to increase transnational cooperation between RTD and innovation programmes and to contribute to achieving the objectives of the Solar Europe Industry Initiative (SEII) through dedicated transnational activities, especially joint transnational calls.

SOLAR-ERA.NET is an EU funded FP7 project running from 2012 to 2016. Through the support of the funding organisations, more than 100 MEUR shall be mobilised for transnational RTD and innovation projects in PV and CSP fields.

Aims of the project / network

The overarching objective of SOLAR-ERA.NET is to effectively implement the Solar Europe Industry Initiative. On this purpose, SOLAR-ERA.NET needs also to:

- build a strong network involving key stakeholders of national and regional RTD and innovation programmes relevant for solar energy (PV and CSP)
- create critical mass and mobilise resources for accelerated technology development and deployment
- apply an efficient and coherent approach for effective transnational collaboration
- support concrete joint activities and projects

If the SOLAR-ERA.NET is effectively implemented, it will:

- contribute to Europe's leading position in solar technologies and sustainable development
- enhance coherency and durable cooperation in ERA

Description of the project

SOLAR-ERA.NET is a FP7 funded European network of national and regional funding organisations and RTD and innovation programmes in the field of solar electricity generation, i.e. photovoltaics (PV) and concentrating solar power (CSP) / solar thermal electricity (STE).

SOLAR-ERA.NET consortium members (organisations participating):

- NET Nowak Energy & Technology, Switzerland (coordinator)
- Federal Department for Environment, Transports, Energy and Communication, Switzerland
- Forschungszentrum Jülich, Germany
- Teknologian Ja Innovaatioiden Kehittaemiskeskus (TEKES), Finland
- Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME), France
- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spain
- Service Public de Wallonie (SPW), Belgium
- Agentschap voor Innovatie door Wetenschap en Technologie (IWT), Belgium
- Narodowe Centrum Badan i Rozwoju (NCBR), Poland
- Turkiye Bilimsel ve Teknolojik Arastirma Kurumu (TUBITAK), Turkey
- Ministerie van Economische Zaken, Landbouw en Innovatie / NL Agency, The Netherlands
- Kentro Ananeosimon Pigon ke Exikonomisis Energeias (CRES), Greece
- The Technology Strategy Board (TSB), United Kingdom
- Research Promotion Foundation (RPF), Cyprus
- Regione Puglia, Italy
- Regione Sicilia, Italy
- Bundesministerium für Verkehr, Innovation und Technologie (BMVIT), Austria
- Klima- und Energiefonds, AustriaSwedish Energy Agency, Sweden

SOLAR-ERA.NET has a double mission: i) as a network in the ERA-NET scheme, it shall improve coordination and cooperation between national / regional RTD and innovation programmes and ii) as a network in the context of the European Strategic Energy Technology Plan (SET-Plan) and Solar Europe Industry Initiative (SEII), it shall implement the SEII on the <u>trans</u>national level (complimentary to actions taken on national and EU level). Altogether SOLAR-ERA.NET shall contribute to reaching the objectives of the Solar Europe Industry Initiative (SEII) by carrying out the coordination and support actions for the implementation of the SEII between national and regional RTD and innovation programmes.

The SEII is embedded in the European Strategic Energy Technology Plan (SET-Plan) which aims to increase, coordinate and focus EU support on key low-carbon energy technologies in order to achieve Europe's 2020 energy objectives in the future. The SEII is a joint initiative of the industry sector, EC and member states. The objective of the SEII is to boost the development of the PV and CSP sector beyond "business-as-usual" in the areas of Research and Development, Demonstration and Deployment. For the concerned solar electricity technologies Implementation Plans have been developed setting out priorities for RTD in Europe.

Key activities of SOLAR-ERA.NET are to undertake joint strategic planning, programming and activities for RTD and innovation in the area of solar electricity generation. Joint activities, namely joint calls, are defined for key topics and priorities in accordance with the SEII. Four transnational calls are planned (one per year) that shall mobilise 50 MEUR of public funding and, in total, 125 MEUR for industry-led RTD and innovation projects.

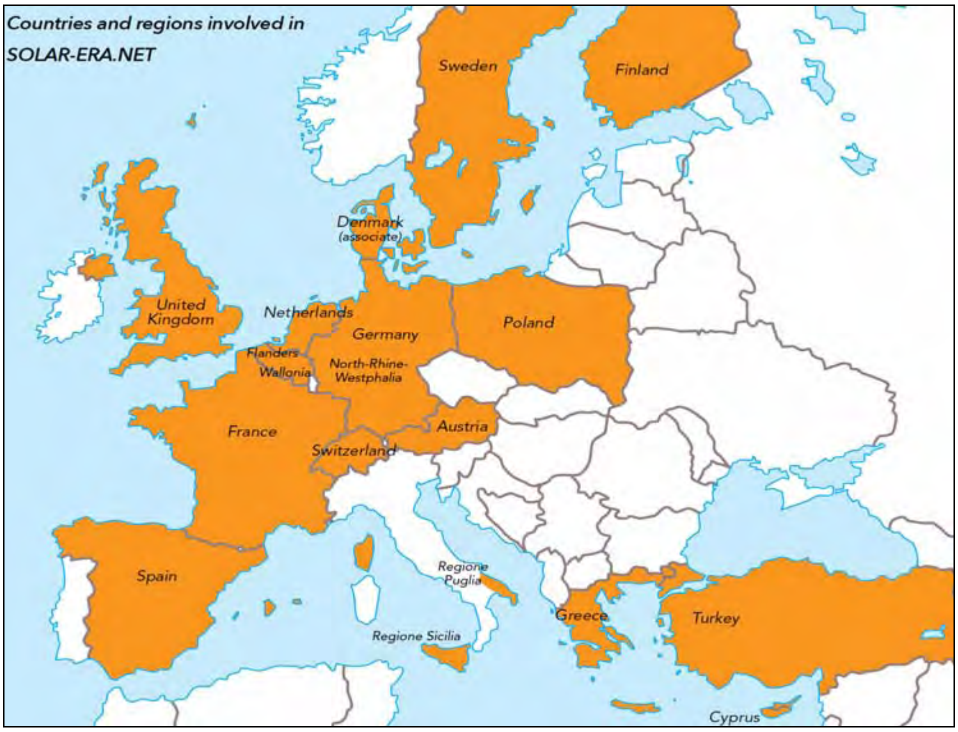

***Figure 1**: Map with countries and regions involved in SOLAR-ERA.NET*

Work carried out and results achieved

SOLAR-ERA.NET officially started on 1st of November 2012. Its kick-off meeting took place in conjunction with the Solar Europe Industry Initiative Team (composed of representatives from the European Commission, industry and research) meeting in Brussels mid-November 2012 (see Figure 2).

***Figure 2**: SOLAR-ERA.NET kick-off meeting in conjunction with the Solar Europe Industry Initiative Team (composed of representatives from the European Commission, industry and research) meeting in Brussels*

One focus was on the organisational and administrative set-up of the new network. But from the very beginning, most important focus was on the first joint calls. SOLAR-ERA.NET prepared the first set of transnational calls PV1 and CSP1, defining subjects based on the priority topics identified by the SEII Team (see Box on next page).

Topics of the first and second set of transnational calls (*additional topics in second joint call in italics*):

- PV1 Innovative processes for inorganic thin-film cells & modules
- PV2 Dedicated modules for BIPV design and manufacturing
- PV3 Grid integration and large-scale deployment of PV
- PV4 High-efficiency PV modules based on next generation c-Si solar cells
- PV5 Solar glass and encapsulation materials
- *PV6 Concentrator PV technology*
- *PV7 Si feedstock, crystallization and wafering*
- CSP1 Cost reduction and efficiency increase in components
- CSP2 Dispatchability through storage and hybridisation
- CSP3 New fluids for STE plants
- *CSP4 Innovative thermodynamic cycles*

Intense discussion and preparation was also needed in order to define procedures and synchronise the timeline within and between the different countries and programmes involved. The main characteristics of the procedure can be summarised as follows:

- Two step procedure (preproposals and full proposals)
- Parallel call topics for PV and CSP; each funding organisation selects which call topic & which type of research and organisation it supports.
- National/regional rules define the eligibility of an applicant; funding decisions by national/regional funding organisations according to the list of projects suggested for funding.
- No common pot.
- Minimum size of the consortium: two countries or regions (of two different countries) participating in the joint call.
- Industrially relevant projects.
- The preproposals are recommended (or not) by the funding agencies as to whether they are invited for submitting a full proposal.
- The full project proposal is evaluated by external independent experts – their results are the base for a ranking list. Main criteria are i) potential commercial impact / relevance to industrial and market needs / contribution to the Solar Europe Industry Initiative and added transnational value, ii) scientific and technological excellence and iii) quality and efficiency of the implementation and the management by international experts.
- Funding agencies can do their own evaluations and their funding decisions is based on the ranking list and / or own criteria and priorities.
- Projects suggested for funding are negotiated on the national level. The principle is that funding agencies contract and fund the project participants of their own country / region.
- Some concise transnational reporting and monitoring of the projects initiated in the SOLAR-ERA.NET context is done (complementary to the common national / regional reporting and monitoring).

