Schweizerische Eidgenossenschaft
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Bundesamt für Energie BFE

Forschung, April 2007

Programm Photovoltaik Ausgabe 2007

Überblicksbericht, Liste der Projekte
Jahresberichte der Beauftragten 2006

ausgearbeitet durch:
NET Nowak Energie & Technologie AG

Programm Photovoltaik - Ausgabe 2007

Forschung

Titelbild:

Landwirtschaftsbetrieb Béat und Elsbeth Aeberhard, Barberêche FR
110 kWp Photovoltaikanlage realisiert mit PV Indachsystem SOLRIF®

(Bildquelle: NET)

ausgearbeitet durch:
NET Nowak Energie & Technologie AG
Waldweg 8, CH - 1717 St. Ursen (Schweiz)
Tel. +41 (0) 26 494 00 30, Fax. +41 (0) 26 494 00 34, info@netenergy.ch

im Auftrag des:
Bundesamt für Energie BFE
Mühlestrasse 4, CH - 3063 Ittigen Postadresse: CH- 3003 Bern
Tel. 031 322 56 11, Fax. 031 323 25 00 office@bfe.admin.ch www.bfe.admin.ch

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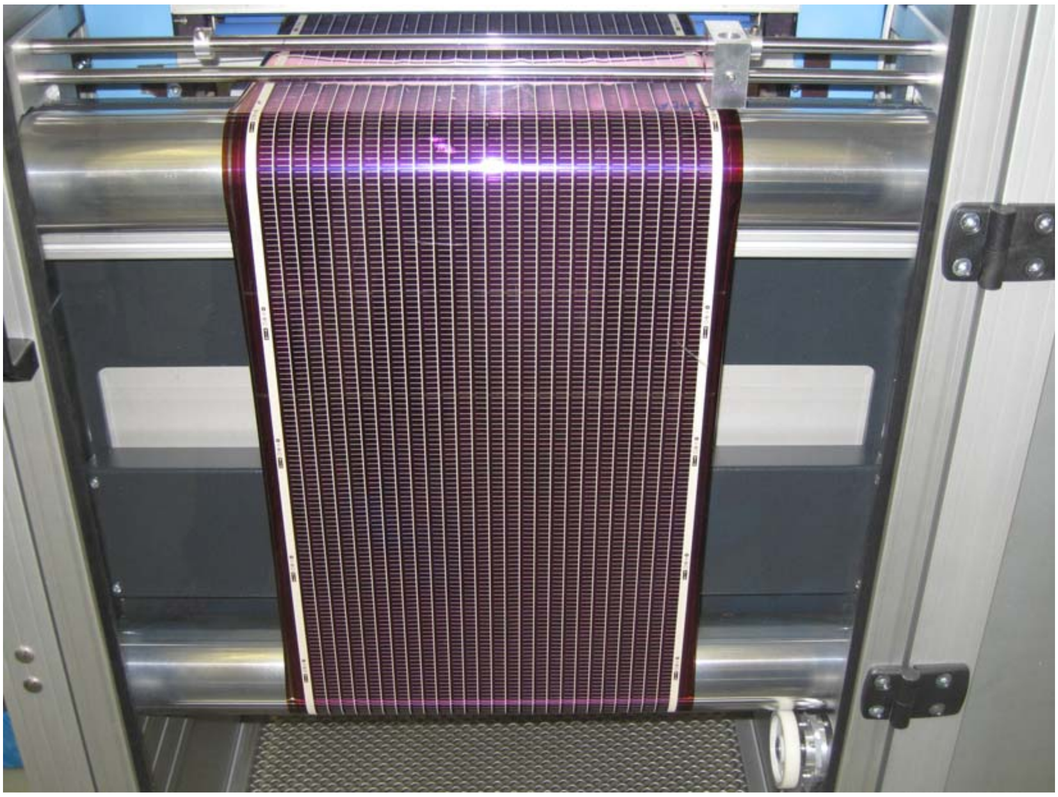
PROGRAMM PHOTOVOLTAIK

Überblicksbericht zum Forschungsprogramm 2006

Stefan Nowak
stefan.nowak@netenergy.ch



Vom Technologie Start-up Unternehmen zur industriellen Investition:

VHF-Technologies, ein Start-up Unternehmen des IMT, Universität Neuenburg, aus dem Jahr 2000 wurde im Verlauf von 2006 als strategische Investition des grössten europäischen Solarzellen Herstellers Q-Cells ausgewählt. In einem ersten Schritt wird eine Pilotfertigung dünner und flexibler Solarzellen von 2 MWp Produktionskapazität aufgebaut (Bildquelle: NET).

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1. Programmschwerpunkte und anvisierte Ziele

Das Programm Photovoltaik stand im Jahr 2006 im Spannungsfeld zwischen neuen und wachsenden Industrieprojekten, weiterhin knappen Mitteln für die Forschung, insbesondere im Bereich der P+D-Projekte, sowie der anhaltenden energiepolitischen Diskussion, bei welcher gerade die Photovoltaik immer wieder im Zentrum stand. Durch die breite Programmabstützung im Bereich der Forschung konnte das Niveau wenigstens hier weitgehend gehalten werden. Das anhaltende Wachstum des internationalen Photovoltaik Marktes bildet eine wichtige Grundlage für den weiterhin erfolgenden, deutlichen Ausbau der Photovoltaik Industriebasis in der Schweiz.

Das Programm Photovoltaik verfolgt eine ausgeprägte Ausrichtung auf die industrielle Umsetzung und die internationale Wettbewerbsfähigkeit, sowohl für Produkte wie auch für die vorgelagerte Forschung. Laufende Aktivitäten in Forschung und Entwicklung sowie noch bestehende Projekte im Bereich von Pilot- und Demonstrationsanlagen umfassen im Berichtsjahr 2006 ca. 50 Projekte, wobei alle bekannten Projekte mit einer Förderung der öffentlichen Hand berücksichtigt sind.

Gestützt auf das Energieforschungskonzept der Eidgenössischen Energieforschungskommission CORE [56] verfolgt das Schweizer Photovoltaik Programm in der Periode 2004 – 2007 die folgenden wesentlichen Ziele [57]:

- Es soll eine weitere Kostenreduktion des Energiesystems Photovoltaik erreicht werden (typische Werte 2007: Modul 2.5 CHF/Wp; System 5 CHF/Wp) und entsprechende Verbesserungen der einzelnen Komponenten in Bezug auf elektrische Eigenschaften (2007: Dünnschichtmodule mit >12% Wirkungsgrad), Herstellungskosten und industrielle Fertigung;
- Etablierung bzw. Konsolidierung der industriellen Basis für Produkte der Photovoltaik, einschliesslich Solarzellen und Module in ausgewählten Technologieansätzen;
- Hohe Integration und Standardisierung der Produkte und Systeme für Massenmärkte.

Dazu ist das Programm Photovoltaik in folgende Bereiche aufgeteilt:

Solarzellen der Zukunft

Die Arbeiten zu **Dünnschicht Solarzellen** waren im Berichtsjahr fokussiert auf die Schwerpunkte **Silizium** (amorph, mikrokristallin), Zellen auf der Basis von **Verbindungshalbleitern** (CIGS) sowie **Farbstoffzellen**. **Neue Konzepte** (Materialien und Prozesse) für langfristige Technologieoptionen gewinnen in der Grundlagenforschung gesamthaft an Bedeutung und bewegen sich gleichzeitig vom Konzept zur Solarzelle. Die mit Nachdruck verfolgte Industrialisierung von Produktionsprozessen steht bei den Silizium Dünnschicht Solarzellen in einem fortgeschrittenen Stadium, bei den Verbindungshalbleitern ist ein industrielles Projekt im Aufbau. Solarzellen auf flexiblen Substraten gewinnen zunehmend an Bedeutung.

Module und Gebäudeintegration

Die **Integration der Photovoltaik** im bebauten Raum bildet weiterhin den wichtigsten Schwerpunkt der angestrebten Anwendungen. Währenddem der Markt für Montagesysteme mittlerweile eine breite Produktpalette anbieten kann, stellen neue Produkte und Erfahrungen mit Dünnschicht Solarzellen in der Gebäudeintegration weiterhin ein wachsendes Thema dar.

Elektrische Systemtechnik

Die **Qualitätssicherung** von Photovoltaikmodulen, von Wechselrichtern und von gesamten Systemen ist, zusammen mit **Langzeitbeobachtungen** an diesen Komponenten, für die Praxis von anhaltender Bedeutung und wird in entsprechenden Kompetenzzentren an Fachhochschulen bearbeitet. Langjährige Messreihen und die vermehrte Analyse von Fehlverhalten der einzelnen Komponenten sollen in Hinsicht auf kritische Parameter und die Erhöhung der Lebensdauer genutzt werden. Aufgrund dieser systembezogenen Arbeiten soll die spezifische Energieproduktion von Photovoltaik-Anlagen (kWh/kWp) weiter erhöht werden. Für **Inselanlagen** wächst die Bedeutung der Kombination mit anderen Energietechnologien in Hybridanlagen.

Ergänzende Projekte und Studien

Die Arbeiten in diesem Bereich sollen die Grundlagen zu allgemeinen Fragestellungen im Zusammenhang mit dem Marktaufbau der Photovoltaik liefern, insbesondere zu **Potenzial**, **Umweltaspekten** und **Energieplanung** sowie praxisorientierten **Hilfsmitteln** zur Anlagenplanung und –überwachung. Neuste Technologien des Internets, Computermodelle, Bildverarbeitung, geografische Informationssysteme bis hin zur Satellitenkommunikation gelangen dabei zum Einsatz. Für Anwendungen in

Entwicklungsländern stehen dagegen nicht-technische Aspekte im Vordergrund. Dieser Bereich des Programms umfasst zudem die Vorhaben an den Schnittstellen zu anderen Energietechnologien.

Institutionelle internationale Zusammenarbeit

Die internationale Zusammenarbeit bildet ein zentrales Standbein in allen Bereichen. Der Anschluss an die internationale Entwicklung sowie ein intensivierter Informationsaustausch war im Berichtsjahr ein wichtiges Ziel, welches im Rahmen der internationalen Programme der **EU** sowie der **IEA** mit Kontinuität weiterverfolgt wurde. Die erfolgreiche internationale Zusammenarbeit konnte in neuen grossen EU-Projekten fortgesetzt werden. Von übergeordneter Bedeutung war im Berichtsjahr zudem die Schweizer Beteiligung an den Arbeiten in europäischen Netzwerken (**PV-ERA-NET** und **Europäische Photovoltaik Technologie Plattform**).

2. Durchgeführte Arbeiten und erreichte Ergebnisse 2006

ZELL-TECHNOLOGIE

Die **grosse Bandbreite der Schweizer Solarzellenforschung** konnte im Berichtsjahr 2006 dank der breiten Abstützung dieser Forschung mit Erfolg fortgesetzt werden. Die Beteiligung an EU-Projekten des 6. Rahmenforschungsprogramms bildete eine wichtige Komponente; im Berichtsjahr konnten hier neue Projekte im Bereich der Dünnschicht Solarzellen begonnen werden. Damit ist die Schweiz nun an den meisten laufenden *Integrierten Projekten* der Europäischen Kommission im Bereich der Photovoltaik direkt oder indirekt beteiligt.

Dünnschicht Silizium

Die Entwicklungen im Bereich des Dünnschicht Siliziums finden an der Universität Neuchâtel (IMT), an der EPFL (CRPP), der Haute Ecole Arc ingénierie (Le Locle), dem NTB (Buchs) sowie bei den Unternehmen *oerlikon* (vormals *Unaxis*, Trübbach und Neuchâtel) und *VHF-Technologies* (Yverdon) statt und stellen einen wichtigen Schwerpunkt des Photovoltaik Programms dar.

Das IMT an der Universität Neuchâtel setze im Berichtsjahr das Projekt zu **Silizium Dünnschicht Solarzellen** [1] fort. Die Ziele dieses BFE-Projektes bestehen darin, den Wirkungsgrad der Solarzellen auf verschiedenen Substraten weiter zu erhöhen (Ziel 14% für mikromorphe Solarzellen), die Prozessführung und Charakterisierung der Solarzellen weiter zu entwickeln und die notwendige Infrastruktur (Prozesse, Herstellung und Charakterisierung) zur Unterstützung der Industriepartner sicherzustellen. Dazu werden verschiedene Depositionssysteme erneuert und automatisiert, die Systeme zur Charakterisierung der Solarzellen standardisiert und ein spezieller Akzent auf die Reproduzierbarkeit der einzelnen Fabrikationsschritte gelegt. Die Zusammenarbeit mit der Industrie erfolgt primär mit den Unternehmen *oerlikon* und *VHF-Technologies*, welche ihrerseits die am IMT entwickelten Prozesse in ihre Produkte implementieren. Folgende Resultate wurden im Berichtsjahr erreicht:

Auf der transparenten Oxydschicht (*Transparent Conductive Oxyde - TCO*) aus ZnO auf Glas konnten p-i-n mikrokristalline (μc-Si:H) Solarzellen mit einem Anfangswirkungsgrad von 9.99% hergestellt werden. Dies stellt für *LPCVD (low pressure chemical vapor deposition)* einen Rekordwert dar. Amorphe p-i-n Solarzellen erreichten ihrerseits den guten Anfangswert von 10.2%, solche aus mikromorphem Silizium 11.8%. Bei den Arbeiten zu Kunststoffsubstraten wurde ein besonderes Augenmerk auf die mikrokristalline Zelle gelegt. Auf dem Kunststoff PEN (Polyethylennaphtalat) wurde mit diesem Material ein Anfangswirkungsgrad von 8.3% erzielt. Für amorphe Zellen auf PET (Polyethylenterephthalat) wurden 7.8% erreicht. Wichtige Grundlagenarbeiten sowie Fortschritte betrafen die TCO-Schichten aus ZnO. In Bezug auf die Analytik wurden verschiedene Messmethoden weiterentwickelt und automatisiert, z.B. für Messungen der Strom-Spannungskennlinie, der spektralen Empfindlichkeit, des Dunkelstroms oder für Infrarotmessungen. Parallel dazu wurde die Laborinfrastruktur durch ein neues, automatisiertes Doppelkammer-Depositionssystem ergänzt (Fig 1).

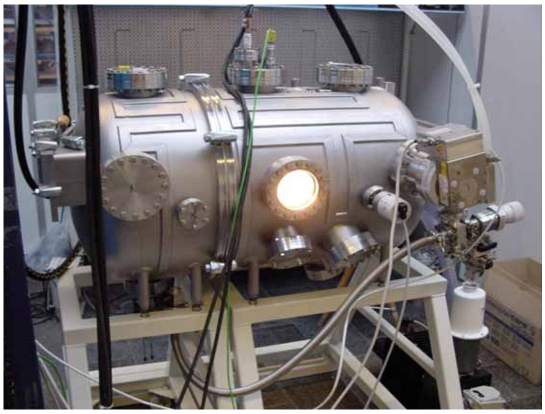
Das KTI-Projekt in Zusammenarbeit mit *oerlikon* für den ***Prozess*** **der schnellen Abscheidung von mikrokristallinem Silizium** [2] auf der Grundlage der KAI Plasmadepositionsanlagen wurde im Berichtsjahr abgeschlossen. Damit wird die Grundlage für den grossflächigen (1.4m²), industriellen Prozess für mikromorphe Solarzellen gelegt. Auf der Versuchsanlage am IMT konnten im Berichtsjahr mikrokristalline Silizium Solarzellen mit 8.4% Wirkungsgrad hergestellt werden; bei *oerlikon* wurden damit mikromorphe Mini-Module (10x10cm^2) mit einem Wirkungsgrad von 9.5% erreicht. Mit den Resultaten dieses Projektes konnte gezeigt werden, dass die ursprünglich für Flachbildschirme konzipierte KAI Depositionsanlage für die industrielle Herstellung von Dünnschicht Solarzellen verwendet werden kann.

Das CRPP an der EPFL hat zusammen mit *oerlikon* das verwandte KTI-Projekt eines neuen, grossflächigen ***VHF-Reaktors* für die Abscheidung von amorphen und mikrokristallinen Siliziumsolarzellen** ebenfalls abgeschlossen [3]. Es werden Plasmaanregungsfrequenzen bis 100 MHz untersucht, was eine schnelle Abscheidung (≥ 4 Å/s) erlaubt, jedoch für die Homogenität der Schichten auf einer Fläche von ≥ 1 m² besondere Herausforderungen darstellt. Das Schlussresultat besteht aus einem Hochfrequenzreaktor, in welchem amorphe und mikrokristalline Siliziumschichten auf einer Fläche von 1m² schnell und mit einer Gleichmässigkeit von 5-10% hergestellt werden können.

Ein weiteres KTI-Projekt zwischen dem IMT und *oerlikon* zur **Stabilität der transparenten Oxydschichten** (TCO) aus ZnO in laminierten Solarzellen [4] wurde im Berichtsjahr abgeschlossen. Die Dampf-Wärme Prüfung der IEC Tests für Solarmodule (IEC 61646: 1000h @ 85°C & 85% rel. Feuchtigkeit) wurde bestanden. Damit konnte gezeigt werden, dass die LPCVD TCO-Schicht unter adäquater Verpackung die Anforderungen an die notwendige, langfristige Zuverlässigkeit erreicht.

Das NTB in Buchs schloss die Arbeiten des KTI-Projektes für ein auf die industrielle Produktion ausgerichtetes, spektral aufgelöstes **Photostrom Messgerät** (*Spectral Response Measurement System SRMS*) [5] zusammen mit *oerlikon* erfolgreich ab. Die Projektziele wurden erreicht, indem auf Solarmodulen vollflächige Messungen mit stabilen Resultaten durchgeführt und entsprechende Bilder dargestellt werden können. Diese verschiedenen KTI-Projekte bilden, zusammen mit den regulären Arbeiten am IMT, die Grundlage für die industrielle Umsetzung in Hinsicht auf Produktionsanlagen für Silizium Dünnschicht Solarzellen durch *oerlikon*.

Figur 1 *Aufbau des Dünnschichtsilizium-Doppelkammer-Depositionssystems auf der Grundlage der KAI-M plasma box von oerlikon (Bildquelle: IMT)*



Figur 2 *Depositionssystem zur Hochskalierung der CIGS Dünnschicht Solarzellen (Bildquelle: ETHZ)*

Das IMT und *VHF-Technologies* arbeiten seit Herbst 2005 im neuen EU-Projekt **FLEXCELLENCE** [6] am Thema der flexiblen Solarzellen auf Kunststoffsubstraten weiter. Zum ersten Mal erfolgt dabei im Bereich der Photovoltaik eine EU-Projektkoordination durch einen Schweizer Partner (IMT). Im ersten Berichtsjahr betrafen die Arbeiten des IMT die Entwicklung von mikrokristallinen Silizium-Schichten hoher Qualität und hohen Depositionsraten auf 30x30 cm^2 grossen Substraten in einem VHF Prozess. Es wurden Depositionsraten von 2nm/s bei guten Schichteigenschaften erzielt. Anhand dieser Resultate soll ein Vergleich mit alternativen Produktionsverfahren erfolgen. Die Arbeiten von *VHF-Technologies* befassen sich mit den erreichbaren Modulkosten bei der industriellen Umsetzung im grösseren Stil. Mit amorphen Silizium Solarzellen von 5% Wirkungsgrad könnten demnach bei 50 MW Produktionskapazität Kosten von unter 0.8 €/Wp erreicht werden.

Das IMT nahm im Berichtsjahr die Arbeiten zum EU-Projekt **ATHLET** [7] auf. Dieses, vom HMI in Berlin koordinierte, über 4 Jahre laufende *Integrierte Projekt* – das europaweit bisher grösste Forschungsprojekt zu diesem Thema – befasst sich mit zwei Technologien im Bereich der Dünnschicht Solarzellen, der mikromorphen Solarzelle und der CIS-Technologie (siehe unten). Das Projekt strebt Modulkosten von 0.5 €/Wp an. Für mikromorphe Tandemzellen lautet das Ziel 10% stabiler Wirkungsgrad bei einer Fläche von 1 m^2 und 10 Å/s Depositionsrate. Das IMT befasste sich im ersten Jahr mit den Arbeiten zu Solarzellen kleiner Fläche sowie der Hochskalierung bis zum KAI 1200 Reaktor (1.4 m^2 Fläche) von *oerlikon*. Dabei erfolgen Zwischenschritte über die Reaktoren KAI-S (35 x 45 cm^2) und KAI-P (45 x 55 cm^2).

Kristallines Silizium

Die EMPA in Thun untersucht im neuen KTI-Projekt **SIWIS** [8] in Zusammenarbeit mit *HCT Shaping Systems* die Mechanismen, welche bei Drahtsägen von dünnen Waferscheiben zu Oberflächendefekten führen können, um daraus entsprechende Modelle zu entwickeln. Übergeordnetes Ziel des Vorhabens ist die Herstellung von Wafern unter 100 µm Dicke für die Produktion von kristallinen Siliziumsolarzellen.

HCT Shaping Systems setzte im Berichtsjahr die Beteiligung am EU-Projekt **BITHINK** [9], in welchem hocheffiziente bifaciale kristalline Solarzellen entwickelt werden (Wirkungsgrad 16+16%), erfolgreich fort. Dabei kommt sowohl Material vom Czochralski-Typ wie mulitkristallines Silizium zum Einsatz. HCT befasst sich im Projekt einerseits mit dem Thema der Herstellung dünner Wafer, wobei als Zielparameter die Anzahl Wafer pro Meter festes Silizium betrachtet wird. 3000 Wafer pro Meter Silizium wurden bisher erreicht, das Ziel ist 3500 – 4000 Wafer/m. In einer bifacialen Solarzelle führt dies, je nach Annahme, zu einem Siliziumbedarf von lediglich 4.3 - 5.9 g/Wp. Andererseits wird die maschinelle Handhabung und weitere Verarbeitung der so hergestellten sehr dünnen Wafer untersucht.

II-VI Verbindungen (CIGS)

Die Gruppe Dünnschichtphysik an der ETHZ hat über viele Jahre EU-Projekte zum Thema Solarzellen auf der Basis von Verbindungshalbleitern (CIGS, CdTe) durchgeführt. Im Berichtsjahr wurde die erste Phase des BFE-Projektes **FLEXCIM** [10] zur Entwicklung von flexiblen CIGS-Solarzellen abgeschlossen. Diese flexiblen, 5x5 cm^2 grossen CIGS-Solarzellen wurden auf Polyimid- und Metallfolien entwickelt. Dabei gelangte die an der ETHZ entwickelte Verwendung von Natrium zum Einsatz, wodurch Wirkungsgrade von 10-12% regelmässig erreicht werden konnten. Der früher auf Polyimid erzielte Weltrekord für den Wirkungsgrad von flexiblen Solarzellen auf Kunststoff von 14.1% stellt noch immer den höchsten erreichten Wert dar. Im Berichtsjahr wurde an der Hochskalierung des Prozesses auf 30x30 cm^2 gearbeitet. Dazu wird ein neues, industriell ausgerichtetes Depositionssystem aufgebaut (Fig. 2). Als Zwischenresultat liegt ein Mini-Modul von 16 cm^2 mit einem Wirkungsrad von 7.9% vor. Als weiteres Substrat für die flexiblen CIGS-Solarzellen wurde Aluminium untersucht; dieses stellt ein neues Gebiet mit grossem Anwendungspotenzial dar. Der Depositionsprozess muss dafür aufgrund der unterschiedlichen Ausdehnungskoeffizienten auf tiefere Temperaturen ausgelegt werden. Die beste Solarzelle auf Aluminium erreichte bisher einen Wirkungsgrad von 6.6%; dabei wurde noch kein Natrium eingesetzt.