In first joint call, 15 countries and regions participated with their RTD and innovation programmes in these calls. The total public funding budget for the first set of calls was at approx. 12 million euros, covering topics both in photovoltaics (PV) and concentrating solar power (CSP). Key results of the preproposal phase of the first set of transnational SOLAR-ERA.NET calls PV1 and CSP1 can be summarised as follows:

- Some 60 preproposals with a total project volume of around 90 million euros were submitted by the deadline set (15 May 2013).
- 257 partners can be counted, a fourth of them come from Germany. Numberous are also partners from Spain and France with 30 resp. 28 partners. But interest has also been considerable in a series of smaller countries and countries with an emerging solar industry as can be seen in Figure 3.
- The majority (60%) of the organisations involved in the preproposals submitted belong to the categories of small and medium sized enterprises and large enterprises; research organizations have a share of 39%.
- 47 out of the 60 preproposals were submitted for PV topics, 13 preproposals for CSP topics (see Figure 4).

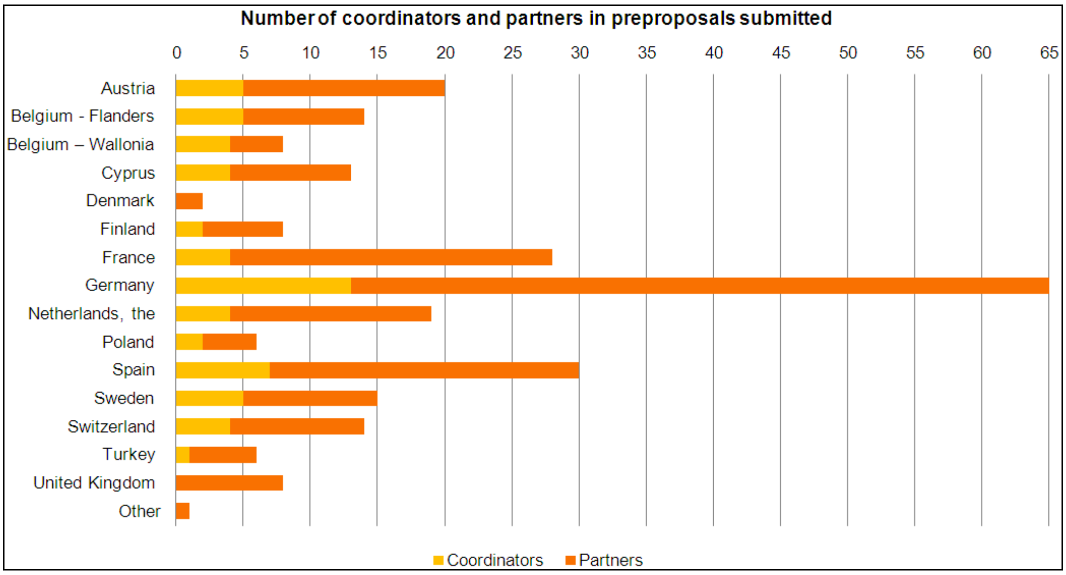

***Figure 3**: Number of coordinators and partners in the preproposals submitted by country / region participating in the SOLAR-ERA.NET call*

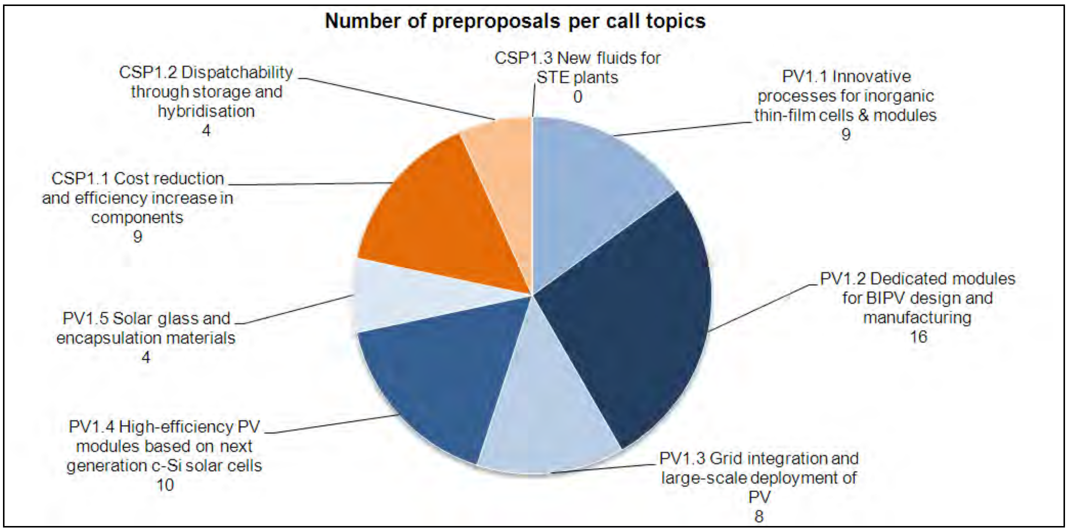

***Figure 4**: Number of preproposals submitted per call topic*

***Figure 5**: The General Annual Meeting as well as the Preproposal Meeting of the SOLAR-ERA.NET joint call consortium took place mid-June 2013 in Neuchâtel where a guided tour of the Neuchâtel-based Photovoltaics and thin film electronics laboratory PV-LAB was organised (see picture above).*

27 out of preproposals were recommended for the second stage, i.e. full proposal phase. 21 full proposals with a total project volume of more than 40 million euros were finally submitted by the deadline set (9 October 2013). Out of the 21 full proposals submitted, 17 were for PV topics and 4 for CSP topics. 114 potential project partners could be counted from 15 different countries and regions.

Independent external experts evaluated the 21 full proposals and two ranking lists (one for PV projects and one for CSP projects) were set up. The Full Proposal Meeting of the SOLAR-ERA.NET joint call consortium took place mid-November 2013 in Namur where full proposals, their evaluation results and their chances for obtaining funding were discussed. Negotiation and contractual issues are currently dealt with on the national / regional level (status end of 2013). First projects are expected to start in first quarter of 2014. Among the 21 full proposals, there are 4 projects with Swiss participation (2 in PV projects and 2 in CSP projects). Further information, e.g. on what / how many projects are funded, will be available in 2014.

In parallel to the full proposal phase, the second set of transnational calls PV2 and CSP2 was prepared.

National and international cooperation

International cooperation is in the very core of SOLAR-ERA.NET with the goal to enhance coordination and collaboration between more than 20 RTD and innovation programmes from 18 countries and regions.

Evaluation 2013 and outlook 2014

The current situation and competition in the PV and CSP industry sector can be characterised as harsh and presents a challenging context as well for SOLAR-ERA.NET. SOLAR-ERA.NET strives to cope best with these challenges and translate them in opportunities for both Europe as a whole and the participating states individually.

The first set of transnational calls PV1 and CSP1 found very good interest in the solar power industry sector and research community with 60 preproposals with a total project volume of around 90 million euros. 21 full proposals were finally submitted with a total project volume of more than 40 million euros. Results on projects funded will be available in 2014.

The first set of transnational calls PV1 and CSP1 was set up in a very fast and efficient manner, involving agencies from 15 different countries and regions. A few modifications will be implemented in the second joint call in order to further improve the call procedure, e.g. providing longer lead time between the call launch and preproposal submission deadline with the goal that applicants have more opportunities for building project consortia.

The second set of transnational calls PV2 and CSP2 will be launched mid-January 2014, with the participation of two additional funding agencies (Israel and North-Rhine-Westphalia). Preproposals in the second joint call shall submitted by end of April 2014, full proposals by early October 2014.

Bibliography

Information can be found on the network’s website **www.solar-era.net**.