Das EU-Projekt **LARCIS** [11] befasst sich mit grossflächigen Prozessen zur industriellen Produktion von CIGS-Solarzellen. Dabei konzentriert sich die Gruppe Dünnschichtphysik an der ETHZ auf die Optimierung der Zellrückkontakte auf der Grundlage von Molybdän sowie alternativer Materialien, insbesondere TiN. Zudem wurden im Berichtsjahr die Arbeiten zum EU-Projekt **ATHLET** [12] aufgenommen (vgl. oben). Die Gruppe Dünnschichtphysik ist in diesem *Integrierten Projekt* an zwei Arbeitspaketen zu CIGS-Solarzellen beteiligt. Im Vordergrund stehen ergänzende Entwicklungsarbeiten für flexible Solarzellen auf Polyimid; dabei werden insbesondere neue Verfahren für Pufferschichten auf der Grundlage von In_2S_3 und die Abscheidung der Solarzellen auf TCO Schichten vertieft untersucht. Weitere Arbeiten befassen sich mit der Hochskalierung auf grössere Flächen und die Entwicklung von Tandemsolarzellen.

Das ETHZ Spin-Off Unternehmen *FLISOM* [58] zur industriellen Umsetzung der flexiblen CIGS-Solarzellen wurde im Berichtsjahr verschiedentlich ausgezeichnet, so z.B. mit dem ZKB-Pionierpreis des Technoparks Zürich oder der Auszeichnung als *Technology Pioneer* des *World Economic Forum* WEF.

Farbstoff und organische Solarzellen

Die Entwicklung von farbstoffsensibilisierten, **nanokristallinen Solarzellen** [13] wurde am ISIC der EPFL fortgesetzt. Im Berichtsjahr standen die Farbstoffsynthese und die Langzeitstabilität der eingesetzten Elektrolyten bei höheren Temperaturen (ca. 80°C) im Vordergrund. Damit wird eine Lebensdauer der Farbstoffzellen von 10 bis 20 Jahren angestrebt. In Langzeitmessungen an den neusten Zellkonzepten während 1000 Stunden bei AM1.5 Strahlung und 80°C konnten 97.7% der Anfangsleistung nachgewiesen werden. Die Laborzellen selbst erreichten einen Anfangswirkungsgrad von 10.1%.

Das ISIC schloss das KTI-Projekt zusammen mit *Greatcell Solar* zur **Erhöhung der Zellenspannung** von Farbstoffzellen [14] ab. Eine wesentliche Rolle spielt dabei der eingesetzte Farbstoff, welcher diesbezüglich weiter entwickelt wurde. Über *Greatcell Solar* besteht zudem eine direkte Verbindung zum australischen Technologieunternehmen *Dyesol* [59], welches im Dezember 2005 eine Produktionsfirma für Farbstoffzellen in Griechenland angekündigt hat.

Das EU-Projekt **MOLYCELL** [15] wurde im Berichtsjahr abgeschlossen. Es befasste sich mit flexiblen organischen Solarzellen, wobei sowohl vollständig organische wie hybride nanokristallin–organische Solarzellen entwickelt wurden. An der EPFL standen letztere im Vordergrund, wobei dazu ein fester Heteroübergang zwischen nanokristallinen Metalloxyden und molekularen bzw. polymeren Löcherleitern gebildet wird. Prototypen mit dem Metalloxyd-organischen Hybridansatz erreichten auf Glassubstraten bei AM1.5 einen Wirkungsgrad von 4.2%. Auf flexiblen Metallfolien wurde auf kleiner Fläche (1 cm^2) ein Wirkungsgrad von 3.6% ermittelt. Für vollständig organische Solarzellen konnte ein Wirkungsgrad von 5.5% bzw. ein zertifizierter Wert von 4.8% nachgewiesen werden. Die Arbeiten werden im neuen EU-Projekt **OrgaPVNET** fortgesetzt.

Solaronix beteiligt sich am EU-Projekt **FULLSPECTRUM** [16], einem *Integrierten Projekt* im Bereich der Photovoltaik, welches unterschiedliche Ansätze zur besseren Nutzung des Strahlungsspektrums in einem Projekt zusammenführt (III-V *multijunctions*, Thermophotovoltaik, *intermediate band cells*, molekulare Konzepte); dabei werden Wirkungsgrade bis zu 40% angestrebt. *Solaronix* ist in diesem Projekt insbesondere mit unterstützenden Arbeiten im Modul zu neuen molekularen Konzepten beteiligt. Dabei geht es um die Rolle von Farbstoffsolarzellen in 2-Photon Prozessen bzw. in flachen Konzentratoren. *Solaronix* befasst sich hier mit den Messungen der Stromspannungskennlinie und der spektralen Empfindlichkeit. Im Berichtsjahr konnte die Funktion des flachen Konzentrators demonstriert und ein Wirkungsgrad von 1.8% ermittelt werden. Nebst dem Wirkungsgrad muss auch die Stabilität der im Konzentrator verwendeten fluoreszierenden Farbstoffe verbessert werden.

Das LTC an der EPFL schloss das KTI-Projekt zusammen mit *Konarka* für **photovoltaisch aktive Textilien** auf der Grundlage der Farbstoffzellen [17] ab. Dabei wurden photovoltaisch aktive Fasern entwickelt, welche einen Anfangswirkungsgrad bis zu 5.5% erreichten. Die photovoltaischen Eigenschaften der Faser unter mechanischer Belastung wurden ermittelt und erste Prototypen von photovoltaischen Textilien hergestellt.

An der EMPA in Dübendorf wird im Labor für funktionale Polymere eine neue Aktivität für **organische Solarzellen** [18] aufgebaut; diese grundlagenorientierten Arbeiten sind Bestandteil des EMPA Forschungsprogramms „Materialien für Energietechnologien“. Die experimentellen Arbeiten befassen sich mit der Nutzung von Cyanin Farbstoffen sowie mit der Nanostrukturierung des Übergangs zwischen Donor- und Akzeptor-Materialien. Dabei wird ein interpenetrierendes Netzwerk dieses Übergangs angestrebt. Diese Arbeiten sollen auch Bestandteil des durch die EMPA koordinierten nationalen CCEM-Projektes **ThinPV** [19] sein, welches anfangs 2007 beginnt.

Antennen-Solarzellen

An der Universität Bern wurde die laufende Phase zu **Antennen-Solarzellen** [20] im Rahmen des Programms Solarchemie und mit Unterstützung des schweizerischen Nationalfonds abgeschlossen. Unter Verwendung von farbstoffbeladenen Zeolith-Kristallen wurde eine neue Variante farbstoffsensibilisierter Solarzellen angestrebt. Im Vordergrund dieser Grundlagenarbeiten stand die Organisation der Kristalle an der Grenzschicht zu einem Halbleitermaterial im Hinblick auf die elektronische Energieübertragung. Im Berichtsjahr konnten erstmals Antennensysteme aufgebaut werden, welche auf makroskopischer Ebene unidirektionalen Transport von elektronischer Anregungsenergie bewerkstelligen. Bei den farbstoffbeladenen Zeolith-Kristallen konnte die starke Lichtstreuung im sichtbaren Bereich durch Einbau in eine Polymermatrix reduziert werden. Dies kann auch für Fluoreszenz-Konzentratoren verwendet werden. Ein weiterer Bereich betrifft die Kombination von Antennensystem-Materialien mit organischen Solarzellen, wodurch eine bessere Lichtabsorption und damit ein besserer Wirkungsgrad möglich werden.

SOLARMODULE UND GEBÄUDEINTEGRATION

Gebäudeintegrierte Anlagen stellen nach wie vor das wichtigste Anwendungsgebiet der Photovoltaik in der Schweiz dar. Dabei muss aber präzisiert werden, was unter *gebäudeintegrierter* Anlage zu verstehen (angebaute Anlagen oder echte Integration) ist. Während in Solarstrombörsen häufig die kostengünstigsten Lösungen für Flachdachanwendungen zum Einsatz gelangen, wird weiterhin an der Kostenreduktion von Lösungen mit einem stärkeren Integrationsaspekt gearbeitet. Da inzwischen für die Montage am Gebäude eine Reihe von Systemen erfolgreich umgesetzt werden konnten (siehe auch Abschnitt P+D), verlagert sich die Entwicklung vermehrt auf das Solarmodul selbst.

Swiss Solar Systems (3S) schloss das BFE-Projekt zur Verwendung von geätztem **Antireflexglas** (AR) [21] zur Leistungssteigerung von kristallinen Solarmodulen ab. Die Messungen an den mit diesem Glas hergestellten Solarmodulen zeigten in beiden Fällen eine systematische Leistungssteigerung von ca. 2%, die erwarteten 3% konnten somit nicht ganz bestätigt werden. Freiluftmessungen bei verschiedenen Einstrahlungswinkeln zeigen, dass die AR-Module den Grenzbereich mit flachen Einstrahlungswinkeln noch etwas besser ausnützen können, wobei dieser Effekt nicht abschliessend quantifiziert werden konnte. Seit Projektbeginn hat sich die Verwendung von geätzten oder beschichteten Antireflexgläsern in der Industrie vermehrt durchgesetzt. Im EU-Projekt **BIPV-CIS** [22] sollen die Eigenschaften der Photovoltaik-Gebäudeintegration mit Dünnschicht Solarzellen verbessert werden. Auf der Grundlage von CIS-Zellen werden Dach-, Überkopfglas- und Fassadenelemente entwickelt. Für *3S* steht die Entwicklung des Dachelementes im Vordergrund. Durch den boomenden Photovoltaikmarkt sind einige der Industriepartner in diesem Projekt stark ausgelastet, sodass das Projekt Verzögerungen erlitten hat. Neue Produktentwicklungen haben es unter diesen Verhältnissen nicht so leicht.

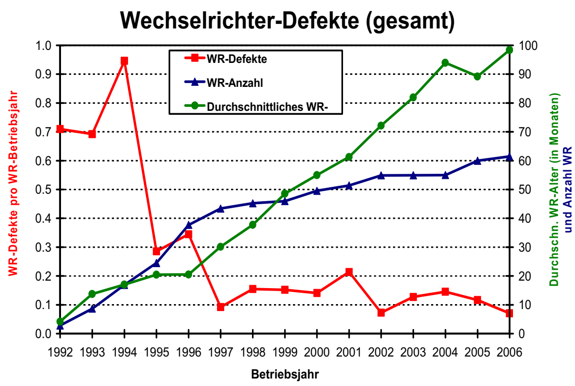
Vereinzelte neue Konzepte und Produkte zur Photovoltaik-Gebäudeintegration wurden im Rahmen von P+D-Projekten erprobt (siehe unten).

ELEKTRISCHE SYSTEMTECHNIK

Das **Schwergewicht in der Systemtechnik** liegt generell auf der Qualitätssicherung von Komponenten (Module, Wechselrichter), Systemen (Auslegung, Energieertrag) und Anlagen (Langzeitbeobachtungen). Die Erkenntnisse aus diesen anwendungsnahen Fragen sind – besonders in einem rasch wachsenden Markt – für Sicherheit, Zuverlässigkeit und Energieertrag künftiger Anlagen wie auch für die Standardisierung der Produkte von grosser Bedeutung.

Das frühere Labor LEEE-TISO an der SUPSI wurde im Berichtsjahr zum Institut ISAAC (Istituto di Sostenibilità Applicata all'Ambiente Costruito) befördert. Es hat im Berichtsjahr seine Testmessungen an Solarmodulen im Projekt **Centrale LEEE-TISO 2003-2006** [23] fortgesetzt. Das gemäss ISO 17025 für Messungen zertifizierte Labor mit dem Sonnen-Simulator der Klasse A erhielt im Juni 2006 die erneute offizielle Akkreditierung. Im Berichtsjahr wurden mehr als 4900 I-V Kennlinien (Blitztests) gemessen, was einer Steigerung von 88% gegenüber dem Vorjahr entspricht. Zudem fanden die jährlichen Vergleichsmessungen mit anderen zertifizierten Labors in Europa (ESTI-JRC und ECN) statt. Zur präziseren Messung von Dünnschichtmodulen wird eine gefilterte Referenzzelle verwendet, sowie die im Vorjahr eingeführte Korrektur für die spektrale Abweichung. Der im Vorjahr im Labor entwickelte MPPT (*Maximum Power Point Tracker,* Fig.3) wurde an der Fachhochschule Burgdorf geprüft. Der statische Wirkungsgrad wurde dabei mit 99.75% bis 99.99% bestimmt, der dynamische beträgt 98.4%. Im Berichtsjahr wurden 28 Einheiten des neuen MPPT gebaut und am ISAAC installiert, sowie weitere 5 an der Universität von Lecce.

Figur 3 *Maximum Power Point Tracker am ISAAC (Bildquelle: NET)*



Figur 4 *Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr (Bildquelle: FH Burgdorf)*

Bei den Aussenmessungen wurde im Berichtsjahr der 10. Testzyklus an 14 kommerziellen Modulen fortgesetzt (7 mc-Si, 3 sc-Si, 1 HIT, 2 a-Si, 1 CdTe). Bei den kristallinen Modulen kann über die Jahre eine stetige Verbesserung der Übereinstimmung zwischen gemessener und deklarierter Leistung beobachtet werden. Die Dünnschichtmodule schneiden diesbezüglich noch besser ab. Das ISAAC hat im Berichtsjahr Arbeiten zur gebäudeintegrierten Photovoltaik aufgenommen. Zum einen wurde eine Marktübersicht erstellt und die Problemebereiche für die Architekten analysiert. Zum anderen fanden Messungen der thermischen Leitfähigkeit von Solarmodulen und der Dämpfung nichtionisierender Strahlung (Elektrosmog) durch solche statt. Bei letzterem zeigten vor allem Dünnschichtmodule günstige Eigenschaften.

Das ISAAC ist Partner im EU-Projekt **PV Enlargement** [24], welches ein europaweites Demonstrationsprojekt in 10 Ländern (5 davon in Osteuropa) mit 27 Anlagen von insgesamt 1.2 MWp Leistung darstellt. Ende 2006 waren davon insgesamt 25 Anlagen in Betrieb. Die wissenschaftlichen Arbeiten sind nahezu abgeschlossen. Am ISAAC wurden 151 Module mit 23 Modultypen (c-Si, a-Si, CIS, CdTe) aus Europa bezüglich der Anfangsleistung charakterisiert, 54 davon wurden nach 1-2 Jahren einer weiteren Messung unterzogen. Trotz besserer Übereinstimmung mit den deklarierten Werten besteht noch Verbesserungsbedarf zur Verwendung und Einhaltung der EU-Norm EN50380.

Das ISAAC nahm im Berichtsjahr die Arbeiten am neuen EU-Projekt **PERFORMANCE** (*A science base on PV performance for increased market transparency and customer confidence*) auf [25]. Dieses, vom Fraunhofer Institut für Solare Energiesysteme in Freiburg koordinierte, 4-jährige *Integrierte Projekt* befasst sich mit allen pränormativen Arbeiten von Solarzellen bis hin zu Systemen und von Momentanmessungen bis zu Langzeitanalysen. Das ISAAC ist an den Untersuchungen zu Performanz und Energieproduktion von Photovoltaik Modulen sowie der Modellierung beteiligt

Wirkungsgrad und Jahresenergieproduktion von Photovoltaik Modulen sind auch Bestandteil eines Projektes am PSI [26]. Aufgrund der Messungen an verschiedenen kommerziellen Modulen bei unterschiedlichen Betriebsbedingungen wird ein semi-empirisches Modell für den Wirkungsgrad parametrisiert. Daraus können Aussagen bei verschiedenen klimatischen Bedingungen gewonnen werden.

Am Photovoltaiklabor an der FH Burgdorf wurde das Projekt **Photovoltaik-Systemtechnik PVSYSTE** [27] fortgesetzt. Im Berichtsjahr konnte das neuentwickelte MPPT-Interface mit integrierter Kennlinienmessung in den Wechselrichter-Messplatz eingebunden werden. Damit steht nun eine effiziente Wechselrichter-Test-Infrastruktur zur Verfügung, mit der sich in einem Arbeitsgang Solargenerator-Kennlinie, DC-AC-Umwandlungswirkungsgrad, MPPT-Wirkungsgrad, totaler Wirkungsgrad und Stromoberwellen bestimmen lassen. Die Testbedingungen für den dynamischen MPPT-Test wurden etwas gelockert. Die 2005 entwickelte FI-Überwachungs-Prüfschaltung wurde an die neue Norm DIN VDE 0126-1-1 angepasst. Nach den in Solarmodulen von BP-Solar im letzten Jahr aufgetretenen Lichtbögen ist sich die Photovoltaik Branche der Gefahr durch DC-seitige Lichtbögen wieder vermehrt bewusst geworden. Deshalb wurden die 1993 – 1998 im Rahmen mehrerer Projekte (mit Alpha Real AG) entwickelten Lichtbogendetektoren wieder reaktiviert, einige neue Ideen entwickelt und ein Patentantrag eingereicht. Die Langzeitmessungen an diversen Photovoltaik Anlagen wurden fortgesetzt, insbesondere auch an der Anlage „Stade de Suisse“ Wankdorf. Ebenso wurde die langjährige Wechselrichterstatistik weitergeführt (Fig. 4).

Enecolo klärt im Projekt **SIMIBU** basierend auf bisherigen Erfahrungen die Machbarkeit eines Wechselrichters mit integriertem Backup ab [28]. Mit diesem Ansatz sollen für dezentrale Photovoltaik Anlagen Synergien und Mehrwerte geschaffen werden. Im Vordergrund stehen derzeit die technische Machbarkeit, die Marktanalyse, die Spezifikationen und die wirtschaftlichen Rahmenbedingungen.

ERGÄNZENDE PROJEKTE UND STUDIEN

ESU-Services hat im Berichtsjahr mit einem **Update Photovoltaik Ecoinvent Data V2.0** begonnen [29]. Aufgrund von Lebenszyklusinventaren aktueller Photovoltaikprodukte werden neue Lebenszyklusanalysen (*Life Cycle Analysis – LCA*) erstellt. Damit wird das Ziel verfolgt, in der Ecoinvent Datenbank [60] möglichst aktuelle Umweltanalysen der Photovoltaikindustrie zu publizieren. Neben der Aufdatierung von mono- und multikristallinen Solarmodulen werden auch erstmals Daten für die Herstellung und den Betrieb von Dünnschichtmodulen (CIS und CdTe) erhoben. Das Projekt erfolgt in Zusammenarbeit mit der Europäischen Photovoltaik Industrievereinigung EPIA.

Enecolo ist am Projekt **ENVISOLAR** der Europäischen Weltraumagentur ESA beteiligt [30]. Das Projekt hat die vermehrte Nutzung satellitengestützter Solarstrahlungsdaten in der Solarindustrie zum Ziel. Mit den im Projekt entwickelten Dienstleistungen sollen Standortanalysen und -entscheide vereinfacht, das automatische Anlagenmonitoring unterstützt sowie Vorhersagen der Energieproduktion von Solaranlagen ermöglicht werden. In der Schweiz besteht ein enger Bezug zum online Photovoltaik monitoring Dienst SPYCE [61], welchen *Enecolo* zusammen mit *Meteotest* betreiben.

Mit Unterstützung der interdepartementalen Plattform (SECO, DEZA, BAFU, BFE) zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit *REPIC* [62] hat das CUEPE an der Universität Genf ein Modul für die Photovoltaiksoftware *PVSYST* [63] erarbeitet, welches **Photovoltaik Wasserpumpen** [31] simuliert. Das Programm ist in der Lage, sehr unterschiedliche Pumpentypen und Systemkonfigurationen zu simulieren. Das Projekt wurde im Berichtsjahr erfolgreich abgeschlossen.

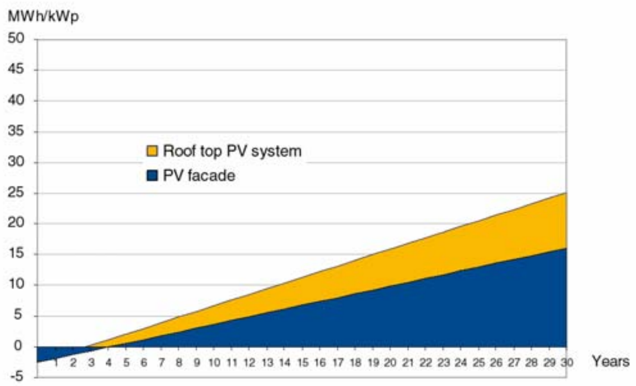
Das PSI beteiligt sich im Rahmen des *Integrierten* EU-Projektes **FULLSPECTRUM** [32] an den internationalen Arbeiten zum Thema der Thermophotovoltaik (TPV). Gestützt auf frühere Projekte bearbeitet das PSI in diesem Projekt im Modul zur Thermophotovoltaik systemtechnische Aspekte in einem gasbetriebenen Testsystem. Der experimentelle Aufbau in einem Prototypen umfasst IR-Filter, Emitter, Zellenverschaltung und –kühlung sowie die entsprechende Messdatenerfassung. Seitens des PSI gelangen dazu Silizium Solarzellen zum Einsatz während bei anderen Instituten GaSb Solarzellen weiterentwickelt werden.

In einer Machbarkeitsstudie klärt das LESO der EPFL das Potenzial von **Quantum Dot Konzentratoren** für die Photovoltaik ab [33]. Es wird untersucht, ob mit dieser neuartigen Methode grossflächige (lateral wirkende) Konzentratoren auf Gläsern realisierbar sind und welche elektrische Leistung damit möglich ist.

Das symbolträchtige Projekt **SOLARIMPULSE** [34] von Bertrand Piccard und verschiedenen Partnern wurde im Berichtsjahr fortgesetzt. Das Ziel dieses Projekts ist die Weltumrundung mit einem photovoltaisch betriebenen Flugzeug.

Ein weiteres Projekt dieser visionären Art ist das Projekt **PlanetSolar** [35], welches von einer Westschweizer Gruppe um den Initianten Raphaël Domjan entwickelt wird. PlanetSolar soll ein solarbetriebenes Boot werden, welches die Erde auf dem Wasser umrunden wird. Die Konzeptstudie (Fig. 5) sieht einen Trimaran von 30m Länge und 16m Breite vor, der Antrieb wird durch eine 180 m^2, rund 30 kWp grosse Solaranlage bewerkstelligt. Das Boot soll eine mittlere Reisegeschwindigkeit von 10 Knoten erreichen. Als Besatzung sind 2 Personen vorgesehen. Auch in diesem Projekt sind grosse technische Herausforderungen zu überwinden, insbesondere was die Statik des Bootes bei Wellengang anbetrifft.

Figur 5 *Konzeptstudie des Solarbootes PlanetSolar (Bildquelle: PlanetSolar)*



Figur 6 Energie-Rücklaufzeit: *Gerechnete kumulierte Energieproduktion einer Photovoltaik Anlage in Bern (Bildquelle: IEA PVPS Task 10)*

INTERNATIONALE ZUSAMMENARBEIT IEA, IEC, PVGAP

Die Beteiligung am Photovoltaikprogramm der IEA (IEA PVPS) wurde im Berichtsjahr mit Kontinuität fortgesetzt, sowohl auf der Projektebene wie im *Executive Committee (ExCo)* [64]. Die Schweiz hält weiterhin den Vorsitz dieses weltweiten Programms inne. Für die Beteiligung an ausgewählten Projekten im Rahmen des IEA PVPS Programms konnte der im Vorjahr geschaffene Schweizer IEA PVPS Pool fortgesetzt werden. Dieser Pool wird derzeit getragen durch das Elektrizitätswerk der Stadt Zürich (ewz), die Kantone Basel Stadt und Genf, die *Gesellschaft Mont-Soleil*, sowie durch den Fachverband SWISSOLAR. Mit diesem Ansatz wird ein stärkerer Einbezug verschiedener Zielgruppen in die Arbeiten im Rahmen von IEA PVPS sichergestellt.