CSP Implementation Plan for 2013 – 2015

PV Implementation Plan for 2013 - 2015

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

SWISS INTERDEPARTMENTAL PLATFORM FOR RENEWABLE ENERGY AND ENERGY EFFICIENCY PROMOTION IN INTERNATIONAL COOPERATION (REPIC)

Annual Report 2013

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Date	Mai 2014

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 2013, phase III of the REPIC Platform was in the third year of operation mainly focusing on the realization of application-oriented projects and possible multiplication of promising project approaches. The REPIC-Platform contributes to the implementation of global climate protection agreements and to a sustainable energy supply in developing and transition countries. The activities represent an important part in the implementation of the Swiss policy for sustainable development on the international level. The REPIC-Platform thereby contributes 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. Project promotion and project realization
2. Information and communication
3. Coordination

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 internationalen Zusammenarbeit – 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 Plattform beteiligten Ämter in der Regel individuell und punktuell Projekte mit erneuerbaren Energien und Energieeffizienz in der internationalen Zusammenarbeit gefördert haben, erfolgt heute ein koordinierter Ansatz zur Förderung solcher Projekte. Damit werden ein besser abgestimmtes und einheitlicheres Vorgehen sichergestellt. Die 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 im Bereich der nachhaltigen Entwicklung auf internationaler Ebene. Der vorliegende zehnte Jahresbericht beschreibt die Projektaktivitäten, Resultate und Erfahrungen im zehnten Jahr der Plattform.

REPIC versteht sich in ihrem Aufgabengebiet als marktorientiertes Dienstleistungszentrum. Unter Berücksichtigung der vorhandenen Erfahrungen kann diese Plattform Anschubfinanzierungen für neue konkrete Projekte mit vielversprechendem Multiplikationspotential im Bereich der erneuerbaren Energien und Energieeffizienz leisten. Ein wichtiges Ziel ist der Know-How Transfer von Schweizer Unternehmen und Organisationen in Entwicklungs- und Transitionsländer. Die REPIC-Plattform baut dazu ihr Netzwerk zur Information und Sensibilisierung interessierter Kreise laufend aus, pflegt den Erfahrungsaustausch zwischen verschiedenen Akteuren und fördert die Kenntnis von lokalen Rahmenbedingungen und Projektmöglichkeiten. Zusätzlich 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.

Schwerpunkte 2013, durchgeführte Arbeiten und Ergebnisse

Die Schwerpunkte der REPIC-Plattform lauteten für 2013 wie folgt:

1. Projektbezogene Aktivitäten
2. Information und Kommunikation
3. Koordination innerhalb der Trägerschaft, mit einschlägigen Finanzorganisationen und mit internationalen Netzwerken

Projektbezogene Aktivitäten

Vor dem Start der dritten REPIC-Phase mussten budget- und verfahrensbedingt diverse Projektskizzen und –gesuche zurückgestellt werden. 2011 wurden dadurch 23 neue Projekte bewilligt und gestartet. Im Jahr 2012 wurden 37 Anfragen, Projektskizzen und -gesuche bearbeitet und 10 Projektgesuche genehmigt. 2013 wurden 48 Anfragen, Projektskizzen und -gesuche bearbeitet und 8 Projektgesuche bewilligt.

Information und Kommunikation

Der Fokus in der dritten REPIC-Phase gilt verstärkt der Umsetzung und Multiplikation von erfolgversprechenden Projektansätzen. Unter anderem wurde hierzu vermehrt der Kontakt zu andern Förderplattformen und Finanzierungsinstituten gesucht, um auf erfolgreiche Projekte aufmerksam zu machen und die Multiplikation dieser Projektansätze zu fördern.

Das REPIC-Sekretariat führte 2013 eine Fachveranstaltung zum Thema „Erfolgsfaktoren für wirkungsvolle Projekte“ in den Bereichen Erneuerbare Energien und Energieeffizienz in der Entwicklungszusammenarbeit durch [2,3]. Der Anlass mit Plenumsvorträgen, parallelen Workshops und Posterbeiträgen war mit rund 110 Teilnehmern sehr gut besucht. Insgesamt 10 hochkarätige nationale und internationale Referenten und Workshopleiter trugen zum guten Gelingen und zur hohen Qualität der Veranstaltung bei. Es kam wiederholt zum Ausdruck, dass die gute Kenntnis der lokalen Bedürfnisse, der lokalen administrativen Abläufe sowie die Zusammenarbeit auf Augenhöhe mit den lokalen Partnern wichtige Erfolgsfaktoren darstellen für den Erfolg von REPIC-Projekten. Das breite Teilnehmerfeld mit Projektierenden, Vertretern von nationalen und internationalen Organisationen, Finanzinstituten und Behörden erlaubte einen konstruktiven und inspirierenden Erfahrungsaustausch.

Über die Teilnahme an weiteren Veranstaltungen konnten neue Kontakte geknüpft und bestehende gepflegt werden.

Die bewährten REPIC-Kommunikationsaktivitäten wurden weitergeführt. Die Website (www.repic.ch) wurde überarbeitet, der 2011 aktualisierte REPIC-Leitfaden [1] und der REPIC-Flyer [4] standen weiterhin zur Verfügung. Auch die Schlussberichte abgeschlossener Projekte wurden jeweils auf der REPIC-Website aufgeschaltet. Für die folgende vierte REPIC-Phase (2014-2017) wurden weiterführende Kommunikationsaktivitäten entwickelt, welche die REPIC-Plattform bei potentiellen Projektierenden aber auch bei Investoren, Politkern und der interessierten Bevölkerung bekannter machen sollen.

Koordination innerhalb der Trägerschaft, mit einschlägigen Finanzorganisationen und mit internationalen Netzwerken

Die REPIC-Plattform wurde auch 2013 intensiv genutzt, um Informationen zu den Tätigkeiten der beteiligten Bundesämter im Bereich der erneuerbaren Energien und der Energieeffizienz in der internationalen Zusammenarbeit auszutauschen und Aktivitäten bei Bedarf abzusprechen. Der Kontakt mit den Kooperationsbüros wurde weiterhin in den Genehmigungsprozess der REPIC-Projekte integriert und so ein intensivierter lokaler Austausch in den Zielländern gesucht. Im Hinblick auf die strategisch verstärkte Umsetzungsorientierung und Multiplikationswirkung wurden Kontakte mit anderen Programmen und Initiativen aufgebaut und erweitert. 2013 betraf dies vor allem Förderorganisationen wie REEEP, UNIDO und Swiss Bluetec Brigde. Ziel dieser Kontakte ist es unter anderem, erfolgreichen REPIC-Projekten den Weg für möglichst selbständige Folgeprojekte ebnen zu können.

Kontakte zu verschiedenen Finanzierungsinstituten zeigen verschiedene vielversprechende Wege auf, die 2014 weiter abgeklärt und ins laufende Coaching von REPIC-Projekten integriert werden.

Projektaktivitäten und Kennzahlen

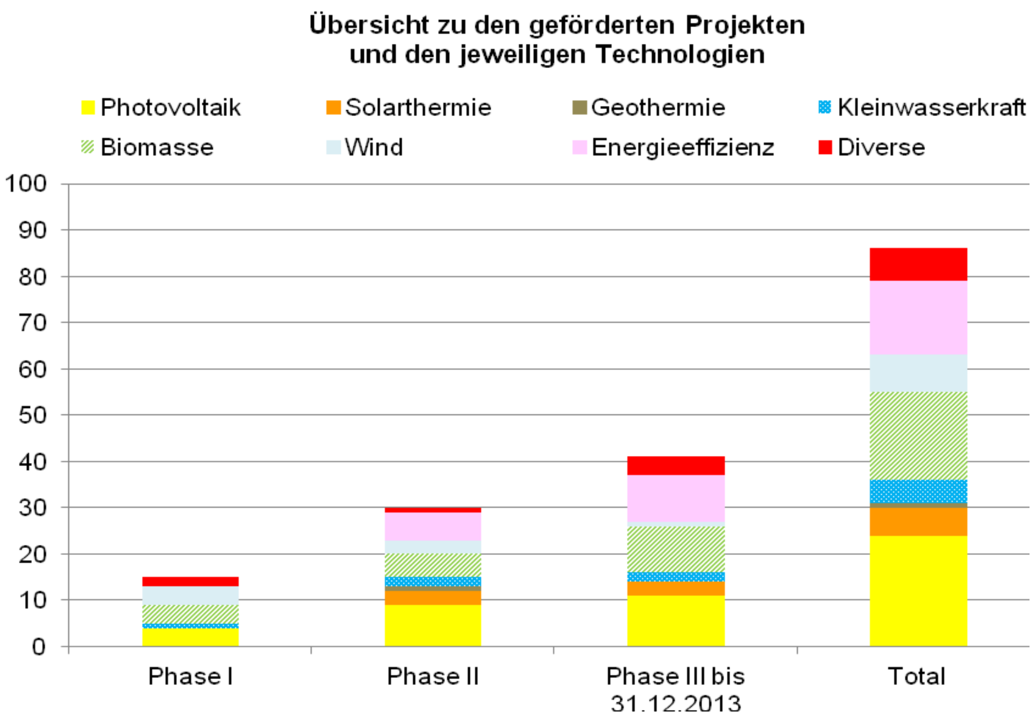
Nach einem budget- und verfahrensbedingten intensiven Start der dritten REPIC-Phase im Jahr 2011 mit 23 bewilligten Projekten blieb die Nachfrage auch 2012 und 2013 weiterhin hoch, wobei die Anzahl der bewilligten Projekte etwas zurückging. Aus den in der REPIC-Phase III per Ende 2013 behandelten 132 Anfragen konnten bisher 41 genehmigt werden. Damit ist erkennbar, dass die REPIC-Plattform auf reges Interesse stösst, jedoch mit dem Fokus auf den spezifischen Schnittstellenbereich der Entwicklungszusammenarbeit und der Erneuerbaren Energien sowie der Energieeffizienz ein spezifisches Zielpublikum anspricht. Es werden Projektierende mit guten lokalen Kenntnissen gesucht, die aus der Schweiz einen Wissens- und Technologietransfer ermöglichen, das Projekt in eine Umsetzungs- und Multiplikationsphase führen und gleichzeitig starke Fähigkeiten im Projektmanagement vorweisen können.

Das Verfahren der Projektbearbeitung und -genehmigung funktioniert gut, auf die Vielfalt der Projektanfragen wird eingegangen und die Projektierenden werden entsprechend beraten. Vorhandenes Verbesserungspotential wird regelmässig geprüft und Massnahmen dazu umgesetzt. Bei der Mehrzahl der Projekte kann das Verfahren effizient und wirksam abgewickelt werden.

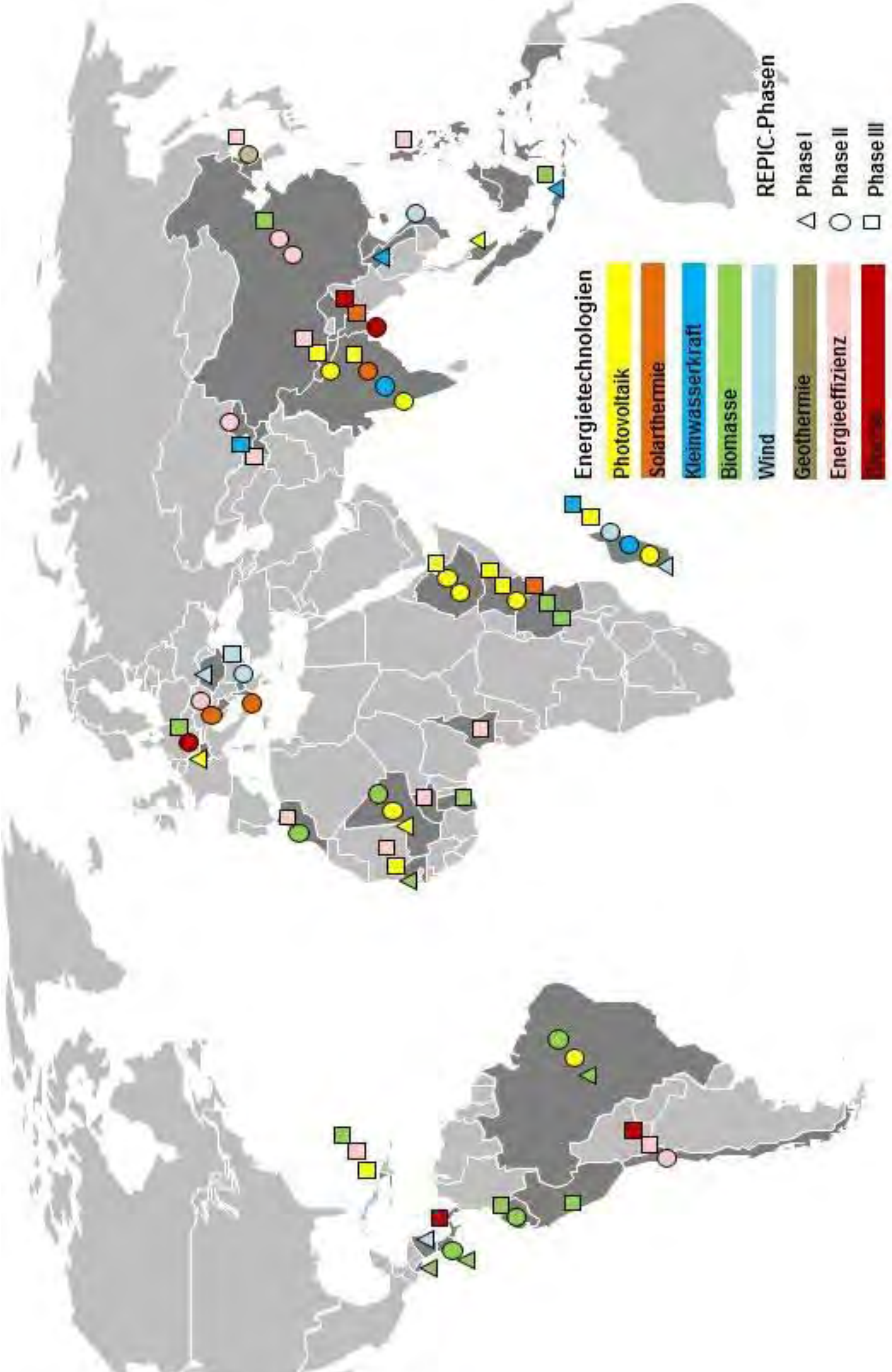
Im Jahr 2013 lagen die Anfragen breit verteilt auf die Bereiche Biomasse, Energieeffizienz, Photovoltaik sowie Diverse. Die genehmigten und laufenden Projekte hingegen liegen jeweils zu gleichen Teilen in den Bereichen der Biomasse, Energieeffizienz und der Photovoltaik.

Seit Beginn der REPIC Projektförderung wurden bis Ende 2013 86 Projekte gefördert, davon wurden 56 Projekte abgeschlossen. Im REPIC Jahresbericht 2013 werden sämtliche im Jahr 2013 laufenden und abgeschlossenen Projekte ausführlicher erläutert.

Die Figuren 1 und 2 geben einen Überblick über sämtliche Projektaktivitäten aus allen REPIC-Phasen und deren Verteilung auf die verschiedenen Energietechnologien und Regionen.



***Figur 1**: Projektaktivitäten und Technologien aller REPIC Phasen bis Ende Jahr 2013*



Figur 2: *Verteilung aller unterstützten Projekte aus allen Phasen nach Region und Technologiebereich*

Stand der bewilligten REPIC-Projekte mit Bezug zur Photovoltaik

Neu abgeschlossene Projekte mit Bezug zur Photovoltaik

- DT-Power / Mobisol, Kenia: Mobisol - Solar Home Systeme mit GSM Modem für die ländliche Elektrifizierung
- WirzSolar, Haiti: Vorbereitung zur Multiplikation des Mali-Solarpumpenprojekts in Haiti
- Tritec, Madagaskar: Elektrifizierung der letzten Meile – Stromversorgung mittels Solarenergie in abgelegenen Gebieten in Madagaskar
- EBP, Chile: Umweltfreundliche Mobilität auf den Flüssen in Valdivia

Projekte in Abschlussphase Projekte mit Bezug zur Photovoltaik.