Nova Energie vertritt die Schweiz in Task 1 von IEA PVPS, welcher allgemeine **Informationsaktivitäten** [36] zur Aufgabe hat. Im Berichtsjahr wurde ein weiterer nationaler Bericht über die Photovoltaik in der Schweiz bis 2005 [65] ausgearbeitet; auf dieser Grundlage wurde die 11. Ausgabe des jährlichen internationalen Berichtes („*Trends Report*“) über die Marktentwicklung der Photovoltaik in den IEA-Ländern erstellt [66]. Dieser Bericht wurde erneut für aktuelle Analysen der Photovoltaik durch den Finanzsektor verwendet [67,68]. Im Berichtsjahr wurden mehrere Workshops organisiert: An der 21. Europäischen Photovoltaik-Konferenz in Dresden fand ein Workshop über den *Trends Report* statt, in welchem wichtige Zielgruppen über die Datenbeschaffung und Interpretation informiert wurden. Ein weiterer Workshop richtete sich an den Finanzsektor [69]; er wurde durch die Schweiz und Japan organisiert und fand im November 2006 in Zürich statt. Der *IEA PVPS-Newsletter* [70] informiert regelmässig über die Arbeiten in und rund um das IEA PVPS Programm.

In IEA PVPS Task 2 über **Betriebserfahrungen** [37] stellt *TNC* den Schweizer Beitrag. Die PVPS-Datenbank *Performance Database* wurde mit neuen Daten ergänzt und umfasst nun 460 Photovoltaik-Anlagen aus 22 Ländern mit insgesamt rund 1600 Betriebsjahren und 13.4 MWp Anlagenleistung. Die Datenbank ist neu auch online verfügbar [71]. Aus der Schweiz sind 66 Anlagen mit einer totalen Leistung von 2.95 MWp in der Datenbank enthalten. Im Teilprojekt *Photovoltaic System Cost over Time* wurde eine breit abgestützte Informations- und Datenbasis für die Entwicklung der PV-Systempreise und Unterhaltskosten geschaffen. Dazu wurden die verfügbaren Projekt- und Betriebsdaten für einen *Global Survey* erhoben. Diese Datenerfassung wurde im November 2006 abgeschlossen; sie enthält Daten von 680 Anlagen aus 19 Ländern.

Im Rahmen der interdepartementalen Plattform (SECO, DEZA, BAFU, BFE) zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit *REPIC* [62] leistet *entec* den Schweizer Beitrag zu IEA PVPS Task 9 über die **Photovoltaik-Entwicklungszusammenarbeit** [38]. Die Schweiz ist in diesem Projekt für die Koordination der Arbeiten mit multilateralen und bilateralen Organisationen verantwortlich. Im Berichtsjahr wurden im Rahmen dieses Projektes Treffen in Canada und Japan abgehalten. Beobachtungen zeigen, dass die weltweit massiv gestiegene Förderung erneuerbarer Energien der Option Photovoltaik in der ländlichen Elektrifizierung nicht unbedingt zu Gute kommt, da die wirtschaftliche Ertragslage schwierig bleibt. Das Projekt befasst sich deshalb besonders mit dieser sich abzuzeichnenden Marginalisierung der Photovoltaik.

Planair vertritt die Schweiz neu im IEA PVPS Task 10 zur **Photovoltaik im urbanen Raum** [39]. Aus Schweizer Sicht stehen städtebauliche Fragen und solche des elektrischen Netzes im Vordergrund. Durch den Einbezug der Stadt Neuenburg in den Schweizer Beitrag sollen die anstehenden Fragen konkret aus dieser Perspektive angegangen werden. Task 10 hat im Berichtsjahr im Weiteren eine Informationsbroschüre zu wesentlichen Umweltparametern der Photovoltaik publiziert [72]; die Umweltparameter Energierücklaufzeit und die mögliche CO_2-Minderung wurden für Städte in OECD Ländern einzeln gerechnet (Fig. 6).

Meteotest [40] und das CUEPE an der Universität Genf [41] erbringen zusammen den Schweizer Beitrag zum Task 36 **Solar Resource Knowledge Management** des IEA SHC Programms. Dieses Projekt sieht vor, die verschiedenen Methoden und Datengrundlagen von Solardaten global aufzuarbeiten und verfügbar zu machen. Task 36 ist organisatorisch Bestandteil des IEA SHC Programms, inhaltlich ist es jedoch für alle Solartechnologien relevant; dementsprechend erfolgt eine Zusammenarbeit mit den weiteren IEA Programmen zur Solarenergie (IEA PVPS und IEA PACES). Im Projekt wird die Qualität verschiedener Strahlungsmodelle und daraus abgeleiteter Produkte verglichen und optimiert.

Alpha Real vertritt im Namen des Fachverbandes SWISSOLAR die Schweiz im TC 82 der IEC und leitet die Arbeitsgruppe, welche internationale **Normenvorschläge** [42] für Photovoltaiksysteme vorbereitet und verabschiedet. Im Berichtsjahr befassten sich die Arbeiten insbesondere mit neuen Dokumenten zur verwendeten Terminologie, den minimalen Anforderungen für die Systemdokumentation, den Sicherheitsbestimmungen für Anlagen auf Gebäuden sowie der Bestimmung der Anlagenperformanz. Ein wichtiges Thema sind weiter Sicherheitsbestimmungen für Wechselrichter, für welche auch Schweizer Hersteller in die Arbeit mit einbezogen wurden. Elektrische Kontakte in Photovoltaiksystemen (z.B. Lötstellen oder Steckverbindungen), erhielten durch die bei Modulen von BP-Solar aufgetretenen Probleme in den Anschlussdosen im Berichtsjahr eine hohe Aktualität. *Alpha Real* beteiligt sich ausserdem an *PVGAP* (PV Global Approval Program), einem weltweiten Programm zur Qualitätssicherung und Zertifizierung von Photovoltaik-Systemen. Es ist vorgesehen, PVGAP in die IECEE [73] überzuführen.

Die Beteiligung am EU-Projekt **PV-ERA-NET** [43], welches Programmkoordinationsstellen und verantwortliche Ministerien aus 13 Ländern unter dem ERA-NET Schema [74] zusammenführt, wurde durch die Photovoltaik Programmleitung (BFE, *NET Nowak Energie & Technologie*) sichergestellt. Die Schweiz leitet in diesem Projekt das erste Arbeitspaket zum Informationsaustausch über Europäische Photovoltaik Programme. Im Berichtsjahr wurden, nebst dem kontinuierlichen Informationsaustausch, die konkreten Forschungsthemen und Modelle der Zusammenarbeit zwischen verschiedenen nationalen Programme ausgearbeitet. Ein bedeutendes Thema bildete zudem die in der Europäischen Photovoltaik Technologie Plattform erarbeitete *Strategic Research Agenda* (SRA) [75], welche als wichtiges europäisches Referenzdokument betrachtet wird. Von Bedeutung ist dieses Dokument einerseits aufgrund seiner umfassenden Beschreibung der kurz-, mittel- und langfristigen Forschungsthemen in der Photovoltaik, der zeitlichen Entwicklung von Technologie und Wirtschaftlichkeit sowie in Bezug auf die Beziehungen zwischen privater und öffentlicher (nationaler und EU) Forschung.

3. Nationale Zusammenarbeit

Im Berichtsjahr wurde die vielfältige nationale Zusammenarbeit anlässlich von verschiedenen Projekten weiter gepflegt; daran beteiligt waren Hochschulen, Fachhochschulen, Forschungsinstitute und die Privatwirtschaft. Die Zusammenarbeit mit Industrieunternehmen konnte deutlich intensiviert werden und das Interesse an der Photovoltaik hält auch bei einem gedämpften Schweizer Markt an.

Auf Programmebene wurde die Zusammenarbeit mit vielen Stellen des Bundes, der Kantone und der Elektrizitätswirtschaft weiter gepflegt. Besonders hervorzuheben sind dazu der stete Austausch mit dem Staatssekretariat für Bildung und Forschung SBF, der KTI, dem BAFU, der DEZA und dem SECO sowie aus der Elektrizitätswirtschaft dem VSE, der *swisselectric* und der *Gesellschaft Mont-Soleil*. Diese vielfältigen Kontakte erlauben die anhaltend wichtige breite Abstützung des Programms.

4. Internationale Zusammenarbeit

Die traditionsreiche internationale Zusammenarbeit wurde auch im Berichtsjahr fortgesetzt: Die institutionelle Zusammenarbeit innerhalb der IEA, der IEC, PVGAP und den Europäischen Netzwerkprojekten wurde bereits beschrieben. Auf der Projektebene konnte die erfolgreiche Zusammenarbeit innerhalb der EU in bestehenden und neuen Projekten fortgesetzt werden. Im Jahr 2006 waren es 10 Projekte im 5. bzw. 6. Rahmenforschungsprogramm der EU, wovon 3 dieser Projekte *Integrierte Projekte* (FULLSPECTRUM, PV-ATHLET, PERFORMANCE) sind. Ein weiteres Projekt fand mit der ESA statt. Es findet ein regelmässiger Kontakt mit Programmverantwortlichen in EU-Ländern statt, ebenso mit den zuständigen Einheiten bei der Europäischen Kommission.

Die Schweiz ist in der Europäischen Photovoltaik Technologie Plattform [75] sowohl im Steuerungsausschuss wie in einzelnen Arbeitsgruppen vertreten. Technologie Plattformen sind ein neues Instrument, welches für ausgewählte Technologien eine breitere Trägerschaft und eine gemeinsame Strategie der beteiligten Akteure ermöglichen soll, indem typischerweise Forschungskreise, Industrie, der Finanzsektor und staatliche Stellen in einer gemeinsam getragenen Plattform eingebunden sind und die notwendigen F&E Anstrengungen sowie die Massnahmen zur Umsetzung koordiniert angehen. Von besonderer Bedeutung ist dabei einerseits die starke Einbindung der Industrie, welche im Rahmen der Technologie-Plattformen eine tragende Rolle spielt. Im Berichtsjahr wurde die *Strategic Research Agenda* (SRA) weitgehend fertiggestellt.

Weitere Kontakte wurden mit internationalen Stellen mit Bedeutung für die Entwicklungszusammenarbeit gepflegt (Weltbank, GEF, IFC, UNDP, UNEP, GTZ, KfW, REEEP u.a.). Die Schweizer Photovoltaik ist angesichts dieser zahlreichen Wechselwirkungen international weiterhin sehr präsent.

5. Pilot- und Demonstrationsprojekte (P+D)

Erstmals seit 2003 konnten im Berichtsjahr zwei neue P+D Projekte begonnen werden. Das eine befasst sich thematisch mit der optimalen Integration einer Photovoltaik Anlage ins Energiekonzept eines Nullenergieschulhauses in Kreuzlingen, das andere mit der Integration von Photovoltaik Dünnschichtelementen ins Dach einer Turnhalle. Trotz dieser beiden neuen Projekte ist das P+D Programm inzwischen auf wenige Projekte geschrumpft, die sich fast alle in der Abschlussphase befinden. Diese Entwicklung ist sehr zu bedauern, weil damit ein wesentliches Glied in der Umsetzung von Forschung und Entwicklung hin zu industriellen Produkten und Verfahren, und damit zum Markt stark geschwächt wird. Damit bleibt die Wirkung dieses Programmteils weiterhin eingeschränkt, und Schweizer Firmen haben es in Kombination mit dem seit Jahren stagnierenden einheimischen Markt zunehmend schwerer, neue und innovative Produkte für den Photovoltaik Anwendungsbereich auf den Markt zu bringen. Internationale Konferenzen zeigen deutlich, dass sich Schweizer Firmen im Bereich der Produktionsausrüstung und teilweise im Wechselrichterbereich gut halten und steigende Umsätze erzielen. Im Bereich der Produktinnovation bei der Umsetzung im Anlagensektor kommen die Neuerungen aber meist aus Deutschland, Japan oder den USA. Immerhin haben einige erfolgreiche Schweizer Projekte der letzten Jahre immer noch eine Wirkung im deutschen Raum.

Der weltweite Photovoltaikmarkt boomt aufgrund grossangelegter Förderprogramme bzw. Einspeisevergütungen in immer mehr Ländern weiterhin mit jährlichen Wachstumsraten von rund 35 %. 2006 erreichte die weltweite Modulproduktion gegen 2300 MWp. Damit sind zur Zeit grundsätzlich gute Exportmöglichkeiten für innovative Produkte vorhanden, die von einigen Schweizer Firmen auch erfolgreich wahrgenommen werden.

Die noch verbleibenden Photovoltaik P+D Projekte behandelten schwerpunktmässig weiterhin die Thematik der **Photovoltaik Gebäudeintegration**.

NEUE P+D PROJEKTE

- Dachanlage Turnhalle Wiesendangen mit amorphen Dünnschichtmodulen (Einsatz von BIOSOL XXL Dachelementen, bestehend aus UNI-Solar Dünnschichtmodulen kombiniert mit Solrif Rahmen; Leitung: *Enecolo*) [44]
- Photovoltaikanlage Nullenergieschulhaus Ekkharthof Kreuzlingen (Einbindung einer PV Anlagen ins Energiekonzept eines Nullenergieschulhauses; Leitung: *Böhni Energie und Umwelt*) [45]

LAUFENDE P+D PROJEKTE

Bei dem laufenden Projekten belegt das Projekt 'PV Fassadensystem für Module mit Dünnschichtzellen' die optischen Qualitäten dieses Fassadentyps. Die Fläche erscheint optisch als eine Einheit, wie man sich das von dunklen Glasfassaden gewohnt ist [46] (Fig. 7)

Die laufenden Projekte umfassen (in chronologischer Reihenfolge):

Komponentenentwicklung

- Neues PV Fassadensystem für Module mit Dünnschichtzellen (Entwicklung eines universellen Fassadensystems wahlweise mit oder ohne thermischer Isolation für Dünnschichtmodule; Leitung: *Zagsolar / Wyss Aluhit)* [46] (Fig. 7)

Anlagen

- 17.6 kWp Flachdachanlage mit Dünnschichtmodulen ETHZ (Optisch diskrete Flachdachanlage mit amorphen Zellen; Leitung: *BE Netz*) [47] (Fig. 8)
- Kleine, autonome Stromversorgungen mit Photovoltaik und Brennstoffzellen (PV Insel Kleinsysteme mit Brennstoffzellen als Backup Stromlieferant zur autonomen Versorgung von netzentfernten Messsystemen im Pilotbetrieb; Leitung: *Muntwyler Energietechnik*) [48]
- 12 kWp Solight Pilotanlage (Pilotmässige Umsetzung von zwei verschiedenen Solight Varianten; Leitung: *Energiebüro*) [49]

Messkampagnen

- Messkampagne Wittigkofen (Detaillierte Messungen und Auswertungen mit Visualisierung der Daten zur 80 kWp Fassade Wittigkofen; Leitung: *Ingenieurbüro Hostettler*) [50]

Studien - Hilfsmittel - diverse Projekte

- Photovoltaikstatistik der Schweiz 2005 (Leitung: *Ingenieurbüro Hostettler*) [51]

Figur 7 *Fassadenintegration mit Dünnschichtmodulen (Bildquelle: Zagsolar)*

Figur 8 *Teil der Flachdachanlage ETHZ (Bildquelle: Energiebüro)*

IM JAHR 2006 ABGESCHLOSSENE P+D PROJEKTE

Im Jahr 2006 wurden die folgenden P+D Projekte abgeschlossen (in chronologischer Reihenfolge):

Anlagen

- 15.4 kWp Flachdachintegration CPT Solar (Pilotmässiger Einsatz einer neu entwickelten Kombination von amorphen Dünnschichtmodulen mit einer dichten Kunststofffolie; Leitung: *ISAAC*) [52]
- 25 kWp Gründachintegration Solgreen Kraftwerk 1, Zürich (Piloteinsatz einer neu entwickelten Modulhaltekonstruktion für den Gründachbereich; Leitung: *Enecolo*) [53]
- Autonome 5.7 kWp Photovoltaik Anlage in Kombination mit einem BHKW (Ganzjährige autonome Energieversorgung von 2 Chalets mittels Photovoltaik, BHKW, thermischen Kollektoren und Holz; Leitung: *A. Reinhard*) [54]

Studien - Hilfsmittel - diverse Projekte

- Solar *Electri* City Guide - Schweizer Solarstromführer für die Gemeinden (Leitung: *NET*) [55]

Die Publikation **Solarstrom in der Gemeinde**, welche aus einem früheren EU-Projekt PV-City Guide hervorgeht, besteht aus einer umfassenden und illustrationsreichen Broschüre und aus weiteren sieben (elektronisch verfügbaren) Dokumenten zur vertieften Behandlung thematischer Schwerpunkte [76]. Damit ermöglicht die Publikation eine neue, bisher nicht vorhandene Gesamtschau der Photovoltaik auf Gemeindeebene in der Schweiz und sie bietet zahlreiche Handlungsbeispiele.

6. Bewertung 2006 und Ausblick 2007

Global war das Jahr 2006 für die Photovoltaik ein weiteres erfolgreiches Jahr. In einer durch hohes Wachstum gezeichneten Marktdynamik konnte die Photovoltaik Industrie ihren Ausbau fortsetzen. Durch das rasche Wachstum hat sich aber der Engpass in der Verfügbarkeit von Rohsilizium weiter verschärft. Es finden weltweit Investitionen in neue Produktionskapazitäten von Solarsilizium statt, welche die angespannte Situation ab ca. 2008 entschärfen sollten. Bereits Ende 2006 zeichnete sich eine Trendumkehr zu niedrigeren Systempreisen ab. Parallel dazu besteht für Dünnschicht Solarzellen aufgrund dieser angespannten Situation ein interessantes „window of opportunity" – sprich Chancen für diese Technologien. Als konkretes Beispiel dieser jüngsten Entwicklung konnte die *oerlikon* im Berichtsjahr grosse Bestellungen für Depositionsanlagen von Dünnschicht Solarzellen aus amorphem Silizium entgegennehmen.

Durch die im Jahr 2006 im Parlament erfolgten politischen Diskussionen rund um das Stromversorgungsgesetz und der darin vorgesehenen Förderung der erneuerbaren Energien erhielt die Photovoltaik auch in der Schweiz grosse Aufmerksamkeit. Mit den inzwischen verabschiedeten Beschlüssen besteht nach vielen Jahren Aussicht auf eine Verbesserung des Photovoltaikmarktes, in dem ab 2008 eine kostendeckende Vergütung vorgesehen ist. Obwohl im quantitativen Ausmass eng begrenzt, sollte dies zu einer Belebung des Schweizer Photovoltaikmarktes führen, und damit auch die technologische Entwicklung stimulieren.

Vor diesem Hintergrund ist auch die Situation der Schweizer Photovoltaik zu beurteilen: Forschung und Technologie befanden sich bisher aufgrund einer breiten Abstützung auf einem auch international betrachtet hohen Niveau. Industrielle Umsetzung und internationale Ausrichtung werden durch die zahlreichen KTI- und EU-Projekte belegt. Andererseits bestehen durch die fehlenden P+D-Mittel und dem bisher stagnierenden Markt gewichtige Nachteile für die Umsetzung im eigenen Land. Trotz diesen erschwerten Bedingungen finden auch in der Schweiz wachsende industrielle Photovoltaik Aktivitäten statt. Gestützt auf Umfragen wird das Exportvolumen der Schweizer Photovoltaik für 2006 auf mindestens 350 Mio. CHF geschätzt. Zusammen mit dem Heimmarkt kann der Gesamtumsatz der Schweizer Photovoltaik mit ca. 400 Mio. CHF beziffert werden.

Die Umsetzung der Schweizer Photovoltaik Forschung in industrielle Produkte ist damit vor allem auf dem Gebiet der Dünnschicht Solarzellen in den letzten Jahren eine Erfolgsgeschichte, welche in guter Übereinstimmung mit den langjährigen Programmzielen geschieht. Ebenfalls erfolgversprechend, aber etwas schwieriger, präsentiert sich die Situation bei der gebäudeintegrierten Photovoltaik, da dieser Markt sowohl national wie international noch nicht so stark ausgeprägt ist. Dies könnte sich aufgrund der neuen Rahmenbedingungen in der Schweiz und in vereinzelten anderen Ländern, z.B. Frankreich, in den nächsten Jahren ändern.

Die bisherigen Anstrengungen im Schweizer Photovoltaik Programm bilden die wissenschaftlich-technische Ausgangslage, um im rasch wachsenden internationalen Photovoltaik Markt mit Schweizer Innovationen und Produkten präsent zu sein. Die lange praktische Erfahrung mit dem Bau und Betrieb von zahlreichen Photovoltaik Anlagen führten zu wichtigen Erkenntnissen, welche die Zuverlässigkeit der Anlagen und eine hohe spezifische Energieproduktion zur Folge haben. Damit sind die technologischen Voraussetzungen gegeben, dass die Schweizer Photovoltaik mit ihrem wissenschaftlich-technischen Know-how und ihren Produkten auch im internationalen Wettbewerb konkurrenzfähig und erfolgreich sein kann.

Das Programm Photovoltaik wird weiter bestrebt sein, durch die breite Abstützung eine kritische Grösse zu bewahren und eine bedeutende Marktwirkung zu erzielen. Dazu soll von allen möglichen Fördermechanismen Gebrauch gemacht werden und diese gleichzeitig optimal koordiniert und zielführend eingesetzt werden. Das neue Energieforschungskonzept der CORE 2008 – 2011 wird im Jahr 2007 die Grundlage bilden für die Ausarbeitung des entsprechenden Photovoltaik Forschungskonzeptes. Darin sollen die jüngsten nationalen und internationalen Entwicklungen berücksichtigt werden, um die Prioritäten der nächsten Jahre festzulegen. Ein intensiver Austausch mit den Akteuren aus Forschung und Industrie soll diesen Prozess begleiten.

Der nationale Informations- und Erfahrungsaustausch bleibt in der Schweiz weiterhin ein wichtiges Thema. Im November 2007 findet in Luzern die 7. Nationale Photovoltaik Tagung statt. Sie wird sich insbesondere den neuen Schweizer Rahmenbedingungen für die Photovoltaik widmen. Die Photovoltaik Webseite http://www.photovoltaic.ch beinhaltet alle wesentlichen Informationen sowie Berichte und dient damit als wichtiges Informationsinstrument, das laufend unterhalten wird. Die Schweizer Photovoltaik war an der 21. europäischen Photovoltaik Konferenz im September in Dresden mit ihren Beiträgen gut vertreten [77].

7. Liste der F+E - Projekte

(JB) Jahresbericht 2006 vorhanden
(SB) Schlussbericht vorhanden

Einzelne Jahresberichte und Schlussberichte können von http://www.photovoltaic.ch heruntergeladen werden. Unter den aufgeführten Internet-Adressen sind weitergehende Informationen vorhanden.

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8. Liste der P+D - Projekte

(JB) Jahresbericht 2006 vorhanden
(SB) Schlussbericht vorhanden

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10. Für weitere Informationen

Weitere Informationen erhalten Sie von der Programmleitung:

Dr. Stefan Nowak, NET Nowak Energie & Technologie AG, Waldweg 8, 1717 St. Ursen, Schweiz
Tel. ++41 (0) 26 494 00 30, Fax ++41 (0) 26 494 00 34, Email: stefan.nowak@netenergy.ch

Bearbeitung Jahresbericht: Manuela Schmied Brügger, Stephan Gnos,
NET Nowak Energie & Technologie AG, info@netenergy.ch

11. Verwendete Abkürzungen (inkl. Internetlinks)

Allgemeine Begriffe

ETH	Eidgenössische Technische Hochschule

Nationale Institutionen

BAFU	Bundesamt für Umwelt	http://www.bafu.admin.ch
BFE	Bundesamt für Energie	http://www.bfe.admin.ch
CORE	Eidgenössische Energieforschungskommission	http://www.bfe.admin.ch
CRPP	Centre de Recherche en Physique des Plasmas EPFL	http://crppwww.epfl.ch
CUEPE	Le Centre universitaire d'étude des problèmes de l'énergie	http://www.unige.ch/cuepe
DACD SUPSI	Architecture Construction and Design Departement	http://www.dacd.supsi.ch
DEZA	Direktion für Entwicklung und Zusammenarbeit	http://www.deza.admin.ch
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt	http://www.empa.ch
EPFL	Ecole Polytechnique Fédérale de Lausanne	http://www.epfl.ch
ETHZ	Eidgenössische Technische Hochschule Zürich	http://www.ethz.ch

FH Burgdorf	Fachhochschule für Technik und Informatik Burgdorf	http://www.hti.bfh.ch
IEC	International Electrotechnical Commission	http://www.iec.ch/
IMT	Institut de Microtechnique Universität Neuchâtel	http://www-imt.unine.ch
ISIC	Institute of Chemical Sciences and Engineering	http://isic.epfl.ch
KTI	Förderagentur für Innovation	http://www.kti-cti.ch
ISAAC	Institute for applied sustainability to the built environment	http://www.isaac.supsi.ch
LEEE - TISO	Laboratorio di Energia, Ecologia ed Economia - Ticino Solare neu ISAAC	http://www.isaac.supsi.ch
LESO	Laboratoire d'Energie solaire et de physique du bâtiment	http://leso.epfl.ch
LTC	Laboratory of Polymer and Composite Technology EPFL	http://ltc.epfl.ch/
NTB	Interstaatliche Hochschule für Technik Buchs	http://www.ntb.ch
PSI	Paul Scherer Institut	http://www.psi.ch
SBF	Staatssekretariat für Bildung und Forschung	http://www.sbf.admin.ch
SECO	Staatssekretariat für Wirtschaft	http://www.seco.admin.ch
SUPSI	Scuola universitaria professionale della Svizzera Italiana	http://www.supsi.ch
VSE	Verband Schweizerischer Elektrizitätsunternehmen	http://www.strom.ch

Internationale Organisationen

EU (RTD)	Europäische Union (RTD-Programme) Forschungs- und Entwicklungsinformationsdienst der Europäischen Gemeinschaft	http://www.cordis.lu
ECN	Energy research Centre of the Netherlands	http://www.ecn.nl
ESA	European Space Agency	http://www.esa.int
ESTI	European Solar Test Installation	http://ies.jrc.cec.eu.int/reu.html
GEF	Global Environmental Facility	http://www.gefweb.org
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit	http://www.gtz.de
HMI	Hahn-Meitner-Institut	http://www.hmi.de
IEA	International Energy Agency	http://www.iea.org
IEA SHC	IEA Solar Heating and Cooling	http://www.iea-shc.org/
IEA PACES	SolarPACES	http://www.solarpaces.org/
IEA PVPS	Photovoltaic Power Systems Implementing Agreement (IEA)	http://www.iea-pvps.org
IEC	International Electrotechnical Commission	http://www.iec.ch
IFC	International Finance Corporation	http://www.ifc.org
KfW	Kreditanstalt für Wiederaufbau	http://www.kfw.de
PV GAP	Global Approval Program for Photovoltaics	http://www.pvgap.org
REEEP	Renewable energy & energy efficiency partnership	http://www.reeep.org
UNDP	United Nations Development Programme	http://www.undp.org
UNEP	United Nations Environment Programme	http://www.unep.org

Private Institutionen und Unternehmen

	oerlikon	http://www.oerlikon.com

12. Weiterführende Internetlinks

	Photovoltaik Webseite Schweiz	http://www.photovoltaic.ch
	EnergieSchweiz	http://www.energie-schweiz.ch
	Energieforschung des Bundes	http://www.energieforschung.ch
SNF	Schweizerischer Nationalfonds	http://www.snf.ch
ETH-Rat	Rat der Eidgenössischen Technischen Hochschulen	http://www.ethrat.ch
BFS	Bundesamt für Statistik	http://www.bfs.admin.ch
IGE	Eidgenössisches Institut für Geistiges Eigentum	http://www.ige.ch
METAS	Bundesamt für Metrologie	http://www.metas.ch/
SWITCH	Swiss Education and Research Network Switch	http://www.switch.ch
Swissolar	Schweizerischer Fachverband für Sonnenenergie	http://www.swissolar.ch
SSES	Schweizerische Vereinigung für Sonnenenergie	http://www.sses.ch
	Photovoltaik Webseite des US Department of Energy	http://www.eere.energy.gov/solar/
ISES	International Solar Energy Society	http://www.ises.org
ESRA	European Solar Radiation Atlas	http://www.helioclim.net/esra/

Solarzellen

THIN FILM SILICON SOLAR CELLS: ADVANCED PROCESSING AND CHARACTERIZATION

Annual Report 2006

Author and Co-Authors	J. Bailat, F. Haug, V. Terrazzoni, S. Faÿ, R. Tscharner, C. Ballif
Institution / Company	Institute of Microtechnology / University of Neuchâtel
Address	Rue A.L. Breguet 2, 2000 Neuchâtel
Telephone, E-mail, Homepage	+41 32 718 33 30, ballif@unine.ch, www.unine.ch/pv
Project- / Contract Number	101191 / 151399
Duration of the Project (from – to)	01.01.2005 – 31.12.2007
Date	December 2006

ABSTRACT

This project aims at:

- Demonstrating the preparation of ultra-high efficiency thin-film silicon based devices
- Fabricating new high-efficiency devices on flexible substrates using low-cost processes
- Exploring new routes for improved processing and characterization
- Providing the best infrastructure (technological know-how, fabrication and characterization systems) to support industrial partners in the frame of projects funded by other sources

To reach these objectives a significant effort has been made to:

- Renew, upgrade and automate several systems for the fabrication of thin film solar cells
- Install and characterize new advanced characterization systems
- Work on process reproducibility by revisiting several fabrication steps, from solar cells patterning and individual layer optimization to the full system optimization on optimized TCO

In 2006, a record efficiency of 9.9% was reached for single junction microcrystalline (μc-Si:H) silicon solar cells on an optimized ZnO front electrode on glass. The transfer of the process of the record amorphous (a-Si:H) solar cell to a newer double chamber deposition system, in which the μc-Si:H solar cells are fabricated, was carried out in order to improve the reproducibility. This transfer, resulting in a-Si:H cells with initial efficiencies higher than 10%, will allow the fabrication of micromorph tandem solar cells within a much shorter time than before as both amorphous and microcrystalline solar cells can now be made in the same deposition system.
On low-cost PEN plastic substrates, continuous progresses have been made using periodic structures: Microcrystalline silicon solar cells were produced with a record-efficiency of 8.3%; amorphous silicon solar cells with efficiencies of 7.8% were also obtained on flexible substrates.
The laboratory infrastructure was further upgraded. In particular, a new, fully automated, large area, double chamber deposition system was completely designed and is now under final assembly in the IMT's clean room. This flexible system, fully equipped with advanced characterization tools, will allow in the mid-term the development and study of innovative processes for the fabrication of the next generation thin film silicon solar cells and modules.

Introduction / Project goals

In 2006, thin film silicon solar cells have made a significant breakthrough in the market thanks to their high potential for low price per watt peak. This decisive advantage is strengthened by the issue of feedstock shortage that the dominating crystalline silicon technology is currently facing. The situation is such that, indeed, most crystalline silicon solar cells companies have announced their own subsidiary in thin film solar cells. The best example is probably Europe's giant Q-Cells, which has entered the domain of thin-film solar cells through massive investments in 4 different companies or subsidiaries representing 4 different thin-film technologies (amorphous, micromorph, CIGS and presumably CdTe).

In this dynamic market, IMT's closest industry partners, VHF-Technologies and OC Oerlikon, are well positioned: the former as being one of the companies Q-Cells chose to invest in; the latter being the only equipment supplier selling a complete solution for manufacturing thin film silicon solar cells. This year, OC Oerlikon has indeed sold production lines to two German companies, Schott Solar and Ersol, which will start production in 2007 with nominal capacities of 30 and 40 MW, respectively.

IMT's main goal in this environment is to reveal the full potential of thin film silicon solar cell technology. IMT aims at demonstrating new ways of further improving the conversion efficiency of the amorphous, microcrystalline and multi-junction thin film silicon solar cells and at showing the feasibility of these concepts in industry-compatible processes or equipments.

Description of the project

This three year long research project aims at reaching the following goals:

- Introducing new concepts for higher efficiency thin film micromorph devices on glass substrates
- Developing the know-how for device preparation on light-weight unbreakable substrates with industry compatible technology
- Exploring new routes for improved processing and characterization
- Providing the infrastructure that enables the support to industrial partners in the frame of projects funded by other sources than OFEN

Results

High efficiency solar cells on glass substrates

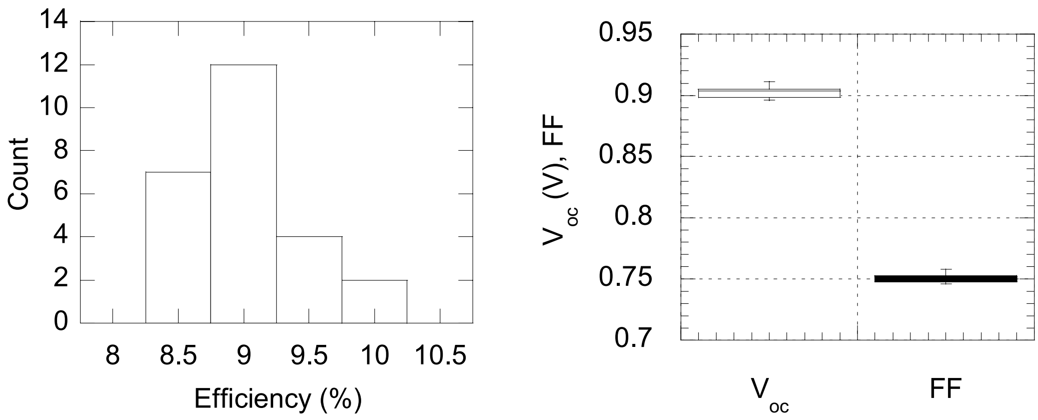
The revised objective for a micromorph tandem silicon solar cell consists of an efficiency of 12.6% in 2007. The ground work, commenced in 2005 and pursued in 2006, has led to significant improvements of the single junction solar cells. This work can be divided into the following subjects:

- Reproducibility of all the processes used in the single junction amorphous and microcrystalline silicon solar cells
- Optimization of single junction amorphous/microcrystalline silicon solar cells for tandem cells
- Optimization of complete micromorph devices with intermediate reflector

Reproducibility

The reproducibility of the processes and the homogeneity of the different layers constituting the solar cells enable the continuous improvement of the electrical characteristics of the devices. In Figure 1 are represented the efficiencies of microcrystalline silicon solar cells deposited in 2006. The best solar cell fabricated in 2005 had an efficiency of 9.0%. In 2006, this value was reached or surpassed 10 times, as represented in the histogram in Fig. 1 a). Most of the solar cells have their efficiency above 8.5% with a maximum at 9.9%. The scattering in the data is due to the deposition conditions that have been varied for various optimization purposes.

So far pin amorphous silicon solar cells had been developed in the first system built at IMT (system C) which will be fully modified and upgraded next year. To maintain the good results obtained in pin a-Si:H cell, the processes in system C were transferred to the double chamber system B, used until now for microcrystalline silicon solar cells only. Two months only were needed to achieve the transfer and to obtain devices with initial efficiencies above 10%. The homogeneity of the electrical parameters is represented in Fig. 1 b); note the very small scattering of the V_{oc} and FF.



a) b)

Fig. 1: a) Histogram of the efficiencies of the pin microcrystalline silicon solar cells fabricated in 2006 at IMT. The best efficiency obtained last year (9%) has been attained 10 times so far. b) Box plots of the V_{oc} and FF for 12 amorphous silicon solar cells deposited in the same run using the newly developed processes in system B. The shunted cells (dust), approximately 25% of the cells on this substrate, were removed from this statistics.

Optimization of single junction solar cells

A new plasma surface treatment discovered last year has been extensively used in 2006 to modify the surface morphology of the front contact made of ZnO deposited by low pressure chemical vapor deposition (LPCVD). The front ZnO has also been re-optimized to take into account the new surface treatment. This work allowed us to understand which substrate morphology is best suited for the growth of microcrystalline silicon solar cells. It resulted in the filing of a patent in March 2006. After optimization of the microcrystalline silicon solar cells in single junction on this new substrate, the efficiency reached a value of 9.99%, which consists in a record on LPCVD ZnO (Figure 2 and Table 1) [4].

Further optimizations focused at enhancing the current of the bottom cell in the micromorph solar cell have shown that short-circuit current-density as high as 25.7mA/cm^2 are achievable for μc-Si:H cell on LPCVD ZnO.

The pin amorphous solar cells developed in the system B have reached initial efficiencies of 10.2% with a relatively thin intrinsic layer of 250nm (Figure 2, Table 1)

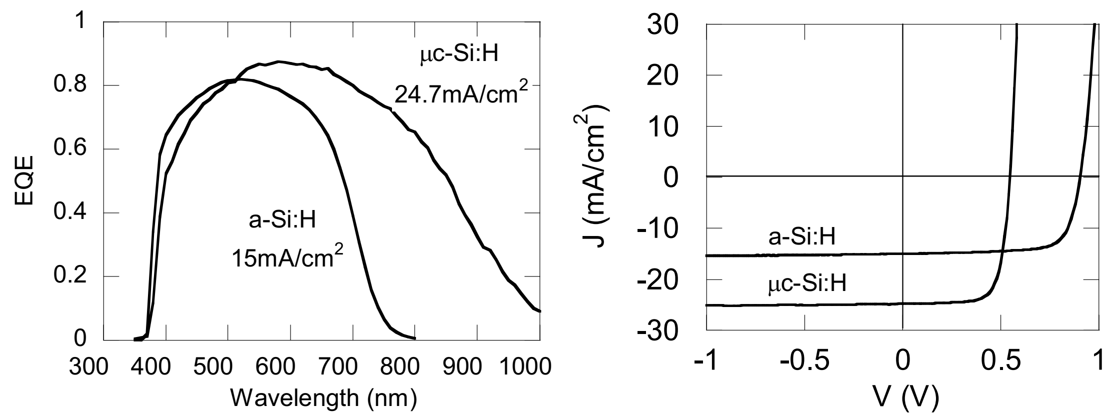


Fig. 2: a) and b) External quantum efficiency and current-density voltage curves of the best amorphous and microcrystalline silicon solar cells fabricated in 2006.

Cell type	V_{oc} (mV)	FF (%)	J_{sc} (mA/cm^2)	Efficiency (%)
a-Si:H (syst.B)	904	75.2	15.0	10.2
μc-Si:H (2006)	545	74.1	24.7	9.99
Micromorph	1316	70.2	12.8	11.8

Table 1: Summary of the electrical characteristics of the best solar cells made in 2006 (initial efficiencies). The thickness of the intrinsic layer of the a-Si:H cell is approximately 250nm; that of the µc-Si:H silicon solar cells is 1.8μm thick. For the micromorph solar cells the thicknesses of the intrinsic layers are 180nm and 1.80µm for the top and bottom cells, respectively.

Optimization of micromorph tandem solar cells

Much effort has been put into the fabrication of single junction devices to establish both the homogeneity of the layers and the reproducibility of the results. This effort was of immediate benefit to the reproducibility of the tandem solar cells. Furthermore, it will enable us to focus our work on more fundamental aspects of the tandem cells like the intermediate reflector and the recombination junction. Up to now, the typical tandem cells fabricated at IMT have either:

- **without intermediate reflector,** high V_{oc} and FF (1.4V and >70%, respectively) and a rather low J_{sc} (typically 11mA/cm^2).
- **with intermediate reflector,** high J_{sc} (12-13mA/cm^2) with low V_{oc} and FF (<1.4V and < 70%, respectively)

In both configurations the state-of-the-art at IMT consists of solar cells that have an initial efficiency comprised between 11.5 and 11.8% [2]. The first results aiming at improving both V_{oc} and FF of the cells with the intermediate reflector have yielded reasonable enhancement of V_{oc} but not yet of the FF. With an intermediate reflector, a V_{oc} of 1.38V was reached this year; this value is to be compared with the 1.315V attained last year. However, the FF remains below 70% because of parasitic shunts that have still to be avoided. The patterning of the cells with intermediate reflector made of ZnO at IMT is also more demanding than the one of the cells without intermediate reflector; alternative ways of fabricating the intermediate reflector with other materials are under investigation now, as well as the establishment of alternative techniques to pattern them.

Light-weight unbreakable substrates

During this year, IMT continued its work on transferring its pioneering results obtained on glass to low cost plastic substrates. The cells must be adapted to new particularities like outgassing, different thermal expansion properties or mechanical tests.

During the reporting period, the efforts have been focussed on μc-Si:H single cells because of their later use in micromorph tandems. Care was taken to use processes and deposition regimes which are totally compatible with industrial processing. In parallel, the effect of substrates with different textures on the FF and V_{oc} of amorphous cells has been investigated, and the deposition processes for TCOs (ITO and ZnO) are being developed in the new sputtering system.

Microcrystalline silicon solar cells

Different substrates could be tested in cells. All substrates were fabricated at OVD Kinegram AG, with their patented roll-to-roll process. The back reflector structure was deposited at the FEP Fraunhofer Institute which is partner in the European Project Flexcellence [9]. During this work two textures showed promising results, one is a replica of the hot-silver surface, the second is a structure provided by OVD which consists of a crossed sinusoidal grating [3]. Figure 3 shows that these structures are capable of increasing the response to long wavelengths; compared to reference cells on a flat substrate the current in μc-Si.H solar cells increases by 25% and 19% for the hot-Ag replica and the periodic grating, respectively. The figure shows that the open circuit voltage is reduced by about 30 mV.

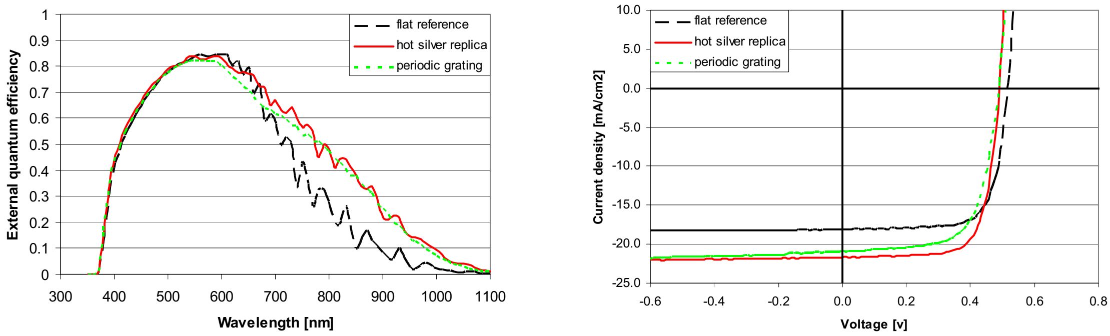


Fig. 3: External quantum efficiencies (left) and current-voltage characteristics (right) of microcrystalline solar cells on plastic substrates with different structures.

The best microcrystalline cells so far have been obtained on PEN with the periodic structure where adapted processes for the doped p- and n-layers resulted in improved open circuit voltage. These cells showed an initial efficiency of 8.3% and the current efforts are directed towards an understanding of losses in V_{oc} and FF. Future experiments will also investigate the cell stability under light-soaking end exposure to high temperatures.

Amorphous silicon solar cells

Light trapping on structured substrates has also been a focus for the solar cells based on amorphous silicon. Compared to the previous period, a doping gas was changed, and an improved process stability could be achieved. Figure 4 presents the quantum efficiencies of solar cells grown on PET with different surface morphologies, one having larger feature size than the other. Compared to the flat reference on glass the two different structures yield a gain in current density of almost 30%. However, there is a loss in open circuit voltage which depends on the type of structure; for the strong texture it amounts to 30mV whereas on the more shallow structure it is only 10mV. The resulting solar cell shows an initial efficiency of 7.8%.

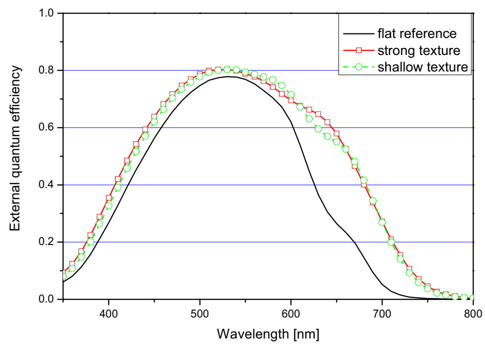


Fig. 4: External quantum efficiency of amorphous solar cells on plastic substrates. Compared to the flat reference (continuous line), the different structures result in enhanced responses at long wavelengths.

TCO / metallic layers

The new deposition system for metals and TCOs (Leybold Univex) has been mainly used for the reproducible deposition of metallic back contacts. Recent experiments were also directed towards the development of TCO front contacts where the load lock facility proved useful to keep atmospheric contamination at a minimum. In the reporting period, the work on TCOs was focussed on ITO (indium tin oxide) deposited by DC sputtering. Because the TCO forms the front contact on flexible nip-type solar cells, the deposition conditions are limited to ambient temperature without intentional heating.

With this restriction, the oxygen partial pressure during ITO deposition becomes a critical parameter. Firstly, it determines the transparency and the conductivity of the films, and secondly it influences the overall electrical performance of the solar cell because of possible damage to silicon surface in the oxygen containing plasma. Figure 5 shows that a moderate addition of oxygen is beneficial to the resistivity of the ITO layer (lower resistivity at [O]/[Ar]= 1%). However, this reduced lateral resistance of the front contact is not directly identifiable in the solar parameters like the series resistance. In fact, in the shown series, the highest efficiencies coincide with the highest values of resistivity in the front contact, indicating the importance of interface effects for ITO deposition on p-layers. Note that the shown cells have comparatively low efficiencies because they have been prepared on flat plastic substrates without light trapping structure.

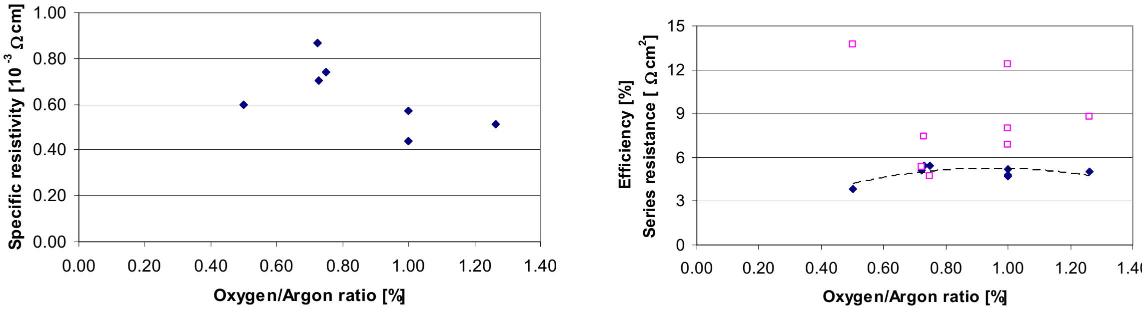


Fig. 5: Specific resistivity of ITO layers as a function of the oxygen partial pressure (left) and the effect on solar cells in terms of series resistance (right panel, open symbols) and efficiency (right panel, full symbols).

LPCVD Transparent conducting zinc oxide

Transparent Conducting Oxides (TCO) layers are of prime importance for high efficiency solar devices. They need to be transparent and conductive enough to let the light reach the active part of the solar cell and to reduce the electrical losses in the series connection. Furthermore, a fine control of the surface roughness of these films is necessary, in order to tune precisely the light scattering scheme within the solar cells. The LPCVD-ZnO layers do not only allow the fabrication of all high efficiency pin devices, Transparent Conducting Oxides (TCO) layers are of prime importance for high efficiency solar devices. They need to be transparent and conductive enough to let the light reach the active part of the solar cell and to reduce the electrical losses in the series connection. Furthermore, a fine control of the surface roughness of these films is necessary, in order to tune precisely the light scattering scheme within the solar cells. The LPCVD-ZnO layers do not only allow the fabrication of all high efficiency pin devices, but are also used both as back electrode and front electrode for different tests in nip devices.