- Swiss Fresh Water, Senegal: Pilotprojekt eines low-cost und dezentralen Entsalzungssystems im Sine Saloum Delta in Senegal
- Stiftung Solarenergie, Äthiopien: Sun-Control - Pilotprojekt zum Einsatz verbesserter Technik zur Handhabung und Finanzierung von Solar-Home-Systemen
- SUPSI-ISAAC, Nepal: Netzgekoppelte PV-Pilotanlage

Laufende Projekte mit Bezug zur Photovoltaik

- Der Schweizer Beitrag für die Netzwerkaktivitäten im Projekt „IEA PVPS Task 9: Photovoltaic Services for Developing Countries (Photovoltaik)“ ausgeführt von entec AG wurde über REPIC bis Mitte 2014 verlängert.
- Muntwyler Engineering, Indien: Demonstrationsprojekt Solare Elektrofahrzeuge im öffentlichen Verkehr in Clean Air Island
- Berner Fachhochschule, Indien: Mikro-Unternehmen und Kleinbäuerinnen im ländlichen Indien: Innovation durch nachhaltige Energietechnologien mit der „Swiss Solar Water Pump

Neue Projektunterstützungen im Jahr 2013 mit Bezug zur Photovoltaik

- Im Bereich Photovoltaik wurden 2013 keine neuen Projekte gefördert.

Mobisol – Solar Home Systeme mit GSM Modem für die ländliche Elektrifizierung

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Kenia	**Projektstatus :**	Abgeschlossen
Partner :	DT-Power GmbH / Mobisol GmbH, Zug, Thomas Gottschalk, www.plugintheworld.com Dirk Junghans (neu: Taiga Elements GmbH, Zug, www.taiga-elements.com)		

© DT-Power

© DT-Power

Schweizer Beitrag

DT-Power ist ein junges Schweizer Unternehmen, welches für das Produkt Mobisol gegründet wurde. Die Verantwortlichen haben mehrere Jahre Erfahrung im Bereich der erneuerbaren Energien.

Portrait

Die Entwicklung der Elektrifizierung in Kenia konzentriert sich hauptsächlich auf das städtische Gebiet. Das SHS Mobisol wurde entwickelt, um auch den Bedarf in den ländlichen Gebieten zu decken. Dieses System besteht aus einem PV Modul, welches mit einem GSM Modem ausgerüstet ist und eine Fernkontrolle des Produkts erlaubt. Das Angebot beinhaltet ein Zahlungssystem (pay-as-you-go) welches speziell an die Zahlungsmöglichkeiten der lokalen ländlichen Bevölkerung angepasst ist. Für das Angebot, die Verteilung und das Monitoring wird das Netz eines nationalen Mobiltelefonanbieters genutzt. Das Pilotprojekt hat zum Ziel, die Vertrauenswürdigkeit der technischen Komponenten, der Vermarktung und die Wirtschaftlichkeit von 100 Mobisol-Systemen in Kenia zu prüfen. Das Mobisol-Projekt versucht, ein System zur Verfügung zu stellen, welches sowohl für die Kunden wie auch für die Investoren finanziell machbar ist.

Resultate

Das Projekt hat im Dezember 2011 angefangen, es konnten 100 Mobisol Solar Home Systeme installiert und erfolgreich betrieben werden. Die Zahlungen der Kunden trafen über M-Pesa ein. Das Pilotprojekt hat wertvolle Erfahrungen im Feld ermöglicht, welche zu Verbesserungen der Dienstleistungen sowie des Systems geführt haben. Bereits nach dieser ersten Phase kann das Projekt erfolgreich weiterlaufen.

Wirkung

Die SHS wurden für Haushalte deutlich erschwinglicher mit dem Zahlungssystem über M-Pesa. Es konnte festgestellt werden, dass Kerosin, Batterien und Kerzen ersetzt werden, die Luftbelastung in den Häusern entfällt, eine finanzielle Entlastung entsteht und die Kinder mehr als doppelt so viel Zeit mit Hausaufgaben verbringen als zuvor. Zudem kann mit den LED-Leuchten ein gewisses Sicherheitsbedürfnis gedeckt werden. Bis zu einem Drittel der Kunden in abgelegenen Regionen starten kleine Geschäfte (Barbershops, Ladestationen, Verkauf kalter Getränke, etc.). Die steigende Nachfrage – seit 2010 wurden über 3'000 solar home systems in über drei Pilotprojekten in Tansania, Kenia und Ghana installiert – führt zur Multiplikation dieser Wirkungen.

Dokumentation

Schlussbericht „Mobisol Project: Affordable Solar Home Systems" [5] zu beziehen bei NET AG, DT-Power / Mobisol oder www.repic.ch.

Vorbereitung zur Multiplikation des Mali-Solarpumpenprojekts in Haiti

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Haiti	**Projektstatus :**	Abgeschlossen
Partner :	WirzSolar GmbH, Sissach, Fredy Wirz		

© WirzSolar

© WirzSolar

Schweizer Beitrag

WirzSolar GmbH besitzt langjährige konkrete Erfahrung mit Solarpumpenprojekten in Entwicklungsländern, insbesondere in Mali, wo bereits solche durch REPIC unterstützte Projekte stattgefunden haben.

Portrait

Dieses Projekt beinhaltet die Vorbereitung für ein grösseres Solarpumpenprojekt in Haiti. Zusammen mit den Wasserbehörden und UNICEF soll ein Programm zur nationalen Ausbildung von lokalen Technikern und Sensibilisierung aller Akteure erarbeitet werden. Zudem sollen durch den Einsatz von Demo-Solarpumpensystemen und dem Austesten von drei in der Schweiz entwickelten Mini-Solarpumpen zum Ausrüsten von Handpumpen konkrete Verbesserungen in der Trinkwasserversorgung vor allem in Schulen im Erdbebengebiet Leogane erzielt werden.

Der vorgesehene Süd-Süd Know-How Transfer der Erfahrungen aus Mali nach Haiti enthält Ausbildungskomponenten zur erfolgreichen Weiterführung und zur Multiplikation der Erfahrungen aus dem Mali Solarpumpenprojekt.

Resultate

In drei Schulen konnten Solarpumpenanlagen installiert und in Betrieb genommen werden. Insgesamt erhalten über 5‘000 Schülerinnen und Schüler sowie das Lehrpersonal in den Schulen Zugang zu sauberem Wasser. Die ersten zwei Anlagen wurden zusammen mit dem malischen Techniker installiert und ein kleines haitianisches Installationsteam wurde aufgebaut und trainiert.

Wirkung

Bisher wurden 6 weitere Projekte mit Solarpumpenanlagen unterstützt durch Caritas Schweiz und die DEZA realisiert. 16 weitere Schulen befinden sich zurzeit in Abklärung. WirzSolar konnte durch die Mitarbeit bei einer Steuergruppe des Erziehungsministeriums für schulische Infrastrukturen die Aspekte von solaren Wasserversorgungen als Richtlinien einbringen. Die Arbeiten von WirzSolar unterstützten die Vorbereitungsarbeiten für ein nationales Programm für Solarpumpenanlagen in Schulen. Dazu konnte Wirzsolar seine Erfahrungen beim ersten dörflichen Wasserprojekt in Grand Boucan einbringen.

Dokumentation

Schlussbericht „Vorbereitung zur Multiplikation des Mali-Solarpumpenprojekts in Haiti – Phase 1“ [6] zu beziehen bei NET AG, WirzSolar oder www.repic.ch.

Elektrifizierung der letzten Meile
Stromversorgung mittels Solarenergie in abgelegenen Gebieten in Madagaskar

Projektart :	Infrastrukturorientiertes Projekt	**Technologie :**	Photovoltaik
Land :	Madagaskar	**Projektstatus :**	Abgeschlossen
Partner :	TRITEC AG, Allschwil, www.tritec-energy.com, Sibylle Hamann Giordano Pauli (neu: Savenergy Consulting GmbH)		

© Tritec International

© Tritec International

Schweizer Beitrag

TRITEC ist seit über 20 Jahren ein Photovoltaik-Systemlieferant und hat anlässlich eines früheren Entwicklungsprojektes bereits an der Implementierung von dezentralen Photovoltaiksystemen in Madagaskar mitgewirkt. Der Schweizer Beitrag bezieht sich auf das Training der lokalen privaten Operateure und Mitarbeiter von ADER sowie auf das Solarmaterial der ersten Gemeinde.

Portrait

87% der madagassischen Familien haben keinen Zugang zum Stromnetz und benützen Kerzen oder Kerosinlampen um ihre Zimmer nachts zu beleuchten. Soziale Infrastrukturen wie Schulen, Gesundheitszentren, Rats- oder Gemeindehäuser und öffentliche Plätze verfügen in ländlichen Gebieten oft über keinen Strom. Das gemeinsam mit der madagassischen ADER (Agence de Développement de l'Electrification Rurale) und der Deutschen Gesellschaft für Internationale Zusammenarbeit (GIZ) durchgeführte Projekt will die elektrische Versorgung für soziale Infrastrukturen in ländlichen Gemeinden im Süden Madagaskars verbessern und über die Vorteile von Solarenergie für einkommensschwache Haushalte in den ländlichen abgelegenen Gebieten informieren.