In 2005, highly diffusive layers with low sheet resistance and improved transparency in the whole visible range including the Near Infra-Red (NIR) part of the spectrum had been prepared and tested in microcrystalline silicon solar cells. Although a clear increase in the photo-generated current was observed due to the increase in the surface roughness of the front TCO, a large drop of the V_{oc} and FF values was simultaneously observed. The use of a new surface treatment of the LP-CVD ZnO films allowed us, however, to obtain high short-circuit current densities while maintaining high values of V_{oc} and FF, resulting in microcrystalline silicon solar cells with record efficiencies on ZnO deposited by LP-CVD.

In 2006, the work on LP-CVD ZnO has focused on improving the reproducibility of deposition processes of two kinds of front electrode: one for efficient light scattering for amorphous silicon solar cells (up to 800nm), and the other for microcrystalline and micromorph silicon solar cells (up to 1100nm). This improved reproducibility of the LP-CVD deposition process is of prime importance to conduct comparison studies of fabrication processes of solar cells over a wide range of time (several months or years). Furthermore, deposition rates have been also drastically improved (with a factor of almost 3), by increasing the vapour flow rates and finely adjusting the substrate temperature during the process in order to stay within the optimal range of deposition condition that lead to optimized rough TCO films.

In parallel to this work of process optimization, a study has been carried out, which focused on the influence of the grain boundaries on the transport mechanisms within the LP-CVD ZnO films. Electron mobility has been found to be directly influenced by the size of the grains, and therefore by the scattering that occurs at the grain boundaries (i.e. the larger the grains the higher the electron mobility and hence, the lower the ZnO film resistivity) in the case of slightly doped ZnO films. For strongly doped ZnO films, the electron mobility is rather limited by the scattering within the grains [5, 8]. As increasing too much the doping level of the ZnO films will increase the absorption of these films, it is evident now that the resistivity of the ZnO films should be lowered rather by increasing the grain size and keeping the doping level low, than by increasing the carrier concentration with higher doping level.

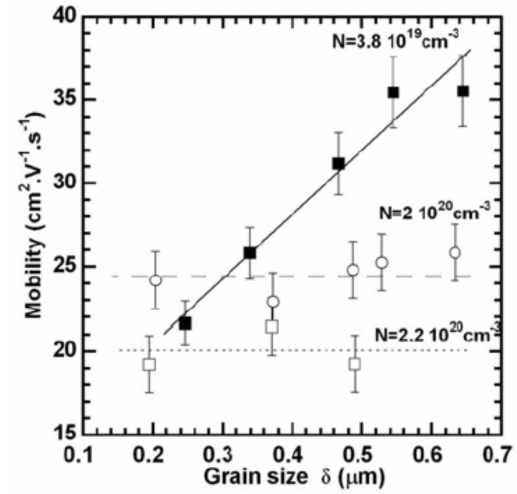


Fig. 6: Hall mobility as a function of grain size for LP-CVD ZnO films with carrier concentration (N) of $3.8x10^{19}cm^{-3}$ (full squares), $2x10^{20}cm^{-3}$ (open circles) and $2.2x10^{20}cm^{-3}$ (open squares) [5].

Characterization tools and Laboratory infrastructure

A continuous effort has been made for the upgrade or setting-up of several measurement techniques including:

- A fully functional IV curve measurement system with LABVIEW interface and with measurement set-up for up to 20 cells simultaneously, with automatic measurements at low illumination level.
- A state-of-the-art spectral response system with LABVIEW interface and faster measurement capabilities.
- An improved dark conductivity measurement setup (used e.g. for the development of doped layer) with LABVIEW control, allowing the simultaneous measurement of up to 4 samples and consequently a strong reduction of the measurement time per sample (usually several hours).
- The infra-red lock-in system was further upgraded with an optical system and systematically used for quality control/shunt detections.

All these systems are now used on a daily basis for performing research and device development. Finally, the tools implemented in the first years (FTPS, VIM) have been used for a thorough characterisation of various layers and devices. In particular, the degradation under illumination and proton irradiation of pin and nip devices has been further investigated [7], and transmission electron microscopy has been intensively used to characterize the microstructure and the apparition/suppression of cracks μc-Si:H solar cells [1].

Fig. 7: Picture of the assembly of the new double chamber deposition system with KAI-M plasma box from OC Oerlikon. The load-lock chamber is in-between the two deposition chambers.

In 2006, the gas systems and pumping of the two LPCVD ZnO deposition chambers were decoupled, allowing a more effective combination of TCO research and layer supply for the other groups. A new deposition system by VHF-PECVD for amorphous and microcrystalline silicon solar cells on large substrates (420x510mm) is under final assembly and testing at IMT (Figure 7). This system, the conception and assembly of which are completely executed at IMT, is composed of 2 deposition chambers equipped with PLASMABOX® (supplied by OC Oerlikon) and a central load-lock and transfer chamber. A free opening for a third reactor chamber is also available. The system is fully automated to permit the fabrication of multi-layer solar cells and the systematic data logging of all important plasma parameters. This system should become fully functional by the beginning of 2007.

Collaboration and synergies with other projects / institutes

IMT is involved into the European projects ATHLET and FLEXCELLENCE. IMT terminated also two CTI projects in 2006. A strong synergy could be realized between all these projects and this running SFOE project, with immediate benefits for companies such as OC Oerlikon and VHF-Technologies. A new project (1.3.2006-28.2008) with the Danish company "Photosolar" financed by Energienet.dk creates also synergies for nip devices development.

Regular academic contacts/scientific exchanges have been maintained throughout 2006 both with national (CRPP-EPFL, EMPA, HE-Arc,..) and international (University of Ljubljana, University of Patras, IPV Juelich, Academy of Science of Prague, ECN….). One IMT Phd. student stayed for one month at the Institute of Physics, Academy of Science, Prague, Czech Republic (Groupe M. Vanecek). Another Phd. Student is staying for six months at NREL (Golden, CO, US).

Evaluation for 2006 / perspectives for 2007

In 2006, the effort has been put into obtaining a high reproducibility of the different deposition processes used in the fabrication of the solar cells, from the ZnO layers to the deposition parameters of the nip and pin solar cells. This effort helped us in reaching higher µc-Si:H solar cell efficiencies for single junction solar cells and in stabilizing the processes for the a-Si:H cells. It has already been of benefit to the development of micromorph solar cells.

The multi-junction cells and especially the tandem configuration will be studied into more details during 2007 in nip and pin solar cells. The focus will be set on the development and improvement of intermediate reflectors in pin silicon solar cells to obtain high stable efficiencies. Some preliminary tests will also be carried out in the triple junction amorphous/microcrystalline/microcrystalline silicon solar cells. Finally, a better control of the substrate nano-structural properties should allow the fabrication of higher efficiency cells on plastic substrates.

The development of all the basis processes needed for the fabrication of thin film silicon solar cells in the new multi-chamber KAI-M will take place in 2007. This automated deposition system should considerably boost the development of new processes for the fabrication of silicon solar cells on large area. It will also help to improve the comprehension of the interaction between the plasma parameters during the deposition and the resulting layer/solar cell properties.

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HIGH RATE DEPOSITION OF µC-SI:H SILICON THIN-FILM SOLAR CELL DEVICES IN INDUSTRIAL KAI PE-CVD REACTOR

Annual Report 2006

Author and Co-Authors	Luc Feitknecht, Christophe Ballif
Institution / Company	Institut de Microtechnique
Address	rue A.-L. Breguet 2, 2000 Neuchâtel
Telephone, E-mail, Homepage	+41 32 718 33 36, ballif@unine.ch, www.unine.ch/pv
Project- / Contract Number	CTI 6928
Duration of the Project (from – to)	1. March 2004 – 28. February 2006
Date	December 2006

ABSTRACT

The scope of this CTI project was twofold: the first task was to upscale the fabrication process for hydrogenated microcrystalline silicon (µc-Si:H) solar cells from laboratory small area deposition (100 cm^2) up to a surface of 14000 cm^2: the latter corresponds to the size of industrial deposition equipment sold by Oerlikon. The second task of the present project was to increase the deposition rate for the fabrication of solar-grade µc-Si:H absorber layers and devices. High-rate deposition is necessary to achieve short fabrication times for the relatively thick µc-Si:H absorber layer in a micromorph tandem solar cell: for comparison, in such a tandem structure the amorphous top cell is thinner than 0.3 µm, contrary to the microcrystalline bottom cell which is typically 1 to 2 µm thick. To be fully "industry compatible" the processing for all doped and intrinsic microcrystalline silicon layers prepared at high deposition rates has to be executed within a single-chamber PE-CVD reactor.

As was already shown in a preceding CTI project, Oerlikon KAI PECVD reactors developed for active-matrix LCD technology possess a high potential for cost-effective manufacturing of thin-film silicon solar cells based on amorphous silicon. The investigation of microcrystalline silicon solar cells on the same industrial reactor was the aim of this present project. Thereby, specific issues relating to the preparation of microcrystalline devices had to be addressed, using both the small KAI-S reactor at IMT Neuchâtel, and the larger area KAI reactors at Oerlikon.

The work executed in the second half of this project focused entirely on device optimisation: the parameter space for deposition conditions could be successfully scanned and both doped and intrinsic layers could be satisfactorily fabricated. The best devices had a conversion efficiency of 8.4%, with an absorber thickness of 1.4 µm and a deposition rate of 0.7 nm/sec. The devices were fabricated in the KAI-S reactor at IMT using thereby a single-chamber process (i.e. the sample remained in the chamber during the whole processing cycle).

The know-how transfer from IMT to the industrial partner was also started: the high-rate solar-grade microcrystalline silicon absorber layer (deposition rate: 0.7 nm/sec) could be successfully incorporated into micromorph tandem solar cells. Oerlikon could prepare first micromorph modules of 10x10 cm^2 area with an initial conversion efficiency of 9.5%, and several microcrystalline layers on the full panel area (1.4 m^2).

Introduction / Project goals

In order to validate the large cost reduction potential for photovoltaic (PV) modules by using thin-film silicon technology, standard production equipment is needed which can be bought 'off the shelf'. Up to now no commercially available equipment for the fabrication of thin-film (TF) silicon solar modules existed on the market. All present suppliers of TF silicon solar panels run on custom-designed equipment. The main goal of **Oerlikon Solar** is to make available complete production equipment for thin-film silicon solar technology, which was achieved in 2006 for a-Si:H modules. The company Oerlikon Solar is an experienced supplier of coating equipment, a company that has developed a strong technological know-how base for the fabrication of deposition equipment for flat panel displays, based on amorphous silicon (a-Si:H) thin film transistor (TFT) technology.

At the **Institut de Microtechnique** (IMT) Neuchâtel, research experience has been built-up in view of future production of improved thin-film silicon solar cells. In 1987 IMT introduced the VHF-GD (Very High Frequency Glow Discharge) technique that allows for an increase in the deposition rate of silicon films, in 1993 has pioneered microcrystalline silicon (µc-Si:H) as a new thin film absorber material for photovoltaics. IMT's concept of combining amorphous silicon (high bandgap) and microcrystalline silicon (low bandgap) cells, the so-called "micromorph" concept which was introduced in 1994, is considered to be one of the most promising thin-film solar cell concepts, as it has the potential of absorbing and converting a wider range of the solar spectrum than single-junction amorphous silicon solar cells.

In this project the experience of IMT and that of OERLIKON SOLAR were combined in order to face a new challenge: The up-scaling of state of the art thin-film solar cell deposition including microcrystalline silicon deposition to areas up to 1.4 m^2. This is a much more difficult task than the industrial implementation of production lines for crystalline wafer technology; in fact, there exists as yet no state of the art production equipment at all for thin-film silicon solar modules. Consequently, thin-film solar modules production is associated with a higher risk regarding the production equipment, whereas for crystalline silicon small well-known production units can be added to increase the production volume.

This work prepares the way for the low-cost fabrication, at an industrial level, of state of the art "micromorph" tandem modules.

Description of the project

The **deposition system** used for this work at IMT is an adapted version of the industrial KAI-S reactor commercialized by Oerlikon Solar. It is a parallel-plate capacitively-coupled reactor which holds substrates of dimensions 47 cm x 57 cm (width x length). The Plasma-Enhanced Chemical Vapour Deposition (PE-CVD) is used as deposition method, with an excitation frequency of 40.86 MHz. This KAI-S reactor has been equipped with a load-lock chamber which allows for shorter deposition cycles and for better vacuum conditions in the deposition chamber. The R&D groups of Oerlikon Solar performed the fabrication of devices both in KAI-M (52 x 41 cm^2) and KAI 1200 (1.4 m^2 substrate size) reactors.

In this work, various types of thin µc-Si:H layers were first deposited onto glass samples. The film thickness of the deposited film was measured by profilometry; the crystalline volume fraction was determined by Raman spectroscopy. Optical absorption measurements are performed by Fourier Transform Photocurrent Spectroscopy (FTPS) as well as by the conventional Constant Photocurrent Method (CPM). Dark-resistance behaviour was measured in order to determine the electrical characteristics of the doped (p-type and n-type) and the intrinsic (undoped) absorber films.

After optimisation of the individual layers, **complete devices (solar cells)** were deposited onto LPCVD Zinc Oxide (ZnO) coated glass samples. The rear contacts were either sputtered (ITO/Al) or prepared by LPCVD ZnO and deposited onto the silicon devices. The solar cells were measured under both a standard AM1.5 sun simulator and in IMT's spectrally dependent Quantum Efficiency (QE) set-up.

The project aimed at mastering the application of KAI-type PE-CVD reactors for the processing of µc–Si:H thin-film solar cells in the VHF plasma domain. In order to facilitate a technology transfer to production size equipment, some additional boundary conditions were set during the final part of the project. These concerned the maximum usable value of RF power, the inter-electrode distance, and the necessity of "true[1]" single-chamber processing, where the samples stay in the deposition chamber during the full processing cycle.

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[1] A "true" single-chamber process means a process where the substrate stays within the single deposition chamber during the whole process cycle (and is not removed to the load-lock e.g. between p-layer and i-layer deposition).

Results

During the initial phase of the project, the KAI reactor at IMT was upgraded to allow the fabrication of high-quality doped layers. These hardware modifications on the deposition reactor allowed for the fabrication of doped p-type and n-type µc-Si:H layers in the KAI reactor, with properties comparable to those of *state of the art layers made on the small-size laboratory PE-CVD reactors at IMT.*

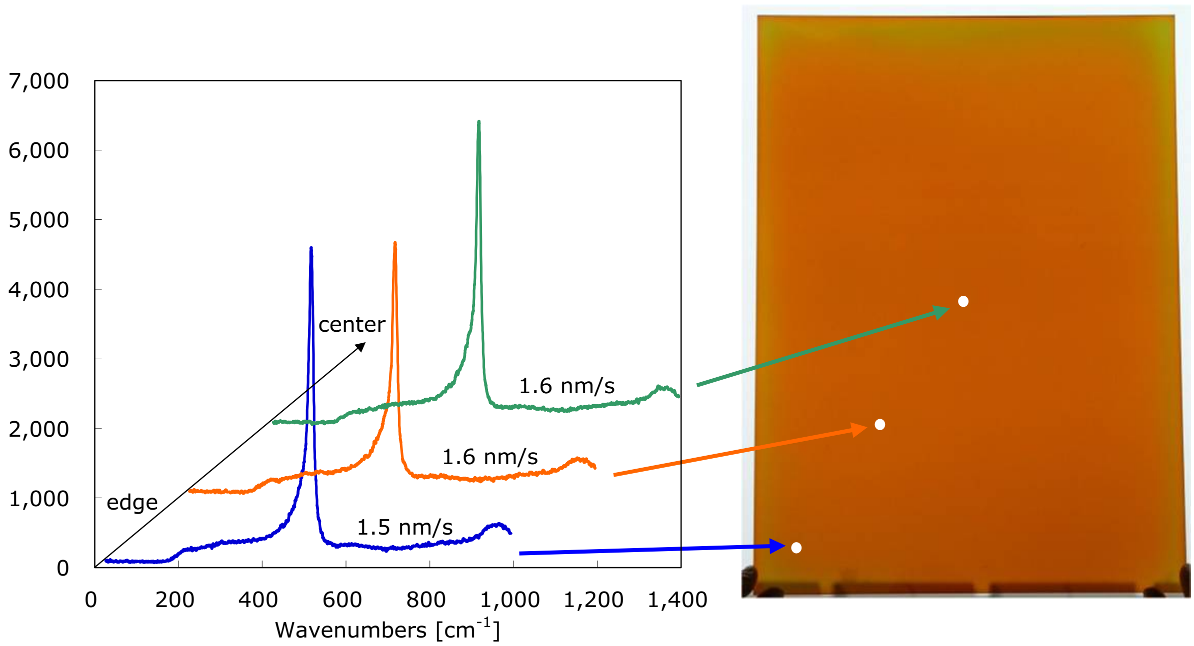

Fig. 1: Raman crystallinity of microcrystalline silicon films grown in the KAI-S reactor at IMT at deposition rates exceeding 1.4 nm/s. The Raman probe (514 nm) is taken from the center to the edge of the whole substrate area. The film has in the center a thickness of 0.96 µm.

The systematic exploration of the parameter space for depositing high-rate intrinsic µc-Si:H absorber films of device quality (=solar grade films) was then investigated. The variation of key parameters, like deposition pressure, silane concentration and injected plasma power required a very intensive work effort given the high level of complexity of the microcrystalline growth process. Indeed, the layer quality depends not only on the deposition parameters, but also on the nature of the substrate. Microcrystalline silicon growth was investigated in three KAI systems (KAI-S at IMT, KAI-M at the Oerlikon Solar lab in Neuchâtel and KAI-1200 at the Oerlikon Solar lab located in Trübbach). Whereas the main focus in the KAI-S was the achievement of high growth rate, in the KAI-M the attention was set towards the improvement of the device performance for micromorph tandem devices and first large-area tests were undertaken in the KAI-1200.

Fig. 1 reflects the best results obtained so far in the KAI-S reactor, in terms of increasing deposition rate: it shows the Raman spectra (incident light at 514 nm) of a microcrystalline layer deposited on a 35x45 cm^2 substrate as well as the deposition rates obtained. Homogeneous and high crystallinity of µc-Si:H layers over the whole substrate area is achieved at an impressive rate of over 1.4 nm/sec, and shows that high-quality µc-Si:H can be prepared in KAI reactors.

After the achievements on the side of intrinsic high-rate layer optimization and decent doped layers, first µc-Si:H devices were fabricated. In Fig. 2, the progress on conversion efficiency is plotted versus the project time period. In 2005, a conversion efficiency of 6.3% for devices fully fabricated in the KAI-S reactor had been achieved. This was a first proof of concept for the single chamber process for microcrystalline cell. The devices were deposited on rough ZnO. However, as reported in [4], microcrystalline devices deposited on rough LP-CVD ZnO tend to show a lower fill factor (because of the surface microstructure), if no special care is taken to make a fine optimisation for the deposition of the different layers or by adapting the TCO. By adjusting the TCO surface morphology and by a careful process optimisation, we could fabricate a best cell at 8.4% efficiency and a V_{oc}-value of 513mV, FF=73% and J_{sc}=22.4mA/cm^2. The deposition rate of the absorber layer was 0.7 nm/s. Note, that for this final result of 8.4% (see I-V curve in Fig. 3), the ZnO of the LP-CVD process at IMT is utilized both as front contact and as back contact.

A final emphasis was set on the homogeneity of µc-Si:H devices. Five substrates have been distributed over the whole electrode area of 35x45 cm^2 for this purpose. The resulting 75 values for V_{oc} and fill factor reach in average 513mV and 67% respectively and have both a relative standard deviation of only 2.2%.

Note that, since June 2005, all cells were fabricated at a deposition rate of 0.7 nm/s in a "true[1]" single-chamber process. During the whole p-i-n layer sequence deposition, the attached load-lock is not used.

The know-how transfer from IMT to the industrial partner was undertaken: the high-rate solar-grade microcrystalline silicon absorber layer (deposition rate: 0.7 nm/sec) could be successfully implemented for micromorph solar cells. Oerlikon Solar could prepare in its KAI-M systems, first micromorph modules of 10x10 cm^2 size with an initial conversion efficiency of 9.5% [4]. Microcrystalline deposition on industry-size glass (1.4 m^2) was undertaken in Trübbach.

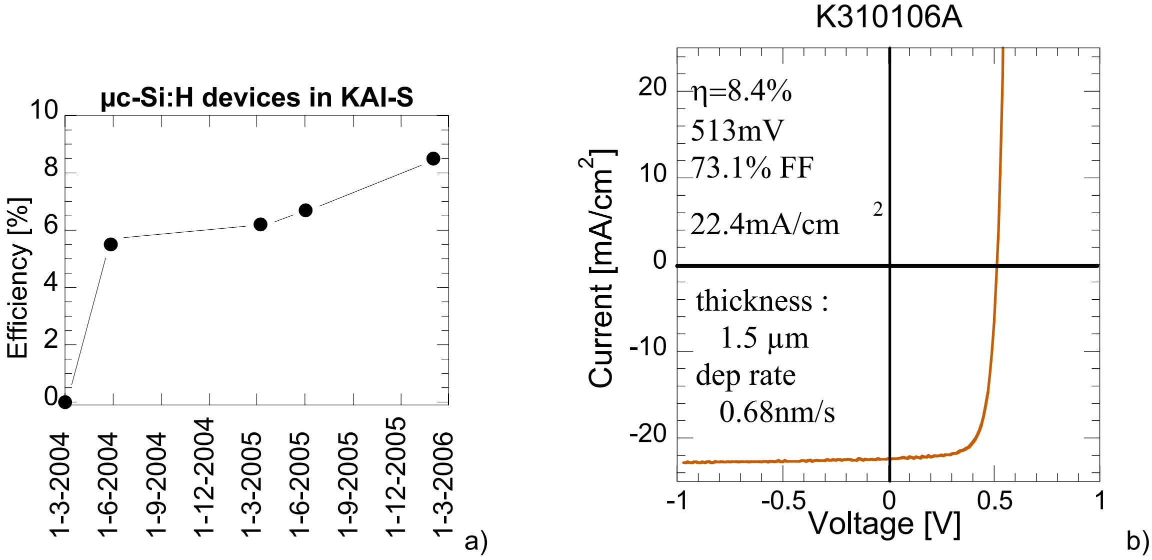

Fig. 2: a) Conversion efficiency of µc-Si:H p-i-n solar cells fabricated in the KAI-S versus project time. b) IV curve under AM1.5 illumination of the state-of-the-art µc-Si:H solar cell fabricated in a 'true' single-chamber process in the KAI-S reactor.