Resultate

Im Rahmen des Projekts wurden in 5 Gemeinden die wichtigsten Einrichtungen wie Schulen, Krankenstationen und Bürgermeisterämter elektrifiziert und wichtige Strassenabschnitte oder Plätze mit Solaren LED Strassenlampen beleuchtet. Private Unternehmer wurden ausgebildet, sie unterhalten die installierten Anlagen und bieten Pico Solarsysteme zum Kauf oder zur Miete an. Für die Sensibilisierung der Bevölkerung wurden Informationsveranstaltungen in 357 Gemeinden mithilfe von zwei mobilen Informationsplattformen durchgeführt.

Wirkung

Das im Rahmen des REPIC Projekts eingeführte Geschäftsmodell mit verschiedenen Solar Services überzeugte einen lokalen Bergbauunternehmer, der zwei zusätzliche Dörfer für die Elektrifizierung unterstützte. Der Unternehmer will nach Abschluss des REPIC Projekts zwei weitere Dörfer unterstützen. Die Elektrifizierung verbessert die Dienstleistungen von Gesundheitszentren, Schulen, Gemeindezentren und Bürgermeisterämtern und verbessert die Sicherheit in den Dörfern. Der Aufbau von Solarladestellen für Akkus und von Verkaufs- und Verleihstellen für Solarlampen verbessert längerfristig die wirtschaftliche und soziale Situation in den Dörfern.

Dokumentation

Schlussbericht „Energizing the Last Mile – Providing Electricity by Means of Solar Energy in Remote Areas of Madagascar" [7] zu beziehen bei NET AG, TRITEC AG oder www.repic.ch.

Folgeprojekt der GIZ: www.giz.de/de/weltweit/20065.html / www.giz.de/de/weltweit/20052.html

Umweltfreundliche Mobilität auf den Flüssen in Valdivia

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Chile	**Projektstatus :**	Abgeschlossen
Partner :	Ernst Basler + Partner AG, Zollikofen, www.ebp.ch, Roger Walther		

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Schweizer Beitrag

Der Schweizer Projektpartner EBP verfügt über viel Erfahrung mit Energieeffizienzprojekten und Mobilität und der Projektleiter kennt die Situation vor Ort sehr gut. Beim Projekt soll auch von den Erfahrungen vom Schweizer Pilotprojekt „Alpmobil“ im Goms profitiert werden, in welchem rund 50 Elektrofahrzeuge eingesetzt und von Touristen und Einheimischen tageweise gemietet werden können.

Portrait

Im Süden Chiles liegt die Stadt Valdivia, die von zahlreichen Flüssen umgeben ist und mit den üblichen Verkehrsproblemen lateinamerikanischer Städte zu kämpfen hat. Hauptziel und Wirkung des vorliegenden Pilot- und Demonstrationsprojektes soll sein, mittelfristig einen Teil des motorisierten Individualverkehrs auf Solar- bzw. Elektroboote umzulenken.

Der Betrieb der Elektroboote wird getestet und evaluiert in Bezug auf Wirtschaftlichkeit, Organisation und soziale Akzeptanz. Gleichzeitig soll das Pilotprojekt in der Öffentlichkeit kommuniziert werden. Durch den Einbezug der lokalen Universität, bei der die operative Projektleitung liegt, soll auch Forschung und Entwicklung im Bereich der erneuerbaren Energien gefördert werden.

Resultate

Das Pilotprojekt konnte mit 3 Elektrobooten und der Solarladestation wie geplant realisiert werden. Die Boote und die Solarstation funktionieren problemlos. Im Rahmen des Pilotprojekts konnten insgesamt 7 Anlegestellen genutzt werden, wobei nur 2 Anlegestellen öffentlich zugänglich sind. Eine Umfrage bei den Fahrgästen zeigte insgesamt eine hohe Zufriedenheit. Für die Zukunft wünschen sich die Nutzer einen Ausbau des Streckennetzes inkl. deutlich mehr Anlegestellen sowie eine klarere Kommunikation der Fahrpläne sowie deren Einhaltung. Gleichzeitig sollen die Fahrpreise nicht oder nur moderat erhöht werden.

Wirkung

Im August 2013 hat die Stadt Valdivia beschlossen, den Fluss Calle Calle offiziell als öffentlichen Transportweg zu nutzen. Die Stadt hat 2013 fünfzehn Anlegestellen für den Bootsbetrieb im Regionalentwicklungsplan ausgeschrieben und rund 700‘000 USD für den Bau von öffentlichen Anlegestellen genehmigt. Das ist ein klares Bekenntnis der Stadt, in ein öffentliches Transportsystem mit Elektrobooten zu investieren.

Dokumentation

Schlussbericht „Förderung eines umweltfreundlichen öffentlichen Personentransports auf den Flüssen von Valdivia“ [8] zu beziehen bei NET AG, Ernst Basler + Partner oder www.repic.ch.

Pilotprojekt eines low-cost und dezentralen Entsalzungssystems im Sine Saloum Delta in Senegal

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Senegal	**Projektstatus :**	In Abschlussphase
Partner :	Swiss Fresh Water, Lausanne, www.swissfreshwater.com, Renaud de Watteville		

© Swiss Fresh Water

© Swiss Fresh Water

Schweizer Beitrag

Swiss Fresh Water ist ein neues Start-up-Unternehmen der ETH Lausanne. Die Leiter weisen breite Erfahrung im Projektmanagement und der Wasserbehandlung auf. Das Projekt wird in enger Zusammenarbeit mit der Firma Impact Finance aus Genf durchgeführt. Sie ist auf die Entwicklung und Finanzierung von Projekten in Entwicklungsländern spezialisiert.

Portrait

Swiss Fresh Water (SFW) entwickelte ein low-cost Entsalzungssystem für Salz- und Brackwasser, welches eine Produktion im kleinen Massstab erlaubt. Das System wurde für eine einfache Benutzung entwickelt, es ist einfach im Unterhalt und konsumiert wenig Energie.

SFW hat entschieden, ein Pilotprojekt im Sine Saloum Delta durchzuführen, in dem 225‘000 Menschen leben. Ausserhalb der Regenzeit, d.h. ca. 8-9 Monate des Jahres, trinkt die Bevölkerung vor allem Wasser aus Brackwasser-Bohrungen. Dieses Wasser ist stark Fluor-belastet und bewirkt ernsthafte Gesundheitsprobleme. Das Projekt von SFW will dazu beitragen, die Auswirkungen der Wasserversorgung auf die Gesundheit und den Bedarf an Zeit, Geld und Energie (Transport) zu verringern.

Resultate

Nach einem ersten Jahr erfolgreichen Betriebs hat das Pilotprojekt grosse Erwartungen bei der Bevölkerung ausgelöst. Daher wurde das Projekt verlängert und zusätzliche Finanzierungspartner nehmen an diesem Projekt teil. Es erfolgt eine weitere Optimierung des Businessmodells um die Replikation innerhalb Senegals und darüber hinaus zu ermöglichen. Ende 2013 sind täglich 20 Maschinen in Betrieb und mehr als 35‘000 Personen erhielten neu Zugang zu Trinkwasser erstklassiger Qualität. Es konnte zudem die Entstehung von weiteren Geschäftstätigkeiten rund um Wasserkiosks und die Schaffung von zusätzlichen Arbeitsplätzen festgestellt werden.

Sun-Control: Verbesserte Technik zur Handhabung und Finanzierung von Solar-Home-Systemen in Äthiopien

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Äthiopien	**Projektstatus :**	In Abschlussphase

Partner : Stiftung Solarenergie, Zürich, www.stiftung-solarenergie.ch, Harald Schützeichel

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© Stiftung Solarenergie

Schweizer Beitrag

Die Stiftung Solarenergie hat mit REPIC-Unterstützung bereits verschiedene Solar-Center, welche Solartechniker-Ausbildungen anbieten, aufgebaut und diese anschliessend weitergeführt und ausgebaut. Sie verfügt dadurch über sehr viel Erfahrung in Äthiopien im Bereich Solarenergie.