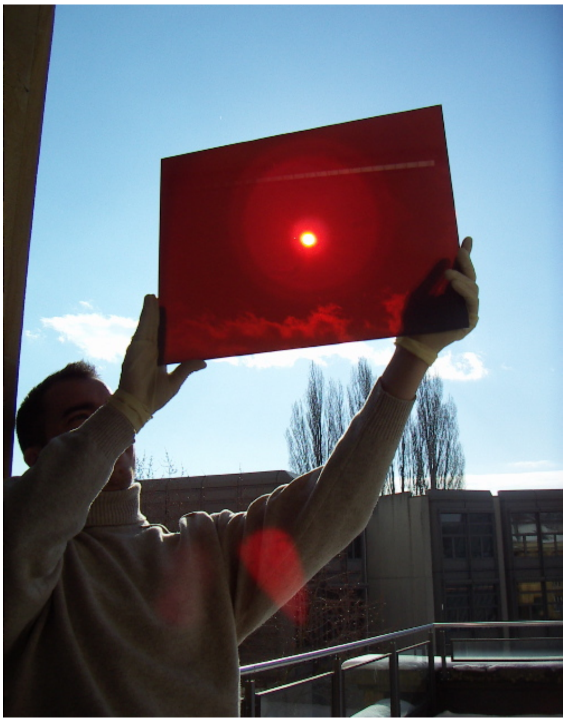

Fig.3: A microcrystalline silicon thin-film solar cell of only 1.5µm thickness deposited on a glass plate (35x45cm^2) absorbs 90% of the visible sunlight. In practice, a back-reflector is introduced in order to collect even the transmitted light.

[1] A "true" single-chamber process means a process where the substrate stays within the single deposition chamber during the whole process cycle (and is not removed to the load-lock e.g. between p-layer and i-layer deposition).

Within the framework of this project, Interstaatliche Hochschule für Technik Buchs (NTB) developed a novel thickness measurement tool which is now in operation both at IMT and at Oerlikon Solar. The tool works with a non-destructive method. Furthermore, unlike other similar tools, it does not require the evaluation of several minima and maxima in the optical spectra. Thus, it is an appropriate production monitoring tool that can be used to measure a-Si:H based thin-films with a thickness as thin as 30 nm and up to more than 1000 nm. Optical parameters of thin films for improved fitting have been obtained in collaboration with the Ecole d'Ingénieurs de l'Arc Jurassien (EIAJ), Le Locle. The thickness measuring tool proved to be more reliable than other thickness determination methods (e.g. stylus profiler or interference fringe counting) especially for thin silicon layers on flat substrates. By now, the measurement system is adequate to be integrated into a functional KAI reactor for in-situ thickness monitoring of solar module production.

More results from the Oerlikon Solar labs, including the use of the NTB thickness monitoring tool, were presented at the 31^{st} IEEE conference in Lake Buena Vista [1], at the 20^{th} European Photovoltaic Solar Energy Conference in Barcelona [2,3] at the 15^{th} PVSEC in Shanghai [4] and at the 21^{th} European Photovoltaic Solar Energy Conference in Dresden [8,9].

Collaboration and synergies with other projects/institutes

The know-how at IMT in the field of silicon thin-film deposition technology and in the characterisation of films and devices is complemented thanks to the collaboration with specialised researchers at the following laboratories:

- *Ecole d'ingénieurs de lArc jurassien – University of Applied Sciences* (EIAJ) in Le Locle, mainly for ellipsometry measurements on silicon films,
- *Interstaatliche Hochschule für Technik Buchs* (NTB) for the development of a silicon film thickness measuring tool which will be capable to determine in-situ the film thickness,
- *Centre de Recherche en Physique des Plasmas* (CRPP) of EPFL in Lausanne for a better understanding of the plasma deposition process under high-rate conditions

Final evaluation / perspectives

The use of the KAI-S type PECVD reactor, as equipped at IMT, was verified for industrial photovoltaic processing: the tool initially constructed for the flat-panel processing industry could be transformed into a tool for the thin-film silicon solar cell processing industry aiming at the micromorph tandem cell concept. In this phase, the emphasis was set on the microcrystalline cell. The goals have been achieved by performing hardware modifications, by careful choice of the TCOs and, by intensive parameter scans in order to reach solar grade microcrystalline silicon films at high deposition rates: the best µc–Si:H solar cell device reach a conversion efficiency of 8.4% at a deposition rate of 0.7 nm/s in a "true" single-chamber process. First high-efficiency micromorph modules could be prepared by the project partner Oerlikon Solar and large area microcrystalline Si deposition could be demonstrated.

This work prepares the way for the low-cost fabrication, at an industrial level, of state of the art “micromorph” tandem modules.

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A NEW LARGE AREA VHF REACTOR FOR HIGH RATE DEPOSITION OF MICRO-CRYSTALLINE SILICON FOR SOLAR CELLS

Annual Report 2006

Author and Co-Authors	Dr. Ch. Hollenstein, Dr. A. A. Howling and B. Strahm
Institution / Company	Centre de Recherches en Physique des Plasmas, EPFL
Address	PPB Ecublens, Station 13, CH-1015 Lausanne
Telephone, E-mail, Homepage	+41 21 693 34 71, christophe.hollenstein@epfl.ch
Project- / Contract Number	KTI 6947.1
Duration of the Project (from – to)	01.05.2004 - 30.04.2006
Date	05.12.2006

ABSTRACT

A novel very high frequency (VHF) plasma source was applied for large area ($1m^2$) deposition of amorphous and microcrystalline silicon for thin film solar cell production. The use of plasma excitation frequencies (up to 100 MHz) higher than the standard 13.56 MHz excitation frequency allows to substantially increase the plasma density and gas dissociation rates without the drawback of high ion energy bombardment of the substrate and consequent damaging. Therefore higher deposition rates at good device quality can be attained. The crucial problem in very high frequency (VHF) plasma reactors, the non-uniform voltage on the RF electrode, was solved by using adequately shaped electrodes. The proof of principle of this new reactor had previously only been made in non-reactive plasmas. In the present project, the novel RF reactor design was used for the first time in applications, in particular for solar cell production. The achieved aim was to have at the end of the project a high density RF reactor operating at elevated excitation frequencies allowing industrial high rate deposition of amorphous and microcyrstalline (micromorph) silicon with a uniformity of 5-10% on large area substrates relevant for solar cells (typically 1x1 m^2).

Introduction / Project goals

The scientific and technological aim of the present project was to apply the newly-developed technology of the high density reactor to the production of large-area solar cells. The development of the process for amorphous and microcrystalline silicon deposition in this new device was necessary and was therefore a large part of the project. Microcrystalline or micromorph silicon are the materials for future solar cells and therefore their production must be industrially possible using the next generation PV production equipment. Particular care was taken regarding the electronic quality of the layer including film density as well as the deposition rate (≥ 4Å/s) and the uniformity of the layer over the whole 1x1m^2 glass substrate. The achieved aim was to have at the end of a project a high density RF reactor operating at an elevated plasma excitation frequency allowing industrial high rate deposition of amorphous and microcrystalline (micromorph) silicon with a homogeneity of 5-10% on solar cells relevant to large area substrates, typically around 1m^2.

Brief description of the project and installation

The work was carried out in collaboration between the Centre de Recherches en Physique des Plasmas (CRPP) at Lausanne, and Unaxis/Oerlikon SPTec at Neuchatel and Truebbach. The CRPP has studied the theoretical and experimental aspects of plasma uniformity in large-area VHF reactors, and has now also investigated the plasma parameters for micro-crystalline silicon deposition. Unaxis/Oerlikon SPTec has developed a KAI 1200 (1100x1250 mm^2) reactor with a stepped vacuum lens operating at 40 MHz for industrial testing and process development.

Work performed and results obtained

Reactor design. The CRPP has shown that there are two principal causes of plasma non-uniformity: the standing wave effect and the telegraph effect. The standing wave non-uniformity occurs when the reactor dimension is one tenth, or more, of the vacuum wavelength of the rf excitation [1,2,6-8]. This effect can be suppressed by using a special, lens-shaped electrode, and Unaxis currently employs a stepped lens design in a KAI 1200 reactor at 40 MHz operation. The second source of non-uniformity can be eliminated by using symmetric electrodes [3-5]. Furthermore, this year the CRPP has proven that these two effects are necessary and sufficient to completely describe the electromagnetic nonuniformity in a rf reactor [9, 10].

Process parameters. The optimization of microcrystalline silicon (μc-Si:H) deposition by PECVD is difficult to achieve. This is due to the fact that the transition zone from amorphous silicon (a-Si:H) to μc-Si:H cannot be simply defined as a function of the deposition process parameters (pressure, RF power, frequency, flow rates, ...) because of their inter-dependence on the plasma physical properties and chemistry. For example, high dilution of the silane gas with hydrogen is a well-known technique to reach the transition zone, however, depending on the different deposition process parameters and reactor configuration, the transition can occur between silane gas concentration as low as 3 % and as high as 10 % and covers the whole intermediate range. Recently, it has been shown that good μc-Si:H at reasonable deposition rate (4 Å/s) can be deposited even from pure silane gas. Nowadays, most of the μc-Si:H PECVD optimization has essentially been done by experimental empirical parametric studies, due to the difficulty of applying relevant and simple plasma diagnostics in real deposition conditions. In parallel, self-consistent numerical plasma models including a large number of species and reaction rates have been developed in order to achieve the closest simulation of the complex phenomena occurring in the plasma. However, such models remain very complicated to use and to interpret, and are very time consuming, so that they require dedicated plasma modelling specialists, and are therefore not systematically used. Taking this into account, there is therefore a need to develop a simple methodological approach based on simple plasma measurements in order to better understand the behaviour of the transition zone from a-Si:H to μc-Si:H as a function of the deposition parameters.

In this work, Fourier transform infrared absorption spectroscopy measurements in the exhaust line of a large area industrial reactor have been used to determine the silane concentration in the plasma. It has been shown that the microstructure of the deposited film can be defined as a function of the silane concentration *in the plasma*, independently of the plasma parameters. It is shown that μc-Si:H is deposited for silane concentration lower than 0.5 % and that a-Si:H is deposited for concentration in the plasma higher than 1.2 %. These two well-defined regimes are separated by a transition zone where the material can be either amorphous or microcrystalline, because in this zone the plasma composition is not the dominant parameter compared to others such as the substrate roughness [11].

Based on this result, it has been shown that low silane concentration necessary to grow μc-Si:H can be reached even from pure silane gas. Moreover, simple analytical plasma chemistry modelling and experiments have shown that for a fixed silane flow rate, the gas utilization efficiency increased with the silane concentration and has an optimum for pure silane gas. Hence, microcrystalline silicon has been deposited over a large area (47 x 37 cm^2) from pure silane at a rate of 11.5 Å/s with a gas utilization efficiency of 81 % [12, 13].

National collaboration

The CRPP and Unaxis/Oerlikon SPTec were in close contact for feedback on industrial specifications, process conditions, and reactor design and modelling. Collaboration with IMT Neuchatel was also established for material characterisation and comparison with other work on micro-crystalline silicon deposition experiments. Regular progress meetings were held in rotation at CRPP and Unaxis/Oerlikon SPTec Neuchatel and Truebbach.

Evaluation of 2006

The aim of this project was to better understand the guiding principles of silicon thin film deposition in large area reactors for the production of photovoltaic (PV) solar cells. This knowledge has provided the basis of the development of the ultimate cost-effective process for industrial PV solar cell production. The final result is a high density RF reactor operating at an elevated plasma excitation frequency allowing industrial high rate deposition of amorphous and microcrystalline silicon with a homogeneity of 5-10% on solar cells relevant to large area substrates, typically around $1m^2$. Both aspects of the work (electromagnetic uniformity and process optimization) have been widely published in refereed journals.

The present results are of importance for the thin film solar cell equipment manufacturer in Switzerland and in general for the large scale industrialisation of the thin film solar cells. The high level of research and development on this topic in Switzerland should also be maintained in the coming years to face the upcoming competition. Since further-reaching projects have been delayed (for instance in the framework of the CCEM), the ongoing work at the CRPP has been funded for a large part of 2006 by its own funds in order to have a continuity of the research and development. However the industrialisation, either of solar cell producing equipment or of the thin film solar cell itself, still needs academic and industrial research in future. The continuation of this effort is necessary to save the advance in technology and science obtained over the last 20 years in Switzerland.

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STABILITY OF ADVANCED LP-CVD ZnO WITHIN ENCAPSULATED THIN FILM SILICON SOLAR CELLS

Annual Report 2006

Author and Co-Authors	S. Faÿ, C. Ballif
Institution / Company	Institute of Microtechnology – University of Neuchâtel
Address	rue A.-L. Breguet 2, CH-2000 Neuchâtel
Telephone, E-mail, Homepage	+41 32 718 33 31, sylvie.fay@unine.ch, http://www.unine.ch/pv
Project- / Contract Number	KTI 7253.2
Duration of the Project (from – to)	01.11.2004 – 31.10.2006
Date	December 2006

ABSTRACT

The goal of this project, which is now ended, was to study and improve the overall stability of LP-CVD ZnO layers, as incorporated within encapsulated thin-films silicon solar cells. This work was done in order to validate a complete commercial concept of photovoltaic (PV) thin-film silicon solar modules.

During the year 2006, efforts have been concentrated on the understanding of the variations of opto-electronic properties that occur in LP-CVD ZnO films exposed to humid environment. Furthermore, treatments for reducing the LP-CVD ZnO degradation have been further investigated and some of them have shown significant improvement of the ZnO stability against damp-heat exposure.

In parallel, Oerlikon has continued the work on optimizing the encapsulation process for PV modules, reporting regularly PV modules containing layers of LP-CVD ZnO. Several of these 1.4m^2 modules passed successfully the damp-heat test performed by the TÜV Rheinland.

Introduction / Goals of the project

Zinc oxide (ZnO) deposited by Low-Pressure Chemical Vapor Deposition (LP-CVD) has already proven to be a very efficient candidate as transparent electrode to contact thin-film silicon solar cells. Indeed, the low resistivity coupled with the high transparency of the ZnO layers minimize the optical and electrical losses that usually append in a thin-film solar cell device. It is known, however, that ZnO layers are sensitive to humidity. Indeed, ZnO has also been identified as a candidate for gas (and in particular humidity) sensor. This sensitivity to humidity is, for the case of PV modules, a clear drawback, because it can, if not properly mastered, lead to a degradation of the performance of solar modules over the years. It can also hinder the modules from successfully passing the so-called damp-heat test (exposure to 85% humidity at 85°C during 1000 hours), one of the various accelerated lifetime tests that are mandatory to fit the international standards for crystalline and thin-film PV modules (IEC 61215 and IEC 61646).

This project proposed therefore to study systematically the stability with respect to humidity and temperature of current and improved doped LP-CVD ZnO thin-films both as individual layers deposited on glass substrates and as layers completely integrated within a PV device as well. Based on this study, solutions have been figured out and tested in order to validate a complete commercially available technology to manufacture PV modules with an efficiency that decreases less than 5% after passing the standard damp-heat test. The following major quantitative goal for this project has been defined as following: the global cell and module efficiency for high performance devices in the laminated state should not decrease by more than 5% after the damp heat test (1000h @ 85 °C & 85% R.H.).

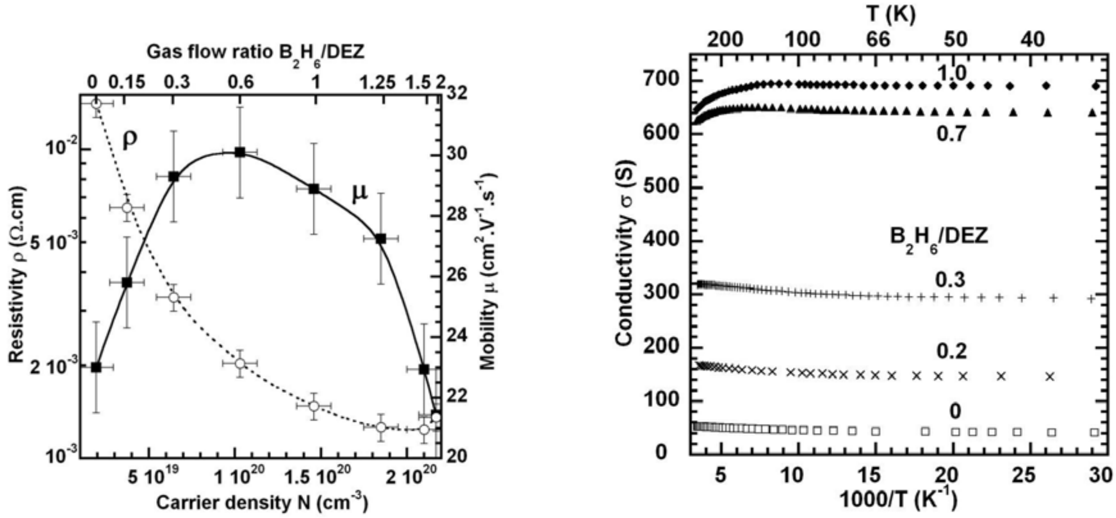
Brief description of the project

Two paths have been explored to achieve the goals of the project:

- **Stability with respect to humidity of doped LP-CVD ZnO layers both individually as well as integrated into the solar modules**: the optical and electrical properties of the ZnO layers have been measured and reported in function of the time spent in the climatic chamber, in order to establish and analyze the functional degradation kinetics. Based on this study, measures to improve the stability of these layers have been proposed and some have been tested.
- **Investigation of various encapsulation materials and techniques:** solar devices and ZnO layers alone have been exposed to damp-heat tests encapsulated with various materials, which were previously tested with respect with their permeation to water and other gases.

Results obtained during the second year of the project

In order to understand more deeply the reasons for the increase of the resistivity of LP-CVD ZnO films which are submitted to humid environment, transport mechanisms have been studied during the year 2006. In particular, the influence of the grain size and the doping level on the electron mobility has been investigated [1, 2]. Fig. 1(a) shows the resistivity (ρ) and the Hall mobility (μ versus the free carrier density (N) for ZnO films grown with the gas phase doping ratio (B_2H_6/DEZ) varied from 0 to 2. ρ decreases from $1.4x10^{-2}$ to $1.2x10^{-3}$ Ωcm with the increase of the gas phase doping ratio from 0 to 2. This variation is mainly caused by an increase of N from $2x10^{19}$ to $2.2x10^{20}cm^{-3}$. μ firstly increases from 23 to $30cm^2V^{-1}s^{-1}$ and then, for $N>10^{20}cm^{-3}$, μ decreases back to $21cm^2V^{-1}s^{-1}$. Fig.1 (b) shows the dependence of the conductivity (σ) as a function of the inverse of the temperature T^{-1} measured from T=300K down to T=30K for ZnO films with various doping levels. From 150K to room temperature, σ becomes temperature dependent with two different trends, according to the doping level of the films. These two different trends, as well as the non-linear variation of μ in Fig.1 (a), can be explained by taking into account two scattering mechanisms whose occurrence depends on the doping level of the ZnO films. Indeed, for low doping levels (i.e. $N < 1x10^{20}cm^{-3}$), σ is increased when T is increased, indicating that some thermally activated mechanisms like the thermoionic emission could occur at the grain boundaries of LP-CVD ZnO films. In contrary, for high doping levels (i.e. $N > 1x10^{20}cm^{-3}$), σ is reduced when T is increased, this trend being characteristic of a metal-like behavior. This is confirmed by the decrease of μ with N for high doping levels, meaning that the electrons are scattered mainly by the added ionized impurities within the grains that constitute the LP-CVD ZnO films. In conclusion, conductivity of highly doped LP-CVD ZnO films is mainly limited by electron scattering within the grains, whereas conductivity of slightly doped ZnO films is mainly limited by electron scattering that occurs at the grain boundaries.



(a) (b)

Fig.1 (a) Resistivity (ρ) and Hall mobility (μ) versus free carrier density (N) for ZnO films grown with gas phase doping ratio (B_2H_6/DEZ) varied from 0 to 2.

(b) Dependence of the conductivity σ as a function of inverse of the temperature T^{-1} for ZnO films with different doping levels.

These results show the strong influence of the electron scattering by grain boundaries for slightly doped LP-CVD ZnO films, whereas electron mobility of highly doped films seems not to be influenced by the size of the grains. Based on these results, further investigations have been carried out to understand the exact role of grain boundaries in the increase of the resistivity for LP-CVD ZnO films submitted to damp-heat test.

In 2005, the industrial partner of IMT, Oerlikon, published results on stability tests done on 10x10cm^2 and 30x22cm^2 encapsulated a-Si:H modules that use LP-CVD ZnO as back contact. Indeed, it has been demonstrated that, with the help of an adequate encapsulation, protected solar modules can pass successfully the damp-heat test. In 2006, Oerlikon published results on stability tests done on 1.4 m^2 encapsulated a-Si:H modules that also use LP-CVD ZnO as back contact [3]. These modules were sent to the German TÜV Rheinland for independent damp-heat investigations, and they also passed successfully the standard damp-heat test of 1000 hours (see Fig. 2).

These results confirm that LP-CVD ZnO has, with a proper adequate encapsulation, a long-term outdoor reliability. Furthermore, these results on 1.4m^2 a-Si:H modules using LP-CVD ZnO as back contact give a good indication that modules made on front LP-CVD ZnO should as well pass the damp-heat test. Indeed, as it has been shown, front ZnO is additionally protected by silicon films which are excellent humidity barriers, meaning that they are much less exposed to moisture than the ZnO back contact.

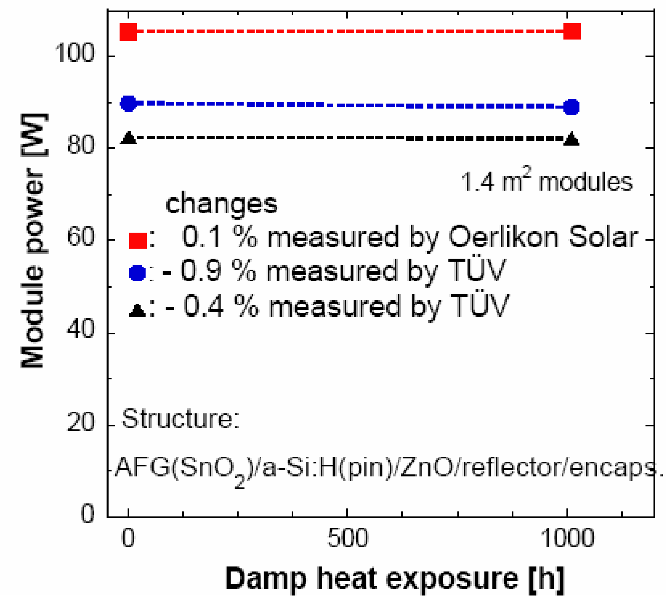


Fig. 2: Damp heat experiments of 1.4 m^2 a-Si:H modules performed and characterized by TÜV Rheinland (Germany) and Oerlikon Solar (note: the red curve represents a recent module where the output power has been measured by Oerlikon before and after the damp-heat experiments of the TÜV.). All modules show an excellent stability over the 1000 h of damp-heat exposure.

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Oerlikon also presented fully encapsulated a-Si-H 1.4 m^2 modules that use LP-CVD ZnO instead of commercially available AFG as front contact. They demonstrated the improved light-trapping within the module obtained by the use of LP-CVD ZnO as front contact (see Fig 3). Initial power of 112.4 W for 1.4 m^2 modules that use LP-CVD ZnO as front contact has been obtained. The damp-heat testing of such modules is still under way.

Fig. 3: AFG a-Si:H p-i-n module (1.4 m^2) on the right hand side and LP-CVD ZnO front a-Si:H p-i-n module on the left hand side. Note the darker appearance of the ZnO, which reflects the improved light trapping compared to AFG.

National and international collaboration

This project was conducted with a close collaboration between IMT and Oerlikon. Indeed, ZnO layers produced by both institutions have been tested and compared systematically, and solar cells and modules have been fabricated by Oerlikon. Furthermore, the NTB research center was also taking part to the project, by developing a tool to perform in-situ measurement of solar modules permeability.

Project evaluation

The objectives of the project have been reached, as complete solar modules using LP-CVD ZnO films have successfully passed the damp-heat test, which is one of the accelerated lifetime tests that are mandatory to fit the international standards for crystalline and thin-film PV modules.

Processes of encapsulation for 1.4m^2 a-Si:H modules have been developed and tested. Complete (laminated and contacted) 1.4 m^2 amorphous modules have been fabricated by Oerlikon using LP-CVD ZnO as back contact. These modules passed successfully the damp-heat tests performed by the TÜV Rheinland (Germany). In parallel, degradation mechanisms within LP-CVD ZnO films have been deeply investigated and well understood. Treatments have been tested and, indeed, some lead to an improvement of the stability of the ZnO films which were submitted to humid environment.

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SPECTRAL PHOTOCURRENT MEASUREMENT SYSTEM OF THIN FILM SILICON SOLAR CELLS AND MODULES

Annual Report 2006

Author and Co-Authors	Dr. Franz Baumgartner
Institution / Company	NTB Hochschule für Technik Buchs, Labor EMS
Address	Werdenbergstr. 4, CH-9471 Buchs
Telephone, E-mail, Homepage	+41 (0)81 755 33 11, Franz.Baumgartner@ntb.ch; www.ntb.ch/pv
Project- / Contract Number	KTI 7112.2 EPRP-IW
Duration of the Project (from – to)	September 2004 - December 2006
Date	February 2007

ABSTRACT

In the last months the industrial project partner OC Oerlikon Solar received overall orders to deliver equipment to build up production lines of thin film silicon solar cells with a yearly production volume above 100 MW. Thereby, up scaling of an optimized laboratory thin film solar cell technology involves always losses in the efficiency of large-area modules due to losses by laser-scribing, by in homogeneities of deposited films, by low control of mass production, etc. Within this optimization process for mass fabrication the analyses of cells and modules by the spectral response measurement is one of the most powerful characterization tool. Today, there are no commercial Spectral Response Measurement System (SRMS) for thin film cells and large scale modules available.

The goal of the present project is to develop an accurate, reliable and fast scan SRMS to analyze a-Si:H single and tandem cells and modules. An SR apparatus on module scale will allow obtaining the photocurrent spectra at different positions on the module. The development process will be performed in close collaboration with the industrial partner to fit the needs of an analytical tool used in an industrial R&D laboratory.

Two SR apparatus on cell level are in operation at the laboratories of the industrial partner. A third SR apparatus measuring the spectral photocurrent on the module level was developed and setup at NTB.

For the first time mapping results of the spectral photocurrent on a 1.4m^2 a-Si:H Oerlikon module was performed. It was found that the method is sensitive to two types of inhomogeneous photocurrent mapping areas. A strong decrease of the spectral response values was localized at a small area of several millimeters, due to pinholes, which were also detected by IR thermo-analyses at the same coordinates. Large scale inhomogeneous photocurrent areas coming along with relatively small changes in photocurrent in the % range are due to changes of layer thickness across the module area.

Zielsetzung und Projektablauf

Zur Optimierung von Solarmodulen bedarf es der geeigneten Messmittel um die Wirksamkeit der Änderung von Prozessparametern zu verifizieren. Alleine aus der Messung des Kurzschlussstroms einer beleuchteten Solarzelle kann noch nicht auf Detailinformationen aus dem vorliegenden Beitrag der einzelnen Schichten bzw. Interfaces einer Dünnschichtsolarzelle geschlossen werden. Der Messung des spektralen Photostroms von Solarzellen, der Bestimmung der Empfindlichkeit der Solarzelle für unterschiedliche Farben des Sonnenlichts, kommt bei dieser Detailanalyse eine zentrale Rolle zu. Aus der Analyse solcher spektraler Photostrommessungen kann beispielsweise auf die optimal gewählte Dicke der p-Schicht einer Dünnschichtsolarzelle oder der optischen Wirksamkeit des TCO geschlossen werden.

(Weitere Details siehe diese BFE Forschungsberichtreihe für die Jahre 2004 und 2005.)

Zusammenfassung: Ziele wurden erreicht

Schon bei kleinflächigen Laborsolarzellen ist die Charakterisierung des spektralen Photostroms im Rahmen der Forschung und Entwicklung ein unverzichtbares Messmittel, um die optimalen Halbleiterschichten zu ermitteln. Sollen allerdings im industriellen Entwicklungsprozess auch kleine Verbesserungen der Charakteristik zuverlässig aufgelöst werden, so bedarf es einer stabilen Messeinrichtung. Im Zuge des vorliegenden Projektes konnte das realisierte Spectral Response Measurement System SRMS für Zellen, bei täglichem Betrieb, über eine ausgezeichnete Langzeitstabilität nachweisen (<1% Eigenabweichung über 4 Monate nach Kalibrierung). Die entwickelte SRMS Software erlaubt den direkten Vergleich und Analyse der Photostrom Spektren verschiedener Messreihen. Zusätzlich bietet das SRMS die automatische Messung von Tandemsolarzellen (Fig. 1) durch die automatische Einstellung des nötigen Bias light. Der Tandem-Zelltyp bietet eine deutliche Steigerung des Zellenwirkungsgrades und wird von OC Oerlikon als zukünftiges Produkt lanciert.

Der Wirtschaftspartner hat in den letzten zwei Jahren seine dominante Rolle als Anbieter von Produktionsanlagen für Dünnschicht a-Si:H Markt ausgebaut. Der anspruchsvollste Teil des vorliegenden Projektes lag in der Entwicklung eines automatischen Messsystems, welches an jedem Punkt eines $1.4m^2$ grossen Moduls den spektralen Photostrom messen kann. Wie das Beispiel des Messergebnisses an einem nicht optimalen Modul in Fig. 2 zeigt, kann mit dem Messsystem punktuelle die Abnahmen des spektralen Photostroms um einige 10% gemessen werden. Dies konnte auf lokalen Störungen in der Schichtstruktur (Pinholes) zurückgeführt werden. Diese auf wenigen Millimetern lokalisierten Bereiche der starken Abnahme des Photostroms konnte durch Vergleichsmessungen mit der Thermokamera eindeutig reproduziert werden.

Zusätzlich bietet jedoch die grossflächige Verteilung des analysierten spektralen Photostroms innerhalb von wenigen % Abweichung (siehe Grenze zwischen gelbem orangem Bereich in Fig. 2) einen Rückschluss auf die Homogenität der abgeschieden Teilschichten. Diese Messauflösung konnte nur erreicht werden, da in unmittelbare Nähe des monochromatischen Spots auch der elektrische Photostromabgriff erfolgt. Dazu musste das Analysesystem in Summe vier unterschiedliche Achsen automatisch steuern.

Mit dem entwickelten Analysegerät konnte erstmals für den industriellen Einsatz die Homogenität eines a-Si Dünnschichtmoduls bei verschieden Wellenlängen gemessen werden. Das System ist auch für die automatische Messung an Tandemmodule einsetzbar.

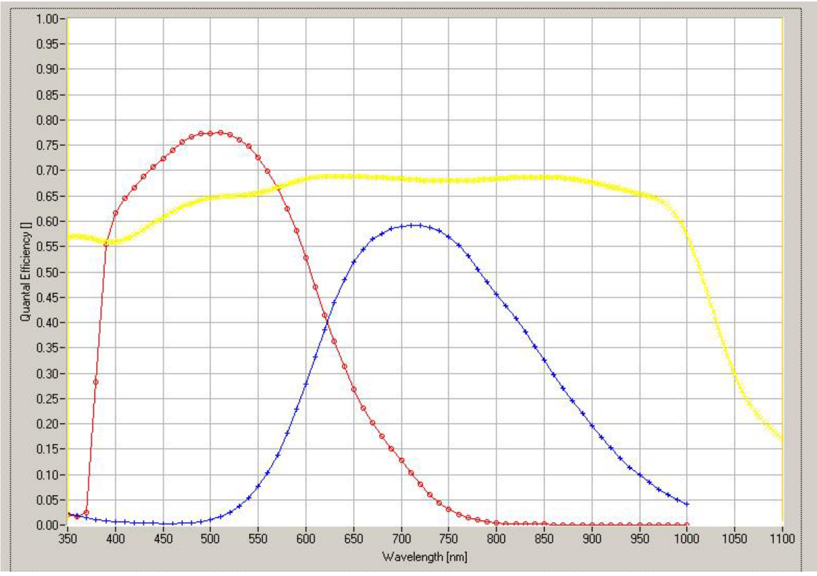

Fig. 1: Automatische Messung der beiden spektralen Photostromcharakteristika der a-Si:H Top- und der µcrSi:H Bottom-Solarzelle einer Oerlikon Dünnschicht-Tandem-Solarzelle.(Ordinate: Quantum Efficiency QE)

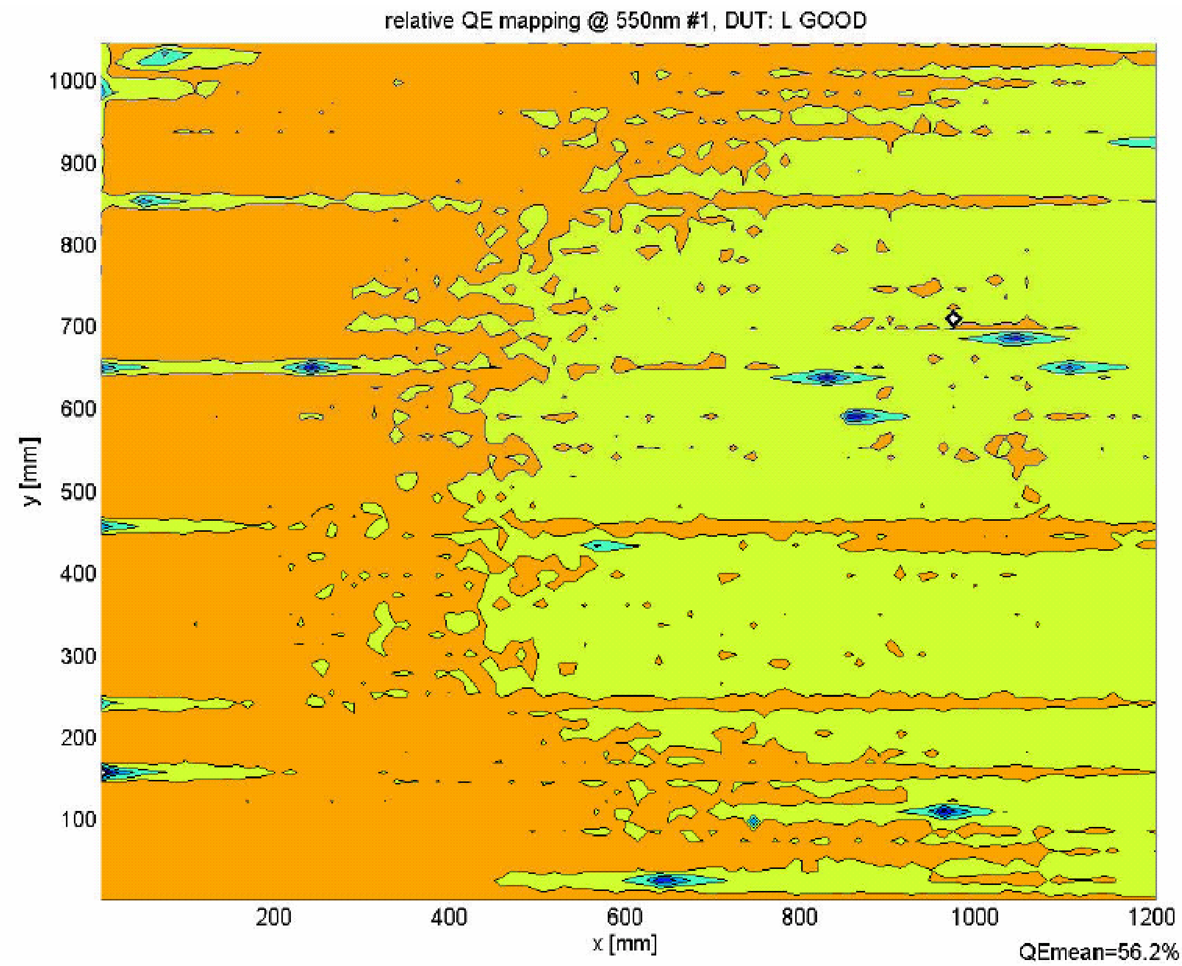

Fig. 2: Homogenität des spektralen Photostroms (bei 550nm) gemessen an einem grossflächigen nicht optimalen 1.4m^2 Oerlikon a-Si:H Dünnschichtsolar-Modul. Die dunklen Punkte korrelieren mit dem Auftreten von Schichtdefekten wobei dadurch der Photostrom um über 30% absinken kann)

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Internationale Zusammenarbeit

Mit der Zielsetzung spektrale Photostrom-Messungen an a-Si:H Dünnschichtmodulen am Europäischen Forschungszentrum JRC, auszuführen, wurden vom Projektleiter zwei wissenschaftliche Aufenthalte am JRC Ispra im Jahr 2005 und 2006 absolviert. Neben den zahlreich durchgeführten Referenzmessungen stand aber der Erfahrungsaustausch über die Problematik der generellen Performance Messungen von amorphen Dünnschichtsolarmodulen jeweils im Hinblick auf die spektrale Charakteristik im Vordergrund. Den Zugriff auf die gesamte Palette der PV Messmöglichkeiten am JRC war ein sehr grosszügiges Entgegenkommen von Seiten des JRC und war sehr fruchtbar für den Erfolg des vorliegenden Projekts. [3]

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FLEXCELLENCE: ROLL-TO-ROLL TECHNOLOGY FOR THE PRODUCTION OF HIGH EFFICIENCY LOW COST THIN FILM SILICON PHOTOVOLTAIC MODULES

Annual Report 2006

Author and Co-Authors	V. Terrazzoni, F.-J. Haug, C. Ballif
Institution / Company	Institute of Microtechnology (IMT) / University of Neuchâtel
Address	Rue A.L. Breguet 2, CH-2000 Neuchâtel
Telephone, E-mail, Homepage	+41 32 718 33 30, vanessa.terrazzoni@unine.ch, www.unine.ch/flex
Project- / Contract Number	SES-CT-019948
Duration of the Project (from – to)	01 10 2005 – 30 09 2008
Date	December 2006

ABSTRACT

FLEXCELLENCE (www.unine.ch/flex) is a European project (STREP) financed by the 6^{th} framework program. It started on October 1^{st} 2005 and is set to last 3 years. FLEXCELLENCE aims at developing the equipment and the processes for cost-effective roll-to-roll production of high-efficiency thin-film modules, involving amorphous (a-Si:H) and microcrystalline silicon (µc-Si:H). Eight partners, with extended experience in the complementary fields of cells and processing, modules and interconnections, production and machinery and reliability are involved; IMT is coordinator of this project.

Within the first year, IMT was mainly involved in the development of high-quality and high-throughput µc-Si:H layers on $30*30cm^2$ area, in the investigation of new textured plastic substrates and in the optimisation of single a-Si:H and µc-Si:H cells as well as tandem micromorph cells.

The deposition on large area and at high rate resulted in device grade quality µc-Si:H layers grown at a rate of 2nm/s on rigid glass substrates. The results will now be transferred to flexible plastic substrates. In tests on different textured PEN substrates initial efficiencies of 7.8% for a-Si:H cells and 8.3% for the µc-Si:H cells have been achieved. The combination into micromorph tandem cells yielded an initial efficiency of 9.6%. Degradation under 1000 hours of continuous illumination resulted in stabilized efficiency of 8.5% which corresponds to a degradation of only 11%. The substrate preparation and the back reflector deposition for these cells was carried out by industrially compatible by roll-to-roll processes.

In the framework of this project and in collaboration with the centre for plasma research at the EPFL, VHF-Technologies has designed and installed a new wider VHF-PECVD electrode, which is now being tested. The first deposition of amorphous layers showed good homogeneity over the web width of 50cm. In parallel to the up scaling towards higher production capacity, VHF is carrying out a wide range of module stability and reliability tests.

Introduction / Project goals

The goal of the project is to **develop the equipment and the processes for cost-effective roll-to-roll production of high-efficiency thin-film modules**, involving microcrystalline (μc-Si:H) and amorphous silicon (a-Si:H) [1]. All aspects necessary for a successful implementation of this novel production technology (cell processing, interconnection, encapsulation and machinery) are considered simultaneously, by benefiting from the extended experience of the partners in the different sectors.

The challenges are (1) to demonstrate that the **technology developed in the project is suitable for high efficiency and reliable modules**, (2) to develop and validate the processes necessary for successful roll-to-roll production including **new technology for interconnection** and **new substrates concepts**, (3) to demonstrate **high-throughput manufacturing techniques**, (4) to conceive and test all the equipment necessary for the realisation of a **roll-to-roll production line**, (5) to achieve a **final blueprint planning** of a complete roll-to-roll production line for modules with production costs of less than 0.5 €/Wp.

Description of the project

In order to achieve high efficiency μc-Si:H/a-Si:H tandem devices, effective light trapping schemes are implemented on flexible substrates and high efficiency solar cells and modules are developed on these new surfaces. Laboratory scale solar cells and mini-modules (10*10 cm^2) with 11% and 10% efficiency, respectively are expected in order to demonstrate that tandem junction μc-Si:H/a-Si:H can compete with current technologies for electricity output per square meter.

The deposition rates of the intrinsic microcrystalline silicon (μc-Si:H) layers need to be increased from typically 0.1nm/s to 2nm/s: three of the most promising techniques for high rate deposition are investigated (Very High Frequency Plasma Enhanced Chemical Vapour Deposition VHF-PECVD, Hot Wire Chemical Vapour Deposition HWCVD and Microwave Plasma Enhanced Chemical Vapour Deposition MW-PECVD). A benchmarking of the different deposition techniques will take place and will indicate which method emerges as the most cost-effective and could be implemented in the different pilot production lines of the partners.

In parallel, the system aspects going from the cells to the modules are studied; the critical aspect of monolithic cell integration with minimum electrical and optical losses will be addressed by using scribing/screen printing techniques, and new concepts for more cost-effective encapsulation materials and processes will be investigated.

All the innovative results, hardware developments, concepts and designs worked out in the project will lead to new systems (substrate preparation/deposition reactor/laser scriber/screen printer) that will be integrated directly into the pilot production lines. They will also be used for the final blueprint of multi-megawatt production lines that can achieve the production of modules with production costs of less than 0.5Euros/Wp.

Results

In the following, different aspects of the work performed at the IMT and VHF-Technologies are presented. The first results concerning the development of high-throughput μc-Si:H layers, the progresses realized in the development of the substrates, and the best results obtained in cells are successively discussed .

High quality and high-throughput μc-Si:H

Within FLEXCELLENCE, the electronic quality and the deposition rate of μc-Si:H deposited on flexible substrates is being improved by studying simultaneously the three most promising methods, which are the VHF-PECVD, MW-PECVD and HWCVD (See Figure 1).

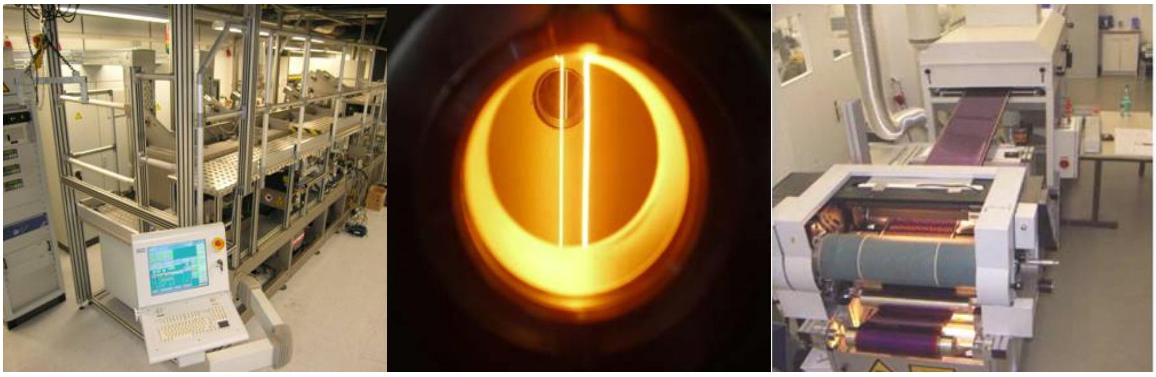

Figure 1: (left) New MW-PECVD roll-to-roll system built by the system manufacturer R&R and now used at ECN, (Middle) New large area HWCVD system at the UBA, (right) Roll-to-roll production line at VHF-Technologies.

At the IMT, high rate and high quality intrinsic μc-Si:H layers deposited in a static process by VHF-PECVD onto 30*30cm^2 substrates could be demonstrated. Deposition rates up to 2 nm/s were reached, and the activation energy E_a, the conductivity σ_{light} and Urbach Tail Slope (UTS) reached 0.47eV, 2.10^{-4} (Ω.cm)$^{-1}$ and 53meV, respectively. The electrical quality of the layers is comparable to the standard μc-Si:H layers deposited in the same system at lower deposition rate of about 0.5nm/s (see Table 1). These high rate layers have also been successfully incorporated into test cells.

Table 1: Data of different microcrystalline layers deposited by VHF-PECVD at high rate.

	Rate	Raman CVF	σ_{RT}	E_A	σ_{light}	UTS
Sample #	[nm/s]	[%]	[1/Ωcm]	[eV]	[1/Ωcm]	[meV]
K060116	0.5	41	2.0x10^{-6}	0.48	n.a.	51
K060815	2.0	63-55	2.1x10^{-7}	0.47	2.0x10^{-4}	53

So far, the experiments have been performed on glass. The next step will be transfer of these results to plastic substrates.

In the meantime, VHF-Technologies together with the Plasma Physics research centre (CRPP) of the EPFL have designed, fabricated and mounted the prototype of a new 50 cm wide VHF-PECVD electrode. The electrode has been installed in the new 2 MW VHF-PECVD reactor and the first trials have shown excellent results; it is anticipated that uniformities of +/-3% across the web width should be reached within the next weeks.

Development of large area and high quality plastic substrates

One goal of FLEXCELLENCE is to develop a new and mature solution for high quality and cost effective substrates, fabricated by roll-to-roll process. Two types of substrates are being developed:

- Metallic substrates, involving an insulating layer to enable the monolithic interconnection,
- Nano-structured plastic Polyethylene Terephthalate (PET) and Polyethylene Naphthalate (PEN) substrates with high quality light trapping properties.

The IMT is mainly involved in the development of the plastic substrates. Therefore, two texturing methods for PET and PEN are tested:

- The hot embossing technique, which gives the possibility to deposit the cells directly on the PET or PEN surface, is currently developed in collaboration with the University of Barcelona (UBA) [2],
- The roll-to-roll proprietary technique of OVD-Kinegram A.G which is currently used at the IMT.

With both methods, different texture shapes and sizes have been achieved [2] and the Fraunhofer Institute FEP developed high quality reflecting stacks deposited on these substrates in its large area roll-to-roll production line (coFlex® 600).

The IMT studied a variety of different reflecting stacks, textures and substrates [3] and promising results have already been obtained in solar cells.

Solar cells

Plastic substrates offer many advantages but the cell processing must be adapted to new particularities, like outgassing, reduced deposition temperatures and different thermal expansion properties which could result in strong mechanical stresses in the the active layers.

In order to demonstrate high efficiency devices, a-Si:H and μc-Si:H single cells as well as micromorph tandem cells were prepared in the nip configuration and optimized on plastics. This work was partly realized in a recently implemented double chamber laboratory scale system. The most promising results are presented in the following:

- Single μc-Si:H cells

Considerable effort has been put on the development of the μc-Si:H single cell on plastic. On the periodically structured PEN substrates supplied by OVD and coated at the FEP, 8.3% initial efficiency could be obtained with V_{oc}=531mV, FF=69.9% and J_{sc}=22.19mA/cm^2.

- Single amorphous cells

A first generation of a-Si:H cells was developed in the double chamber system, on the substrates also used for the μc-Si:H cells. So far, 6.2% initial efficiency (V_{oc}=874mV, FF=64.7%, J_{sc}=11.07mA/cm^2) was obtained on the substrates also used for the μc-Si:H cells. For comparison, in the well established single chamber system the efficiencies on these substrates are about 7.8%. Based on results reported by J. Bailat at al [4], there is still considerable room for the improvement for the a-Si:H devices.