Portrait

Im vorliegenden Pilotprojekt sollen in Äthiopien 500 neuartige Solar-Home-Systeme eingesetzt und getestet werden. Diese werden vor Ort zusammengebaut und verkauft, während der Pilotphase jedoch noch mit Subventionierung. Die neuartigen Solar-Home-Systeme sollen die Verbreitung der Solartechnik erleichtern, indem sie einen neu entwickelten Laderegler einsetzen. Damit sollen die Nutzer bessere Informationen über den Zustand des Solar-Home-Systems erhalten inklusive der verbleibenden Nutzungsdauer. Ein integriertes Prepayment System soll die Finanzierung in Raten erleichtern.

Resultate

Die lokalen Techniker wurden für Zusammenbau, Programmierung und Wartung der Laderegler erfolgreich geschult. Die 500 Systeme wurden vor Ort zusammengebaut und haben alle Qualitätstests bestanden. Alle Solar Home Systeme wurden bis Ende Oktober 2013 installiert, in Betrieb genommen und funktionieren einwandfrei. Die eingesetzten 1W LED Lampen erreichen mit gemessenen 116 Lumen hervorragende Helligkeitswerte. Aufgrund von neuen Auflagen der Behörden konnte das Prepayment-System nicht wie geplant umgesetzt werden.

Netzgekoppelte PV-Pilotanlage in Nepal

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Nepal	**Projektstatus :**	In Abschlussphase
Partner :	SUPSI-ISAAC, Canobbio, www.isaac.supsi.ch, Domenico Chianese, Roman Rudel		

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Schweizer Beitrag

Der Schweizer Partner bringt breite Erfahrung im Bereich netzgekoppelter Photovoltaik und Ausbildung mit. Die Photovoltaik-Abteilung des ISAAC ist ein Schweizer Kompetenz-Zentrum für das Testen von PV-Modulen.

Portrait

Das Projekt handelt von der Realisierung und dem Monitoring einer netzgekoppelten Photovoltaik-Pilotanlage im Kathmandu-Tal. Es hat sich weiterentwickelt aus den ermutigenden Resultaten der bereits durchgeführten REPIC-Machbarkeitsstudie zu netzgekoppelter Photovoltaik in Nepal. Der aktuelle Mangel an einem zuverlässigen Stromnetz und die gestiegenen Bedürfnisse der Nutzer (kleine und mittlere Unternehmen, Bevölkerung) können durch eine dezentrale und partiell autonome Stromversorgung gelöst werden.

Das Pilotprojekt sieht den Entwurf, den Bau und das Monitoring einer 1 kWp netzgekoppelten PV-Anlage vor. Dazu gehört ein Back-Up-System, welches als Mini-Grid funktionieren kann. Zusätzlich zur Realisierung der Pilotanlage beinhaltet das Projekt Ausbildungskomponenten. Ein weiterer wichtiger Teil besteht aus der Demonstration und Verbreitung der Installationsresultate und der gesamten technischen Charakteristiken. Die Erfahrung aus dem Projekt soll auch als Referenz für ähnliche mögliche Entwicklungen in anderen einkommensschwachen Ländern dienen.

Resultate

Inzwischen wurden fünf Anlagen inklusive Überwachung in Betrieb genommen. Die Messungen zeigen die Grenzen des lokalen Netzes auf. Häufige Netzausfälle und grosse Spannungs- und Frequenzschwankungen sind ein Herausforderung für die Netzeinspeisung. Nach Anpassung der Wechselrichter-Parameter laufen die Anlagen mit einer hohen Verfügbarkeit und einer Performance Ratio von > 80%. Unter http://www.pvnepal.supsi.ch können drei der fünf Anlagen online abgerufen werden. An der Tribhuvan Universität in Kathmandu wurde ein Seminar zum Thema ‘Netzgekoppelte Solarstromanlagen‘ mit 60 Teilnehmern durchgeführt. Mit der Durchführung des letzten Workshops mit den wichtigsten lokalen Akteuren steht das Projekt kurz vor dem Abschluss.

Schweizer Beitrag im IEA PVPS-Projekt Task 9
Photovoltaic Services for Developing Countries (PVSDC)

Projektart :	Netzwerk	**Technologie :**	Photovoltaik
Land :	Internationales Projekt	**Projektstatus :**	Laufend
Partner :	entec AG, St. Gallen; www.entec.ch, Alex Arter		

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Schweizer 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.

Portrait

Gestützt auf die umfangreichen weltweiten Erfahrungen mit Photovoltaik Anlagen in Entwicklungsländern strebt dieses Netzwerk 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 nicht-technischen Aspekte dieser Anwendungen. Durch den Status eines internationalen Netzwerkprojektes ist die Expertengruppe in permanentem Kontakt mit zahlreichen internationalen Entwicklungsorganisationen.

Dieses Netzwerkprojekt startete 1999 und wird in verschiedene Arbeitsperioden gegliedert. Seit 2010 steht das Thema Photovoltaik und Wasserpumpen im Mittelpunkt und wird von der Schweiz koordiniert. Hauptanliegen ist die Verbreitung der Erkenntnisse aus diesem Netzwerk. Die Arbeitsperiode 2013 setzt den Schwerpunkt auf den Aufbau von neuen Partnerschaften mit regionalen und nationalen Organisationen und mit Finanzdienstleistern, um innovative Geschäftsmodelle und Finanzierungsmechanismen für die Verbreitung von PV-Lösungen zu stärken. Die Aktivitäten bestehen aus entsprechenden Koordinationsaufgaben, der Erarbeitung und Publikation von Studien sowie der Organisation von Workshops und Veranstaltungen.

Resultate

Die wichtigsten Resultate der laufenden Arbeiten 2013 sind die Publikation von 2 neuen Berichten. Der Bericht „Pico Solar PV Systems for Remote Homes “ behandelt PV Kleinstanlagen, häufig für die Beleuchtung (LED) und das Laden von Handys eingesetzt. Der Bericht „Rural Electrification with PV Hybrid Systems“ thematisiert die Erfahrungen mit Hybriden PV Systemen und die weitere Verbesserung dieser Systeme. Die Publikationen zum IEA PVPS Task 9 sind verfügbar unter http://www.iea-pvps.org/index.php?id=3.

Demonstrationsprojekt Solare Elektrofahrzeuge im öffentlichen Verkehr in Clean Air Island, Mumbai

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Indien	**Projektstatus :**	Laufend
Partner :	Ingenieurbüro Muntwyler und Berner Fachhochschule, Technik und Informatik, Burgdorf, www.ti.bfh.ch, Urs Muntwyler		

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Schweizer 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.

Portrait

Die indische Partnerorganisation Clean Air Island (CAI) 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 Demonstrationsprojekts sollen nun zum ersten Mal Elektrofahrzeuge im öffentlichen Verkehr zum Einsatz kommen und gleichzeitig sollen die Batterien der Elektrofahrzeuge mit Solarstrom gespeist werden. Der elektrische Bus (30 Personen) und das elektrische Sammeltaxi (10 Personen) sollen auf einem Rundkurs zwischen zwei Bahnhöfen und dem Geschäftsviertel Nariman Point verkehren und damit einen Teil der tausenden von Pendlern in diesem Gebiet transportieren. Auf dem Dach des Busdepots soll die Photovoltaikanlage installiert werden. Die Fahrzeuge können dort jeweils ihre Batterien mit Hilfe eines Schnelladesystems aufladen oder leere Batterien gegen eine geladene austauschen.

Resultate

Trotz starken Verzögerungen u.a. durch technische Änderungen des Ladekonzepts, Finanzierungsfragen, Partner- und Standortwechsel konnten schrittweise einige wichtige Resultate erzielt werden:

Der Elektro-Bus fährt, das Elektro-Taxi wurde vorgeführt und getestet. Die Fahrzeuge entsprechen den Erwartungen und sind für den vorgesehenen Fahrbereich in Mumbai geeignet. Das Batteriesystem und die Ladevorrichtung sowie die Photovoltaik-Anlage wurden abgeklärt und sind nun bestimmt.

Durch die Projektänderungen ist der Betrieb der PV-Anlage als Ladestation neu auf dem Dach einer Universität (Indian Institute of Technology, Bombay) vorgesehen, der E-Bus und das E-Taxi werden somit auch einen anderen Rundkurs durchführen. Der lokale Busbetreiber wird nach wie vor in das Projekt miteinbezogen, auch andere Transportunternehmen und Industriepartner werden informiert über den Fortschritt dieses Demonstrationsprojekts. Aus kommerziellen Gründen ist der spätere Betrieb in der südlichen Region der Clean Air Island vorgesehen.

Es sind nun noch Detailarbeiten und Verbesserungen im Passagierbereich des Elektro-Taxi auszuführen und die PV-Anlage zu installieren.

Mikro-Unternehmen und Kleinbäuerinnen im ländlichen Indien: Innovation durch nachhaltige Energietechnologien, mit der „Swiss Solar Water Pump“

Projektart :	Pilotprojekt	**Technologie :**	Photovoltaik
Land :	Indien	**Projektstatus :**	Laufend
Partner :	Berner Fachhochschule, Technik und Informatik, Biel, www.bfh.ch, Eva Schüpbach		

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Schweizer Beitrag

Das Labor für Industrieelektronik an der Fachhochschule Bern in Biel hat für die Entwicklung der Wasserpumpe eng mit Fachpersonen der Entwicklungszusammenarbeit wie Caritas und Seecon zusammengearbeitet. Frau Prof. Dr. Eva Schüpbach pflegt im Bereich der globalen Veränderungen die regelmässige Zusammenarbeit mit den indischen Hochschulen.

Portrait

Das Ziel des Pilotprojekts ist die Einführung einer nachhaltigen Energietechnologie in kleinen indischen Landwirtschaftsbetrieben. Für den Anfang beschränkt sich das Projekt auf die Region Karnataka. Die angewandte Technologie « Swiss Solar Water Pump » ist ein einzigartiges, kleines und günstiges Wasserpumpsystem, welches mit Strom aus 80W Photovoltaikanlagen gespeist wird. Diese Technologie wurde von der Berner Fachhochschule entwickelt. Sie ist flexibel und von langer Lebensdauer und kann lokal produziert und gewartet werden. Die Umsetzungsstrategie des Projekts richtet sich an Frauengruppen und Unternehmerinnennetzwerke. Der Wissenstransfer ist in Form von Seminaren und Arbeitsgruppen vorgesehen, woran auch die Hochschulen und Schweizer sowie Indische Unternehmen teilnehmen werden.

Resultate

Das Projekt startete im Februar 2012 mit einem Kick-off-meeting in Bangalore und der Installation der ersten 8 Pumpen. Aufgrund der ersten Resultate wurde beschlossen, am System zwei wichtige Anpassungen vorzunehmen. Einerseits werden neu stärkere Pumpen eingesetzt, andrerseits wurde das System mit zusätzlichen Wassertanks erweitert, damit die Bewässerung unabhängig vom Betrieb der solaren Wasserpumpen auch in der Nacht stattfinden kann. Im Verlauf des Projekts konnten die Zusammenarbeit mit der lokalen Industrie und einer neuen Frauenorganisation verstärkt werden.

Beurteilung 2013

Nach dem Start der dritten REPIC-Phase Anfang 2011 kann kurz vor Abschluss dieser Phase eine erste Beurteilung bezüglich der formulierten Ziele erfolgen.

In der dritten Phase wurden bis jetzt mehr Projekte gefördert als in der gesamten zweiten Phase, nämlich total 41 bis Ende 2013 gegenüber 30 in der zweiten Phase. Das bisher in der dritten REPIC-Phase ausgelöste Projektvolumen ist über 3-mal grösser als die verpflichteten REPIC-Beiträge. Ende 2013 sind gut 80% der für die Projektförderung zur Verfügung stehenden Mittel für konkrete Aktivitäten in Entwicklungs- und Transitionsländern verpflichtet.

Bei den bisher abgeschlossenen Projekten aus der dritten REPIC-Phase ist ersichtlich, dass diese abhängig vom Entwicklungsgrad der verwendeten Energietechnologie insgesamt tiefer in die Umsetzung gehen. Biomasse-Projekte müssen häufig noch weitere Erkenntnisse für eine erfolgreiche, dem Standort angepasste Umsetzung sammeln. Insgesamt haben jedoch Pilotprojekte mit konkreten Anlagen deutlich zugenommen und es wird darauf geachtet, dass weitere Schritte für die Multiplikation eingeleitet werden. Bei Folgeprojekten stellt sich die Finanzierung oft als grösste Schwierigkeit heraus, häufig zeichnet sich eine Finanzierungslücke zwischen Pilotphase und Markteintritt ab. Für die vierte REPIC-Phase wurden bereits Massnahmen für ein verstärktes Coaching der Projekte entwickelt, damit diese Finanzierungslücke in Zukunft besser überbrückt werden kann. Bei einzelnen abgeschlossenen Projekten der dritten REPIC-Phase sind die Folgeaktivitäten und erste Wirkungen sichtbar. Konkrete Aussagen über die langfristigen Wirkungen der Projekte setzen einen längeren Betrieb der Anlagen voraus und können erst später abschliessend beurteilt werden. Ein für die vierte REPIC-Phase weiterentwickeltes systematisches Monitoring wird konkretere Aussagen über die mittelfristige Entwicklung der REPIC-Projekte und deren Wirkung zulassen.

Die REPIC-Plattform ist unter den relevanten Akteuren gut bekannt. Sie ist etabliert und spielt im schweizerischen Kontext eine wichtige Rolle. Entsprechend wird die Plattform aktiv genutzt, was sich unter anderem an den seit 2004 insgesamt bereits 86 geförderten Projekten zeigt.

REPIC war auch im 2013 bei relevanten Tagungen und Workshops im Bereich erneuerbare Energien präsent. Zudem organisierte REPIC eine Fachveranstaltung zum Thema „Erfolgsfaktoren für wirkungsvolle Projekte“ in den Bereichen Erneuerbare Energien und Energieeffizienz in der Entwicklungszusammenarbeit durch [2,3]. Der Anlass mit Plenumsvorträgen, parallelen Workshops und Posterbeiträgen war mit rund 110 Teilnehmern sehr gut besucht.

Die 2013 komplett überarbeitete REPIC-Website (www.repic.ch) erhielt ein neues modernes Erscheinungsbild und bietet neue Funktionalitäten die teilweise bereits umgesetzt worden sind. Verschiedene positive Feedbacks der Website-Nutzer zeigten die breite Akzeptanz des neuen Internetauftritts.

Die Koordination zwischen den beteiligten Bundesämtern verlief wie bis anhin effizient und die Plattform wird rege zum Austausch genutzt. Die Qualität der Projektförderung wird mit dem zweistufigen Verfahren und den gut begründeten Entscheiden gesichert. Doppelspurigkeiten konnten vermieden werden.

Weiteres Verbesserungspotential für die vierte REPIC-Phase (2014 – 2017) wurde unter Einbezug der Erfahrungen und der Rückmeldungen der relevanten Akteure erkannt und aufgenommen.

Ausblick 2014

Für 2014 stehen der Abschluss der dritten und der Start der vierten REPIC-Phase im Vordergrund. Dabei werden die erfolgreichen Aktivitäten weitergeführt und die erkannten Verbesserungspotentiale ausgeschöpft. Für die vierte REPIC-Phase wurde beschlossenen, die Projektierenden intensiver zu begleiten und verstärkte Massnahmen im Bereich Monitoring, Coaching und Kommunikation zu treffen. So erfahren die REPIC-Projekte in Zukunft eine stärkere Abklärung hinsichtlich deren Relevanz, der Effizienz, der Wirksamkeit, der langfristig erzielten Wirkung, sowie in Bezug auf deren Nachhaltigkeit. Entsprechend sollen bedarfsorientierte Coaching-Massnahmen erfolgen, um die Projekte weit möglichst in eine eigenständige Folgephase führen zu können. In der vierten REPIC-Phase werden die Koordinations-, und Vernetzungsaktivitäten 2014 weiter verstärkt. Weiterhin gilt eine hohe Aufmerksamkeit der Netzwerkpflege zu weiteren Finanzierungspartnern und anderen Initiativen in der Entwicklungszusammenarbeit.

Sämtliche Projekte aus den früheren Phasen werden weiter betreut und erhalten nach Möglichkeit dieselbe Begleitung wie Projekte aus der vierten REPIC-Phase.

Für 2014 ist erneut eine Veranstaltung vorgesehen, welche im kleineren Rahmen erfolgreiche Projekte vorstellt, den Austausch mit Finanzinstituten und weiteren Förderinstrumenten ermöglicht und eine gute Gelegenheit bietet für den Erfahrungs- und Informationsaustausch.

Referenzen

[1] REPIC-Leitfaden

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