- Micromorph tandem cells

Tandem cells up to 9.6% initial efficiency (V_{oc}=1.34V, FF=69% and J_{sc}=10.4mA/cm^2) have been deposited on the same substrates. Current matching has been achieved by adjusting the thicknesses of the two individual absorber layers, but the FF and Voc of the tandem cell still have to be improved. Degradation under 1000 hours of continuous illumination resulted in stabilized efficiency of 8.5% which corresponds to a degradation of only 11% and constitutes a record value on PEN substrate.

Encapsulation and cost simulations

Finally, VHF-Technologies conducted a first cost simulation for a hypothetic reference plant fabricating 1 Mio m^2 per year of flexible encapsulated modules for building integration. The calculation was performed for different type of cell technologies on polymer substrates. Preliminary interesting results have shown that:

- The encapsulation materials dominate the bill, whatever the cell configuration,
- For 5% efficient a-Si:H modules and 50 MW annual capacity, the production costs could be reduced to below 0.8 €/Wpeak.

Collaborations

The project is divided in 8 workpackages, with a minimum of 3 participants in each worpackage. The composition of the WP should ensure a maximum cross-fertilisation and exchange of the scientific and technological know-how. The seven R & D related workpackages are organised in a logical way, starting from substrate preparation (WP2), to cells with increased complexity (WP3-5), to the monolithic interconnection issue (WP6). Then, the complete modules including packaging are tested (WP7) and finally, detailed cost assessments for multi-megawatt roll-to-roll production lines are given in WP8.

An exploitation panel is formed by representatives of the industries in order to optimise the exploitation strategy of the project.

Conclusion

The breakthrough expected in FLEXCELLENCE is the development of a complete technology for the production of flexible, cost-effective and high efficiency PV modules.

In the framework of the project, the IMT has demonstrated high quality μc-Si:H layers deposited by VHF-PECVD at 2nm/s. This result was obtained on glass and will now be transferred to plastic. In addition, a-Si:H, μc-Si:H and tandem micromorph cells are being developed in a new double chamber laboratory-scale system on PEN substrates. The substrates were prepared by roll-to-roll processes and initial efficiencies of 7.8%, 8.3% and 9.6% have been obtained so far for a-Si:H, μc-Si:H and tandem micromorph cells respectively.

VHF-Technologies in collaboration with the CRPP of the EPFL have designed, fabricated and mounted the prototype of a new 50 cm wide VHF-PECVD electrode into the new 2MW pilot line, and conducted preliminary cost estimates showing the low cost potential of flexible thin film Si modules.

More information on the project can be found at: www.unine.ch/flex

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ATHLET: ADVANCED THIN FILM TECHNOLOGIES FOR COST EFFECTIVE PHOTOVOLTAICS

Annual Report 2006

Author and Co-Authors	N. Wyrsch, C. Ballif
Institution / Company	Institute of Microtechnology (IMT) / University of Neuchâtel
Address	Rue A.L. Breguet 2, 2000 Neuchâtel
Telephone, E-mail, Homepage	+41 32 718 33 57, Nicolas.wyrsch@unine.ch, www.unine.ch/pv
Project- / Contract Number	IP 019670
Duration of the Project (from – to)	01.01.2006 – 31.12.2009
Date	December 2006

ABSTRACT

ATHLET (Advanced Thin Film Technologies for Cost Effective Photovoltaics) is a European integrated project (IP) financed by the 6th framework program. The consortium of 23 partners (and 5 associated partners) from 11 EU countries is led by HMI Berlin. The consortium comprises also 3 Swiss partners: IMT, Oerlikon and the ETH Zurich. ATHLET's main goal is to provide scientific and technological basis for an industrial mass production of cost effective and highly efficient, environmentally sound, large-area thin film solar cells and modules. It focused thus in the development of thin-film silicon solar cells and modules, as well as chalcopyrites cells and modules with Cd-free buffer. The project aims at providing production and module concept for a price/efficiency ratio of 0.5 €/W_p or lower.

Regarding thin-film silicon, the project target is to developed micromorph tandem > 1 m^2 modules with a stable efficiency of 10% fabricated at a deposition rate of at least 10 Å/s. In parallel, small area cells will be further developed (next generation of cells) in order to reach a stable efficiency of 14%.

Within the first year, IMT work within ATHLET was split on one hand in the further development of small area component (with a focus on the reproducibility of the deposition process) and on the other hand on the development of μc-Si:H cell in an industrial KAI-S reactor (with a focus on medium to high deposition rates). Design and assembly of a new double chamber KAI-M reactor has also been supported by the project. Finally, an upgrade of our lockin thermography system has been carried out in order to offer an important support for the analysis of defects in solar cells and modules, as well as to help optimizing laser scribing steps for the monolithic interconnection.

Introduction / Project goals

This project focuses on the most promising material and device options for thin film technologies, namely cadmium-free cells and modules, based on amorphous, micro- and polycrystalline silicon as well as on chalcopyrite compound semiconductors (CIGS).
The overall goal is to provide the scientific and technological basis for an industrial mass production of cost effective and highly efficient, environmentally sound, large-area thin film solar cells and modules.
By drawing on a broad basis of expertise, the entire range of module fabrication and supporting R&D are covered: Substrates, semiconductor and contact deposition, monolithic series interconnection, encapsulation, performance evaluation and applications.

The main objectives are:

- significantly reducing the cost/efficiency ratio: towards 0.5 €/Wp on the long run
- providing the know-how and the scientific basis for large-area PV modules by identifying and testing new materials and technologies with maximum cost reduction
- developing the process know-how and the production technology as well as the design and fabrication of specialised equipment resulting in low costs and high yield in the production of large area thin film modules.

In the case of thin-film silicon solar cells, the specific objectives are the following:

- The development of large area micromorph modules (> 1 m^2) with a 10% stable efficiency deposited at ≈10 Å/s
- A production concept for module cost < 0.5 €/W_p

Development of high efficiency thin-film Si cell on small area is also part of the project with a target stable efficiency of 14%.

Description of the project

The project is organised in 6 sub-projects (SP, cf. Fig. 1):

- 2 sub-projects for the large-area development of CIGS modules thin-film Si modules
- 3 supporting sub-project for new cell concept development(high efficiency cell development), device modelling and characterisation and module aspects (substrates, contacts and encapsulation)
- One sub-project dealing with sustainability, training and mobility.

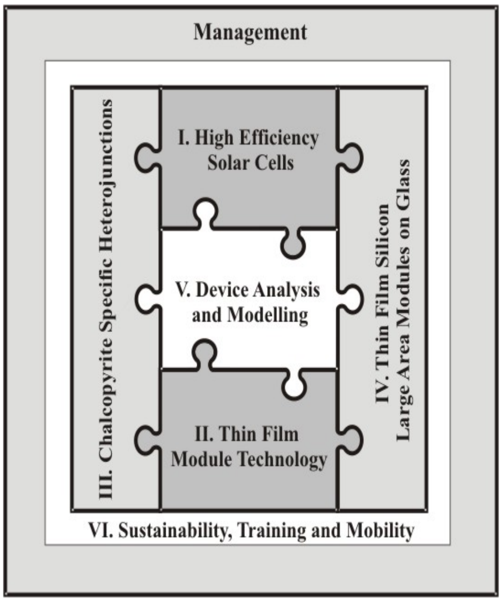


Fig. 1: Schematic organisation of the ATHLET project with its 6 sub-projects. Two vertical sub-projects (SP) are oriented along the value chain:

- SP III focuses on large area, environmentally sound chalcopyrite modules with improved efficiencies
- SP IV deals with the up-scaling of silicon based tandem cells to an industrial level.

Four horizontal sub-projects have a trans-disciplinary character:

- SP V provides analysis and modelling of devices and technology for all other sub-projects.
- SP I will demonstrate higher efficiencies of lab scale cells.
- SP II focuses on module aspects relevant to all thin film technologies.
- SP VI ensures that the performed work have a positive impact on the environment and the society.

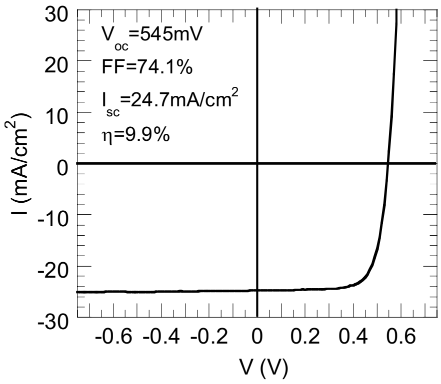
The ATHLET consortium comprises 23 partners from 11 EU countries, including 7 industrial partners, research centres and academic institutions. Athlet is coordinated by HMI Berlin (D). Three Swiss partners are participating: The University of Neuchâtel (IMT) which is coordinating SP IV (SP IV) while also participating in SP I, Oerlikon which is also participating in SP IV and the ETH Zurich (Prof. A. Tiwari) is participating in SP I and III.

Results

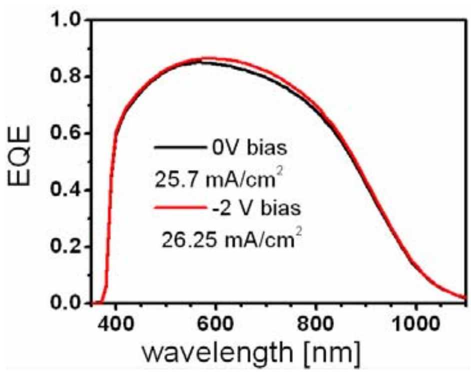
The main results obtained in 2006 by IMT and Oerlikon (in the framework of Athlet and partially also of CTI and OFEN projects) are summarized below.

Small area thin-film silicon cells

Activities of IMT on this topic are strongly linked with the National OFEN project. The main effort in 2006 was focused in the development of component cell for a micromorph tandem. The best efficiency for the a-Si:H and μc-Si:H cells were 10.2% resp, 9.9%; cell IV and quantum efficiency data are given in Fig. 2.



a)



b)

Fig. 2: Current-density voltage curves of the best microcrystalline silicon solar cells fabricated in 2006; the cell efficiency is 9.9% with a 1.8 μm thick intrinsic layer. b) External quantum efficiency of a microcrystalline silicon solar cells optimized for high current.

These good results were obtained thanks to the development of a new ZnO transparent conductive oxide with better surface morphology (developed in the framework of an OFEN project) and to a better reproducibility of the deposition process.

Large area thin-film silicon cells

The up-scaling path from small area reactor to the large area KAI 1200 reactor of Oerlikon (1.4 m^2) goes through 2 intermediate sizes, i.e. the KAI-S (35x45 cm^2 electrode size, work done at IMT) and KAI-M (45x55 cm^2 electrode size, work done at Oerlikon).

Regarding amorphous silicon test cell in KAI-M reactor, the best results are summarized in Fig. 3. The up-scalling to 1.4 m^2 leads to a module efficiency (aperture area) of 8.6%.

IMT has so far focused on the development of μc-Si:H component in the KAI-S reactor. The best efficiency for a test cell was 8.4%. A 6% efficiency has also been obtained for the same kind of cell, deposited at 10 Å/s in the same reactor in a completely different plasma regime with low silane dilution. Micromorph cells and modules are now also developed at Oerlikon in the KAI-M and at IMT in the KAI-S. A 10% initial efficiency has already been obtained by Oerlikon (cf. Fig. 4).

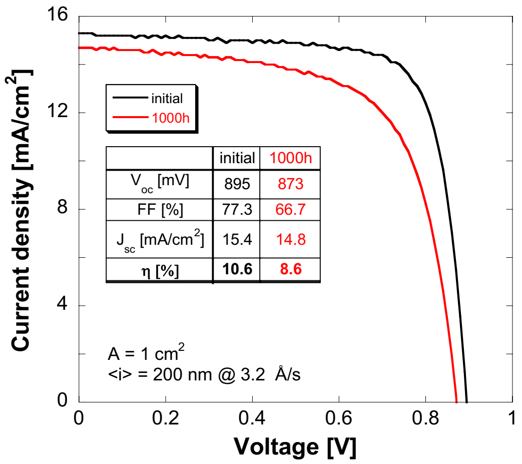


Fig. 3: Best amorphous p-i-n test cells in the initial and light-soaked state processed in a small R&D single-chamber KAI-M reactor. A front TCO Asahi U-type SnO_2 was used.

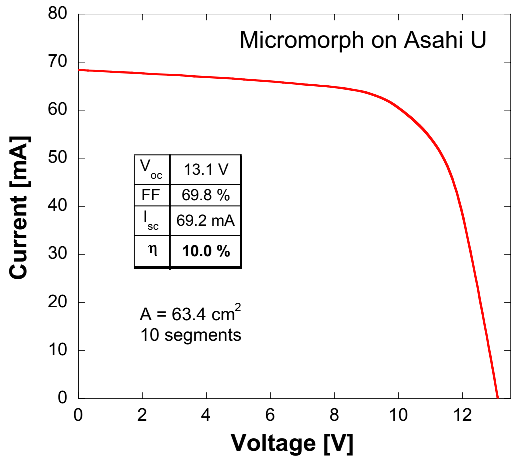


Fig. 4: 10x10 cm^2 micromorph tandem mini-module of 10 segments achieving 10.0 % initial aperture efficiency.

Large area deposition systems

In order to offer a better transfer of IMT developments from IMT to Oerlikon, as well as to study other deposition regimes for μc-Si:H cells, A KAI-M double system was designed at IMT and is currently being assembled with the support of the ATHLET project. This system will also comprise several characterisation tools and plasma diagnostics. For the latter, a close collaboration is underway with the University of Patras who performed several measurement of the various IMT small size and large area reactors.

Module characterisation

Module characterisation is an important aspect of the ATHLET project. IMT has set up in 2005 a lockin thermography system to identify shunts ad defects in solar cells and solar modules. The system has been upgraded in 2006 to allow a superposition of thermal and visible image in order to offer better diagnostics. This system is a very useful tool for optimizing the laser scribing steps of the monolithic interconnection of PV module. An example of a thermal image of a large a-Si:H module is given in Fig. 5.

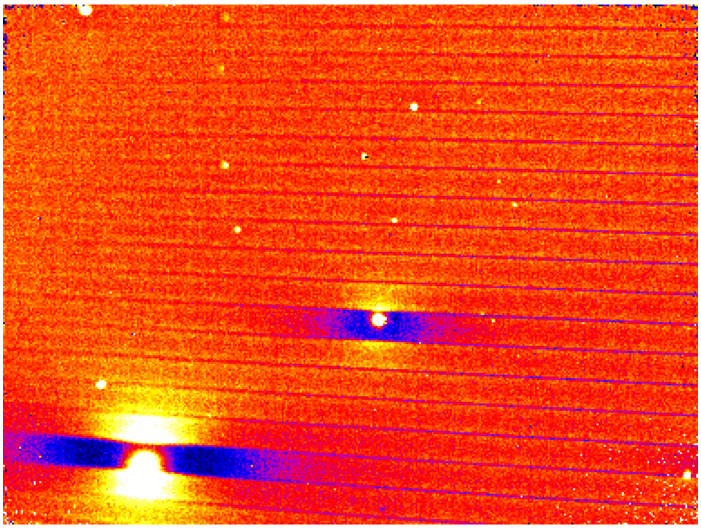


Fig. 5: Thermal image (from lockin thermography system) of a large area a-Si:H modules (part of a 1.4 m^2 module). The individual diodes with the scribe lines are clearly visible, as well as two major shunts which induces a current drop around them (in the same diode.)

Conclusion

The integrated ATHLET project focuses on the two main PV thin-film technologies: thin-film silicon and CIGS. Research is organized either along the value chain of each technology or with a trans-disciplinary (or trans-technology) character in order to target every aspects of the module development from the substrate to the encapsulated module. Despite the large size of the consortium, the organization in sub-projects allows relative good research efficiency and fruitful collaborations. These collaborations comprise the exchange of layers, cells, measurement results, services, but also discussions and experience exchanges during project meetings.

Collaborations

Beside the strong partnership between Oerlikon and IMT, this Athlet project allows a fruitful collaboration with the Institut für PV of the Jülich Forschungszentrum, the Instute of Physics of the Academy of Science of Prague, the University of Patras (Greece), Schott Solar in Germany, Saint-Gobain Research, among the most important ones.

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SIWIS: ULTRA THIN SILICON WAFER CUTTING BY MULTI-WIRE SAWING

Annual Report 2006

Author and Co-Authors	K. Wasmer, J. Michler
Institution / Company	Empa, Materials Science and Technology, Mechanics of Materials and Nanostructures
Address	Feuerwerkerstr. 39, CH-3602 Thun
Telephone, E-mail, Homepage	+41 33 228 36 36, kilian.wasmer@empa.ch, www.empathun.ch
Project- / Contract Number	CTI Nº 7730.2 NMPP-NM
Duration of the Project (from – to)	01.12.05 – 30.11.07
Date	January 2007

ABSTRACT

The industrial partner, HCT Shaping Systems SA (HCT) has a specific machine concept, mutli-wire slurry saw for semiconductor and solar industry. The objectives of the SIWIS project are to understand and control the surface defect generation mechanisms governing the yield in multi-wire sawing of silicon wafers. The development activities of the project focus on analysing and characterising surfaces of sawn wafers and to develop models of free wire sawing. The main motivation of behind this project is to to develop a multi-wire-sawing process technology that allows mass production of thin crystalline silicon wafer (<100μm) suitable for solar cell production.

As of today, the following specific points were achieved:

- Measurement of roughness of sawn wafer to determine the influences of sawing parameters.
- Measurement of sub-surface defects of sawn wafer to determine the effects of sawing parameters.
- Scratching and indentation of silicon by normal nanoindentation machine as well as *in-situ* scanning electron microscope. This study allows a fundamental understanding of the deformation process in silicon.
- Compression tests of micro-pillars under Raman spectroscopy. This investigation let the phase transformation and fracture mechanisms under uniaxial condition to be explored.
- Development of a bench test for wafer strength measurements
- Development of a scale-up wire sawing bench test

Introduction / Project objectives

Silicon ingot material and slicing amounts today to about 1/3 of the total manufacturing costs of solar modules. This is due to the loss of raw material (kerf loss) during slicing which is approximately 50%. Furthermore, the current average wafer thickness in production is 280-220µm. An additional loss comes from the high number of wafers broken during the manipulation after sawing due to sub-surface defects (SSD). Hence, the cost of solar modules can be reduced by diminishing the kerf loss, reducing the thickness of the wafer and increasing the strength of the wafers.

The scientific objectives are:

1. Understand the deformation process of silicon during scratching and indentation
2. *In-situ* observation of deformation process, crack initiation and propagation during scratching and indentation.
3. Controlling the roughness of surfaces, initiation and propagation of microcracks during sawing.
4. Identify and understand the interaction of slurry flow, wire motion and rolling-indenting particles.
5. To understand and model the crack propagation with respect to the different length scale

The technological objectives are:

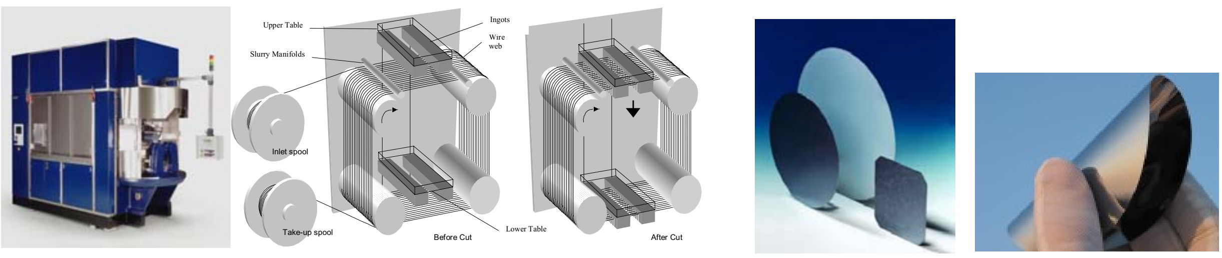
6. Classification of the Sub-Surface Defects (SSD)
7. Set-up a test bank to measure the mechanical fracture strength of sawn wafers
8. Set-up a test bank / scaled-up wire saw to study the interaction between the wire, the slurry and the silicon ingot.
9. Optimisation of the wire saw process including the influence of the slurry.

The first year of the project focused on objectives 1, 2, 3, 6, 7 and 8.

Technical Summary

In essence, a Mutli-Wire Slurry Saw (MWSS) consists of a wire being managed to constitute a multi-wire web, allowing an abrasive liquid to penetrate an ingot driven through the web. More specifically, it consists of one 160µm-dia. steel wire moving, either uni-directionally or bi-directionally, on the surface of the workpiece (e.g., silicon ingot). The single wire is wound on wire-guides carefully grooved with constant pitch forming a horizontal net of parallel wires or web (Figure 1a). The wire-guides are rotated by drives, causing the entire wire-web to move at a relatively high speed (5-25 m/s). A couple of high flow-rate nozzles are feeding the moving wires with an abrasive suspension ("slurry") into the cutting zone to produce a cut. The workpiece (or the wire-web) is moved vertically. The wire tension is maintained constant (10-30 N) during the cutting process with state-of-the-art feedback control. A wire feed reel provides the length of new wire and a wire take-up reel stores the used wire.

In MWSS, material is removed by third-party free abrasive grains transported in a liquid media (slurry). The primary functions of the slurry are as follows: (i) carrying the abrasive particles to the cutting zone; (ii) flush away workpiece chips and residues (kerf); (iii) heat removal by the slurry liquid carrier. Most commonly used slurry are oil-based, water-soluble and water-based coolant, with generally SiC as abrasive. For silicon material, water-based coolant is not recommended because of hazardous hydrogenation effect. Because the cost of slurry (abrasive + coolant) contributes to about 80% of the MWSS consumables cost, slurry consumption becomes one of the very important aspects of the wire saw operation, not mentioning waste issues.



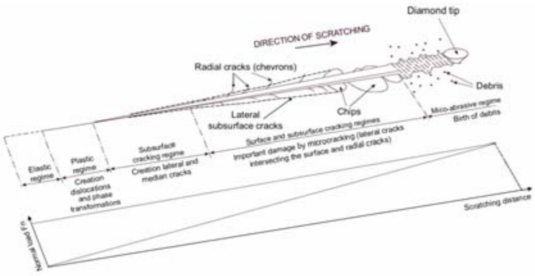
(a) **(b)** **(c)**

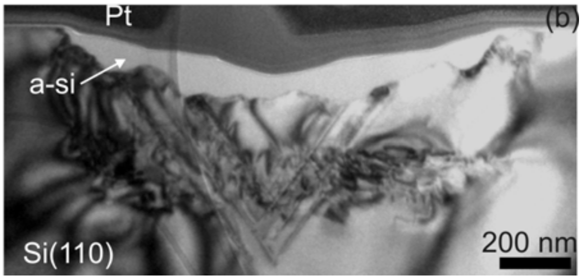
Figure 1: a) Schematic of a mutli-wire slurry saw, b) silicon wafer sawn, c) silicon wafer containing no defects

Ongoing Work and Results 2006

Task 1:

To understand the abrasion process, nanoscratching experiments were performed with different loading conditions to simulate the action of a single abrasive particle on the surface. The deformation mechanisms of silicon {001} surfaces during nanoscratching (see Fig. 2 (a), taken from [1]) were found to depend strongly on the loading conditions [2]. The load-penetration-distance curves acquired during the scratching process at low velocity suggests that two deformation regimes can be defined, an elasto-plastic regime at low loads and a fully plastic regime at high loads. High resolution scanning electron microscopy of the damaged location shows that the residual scratch morphologies are strongly influenced by the scratch velocity and the applied load. Micro-Raman spectroscopy shows that after pressure release, the deformed volume inside the nanoscratch is mainly composed of amorphous silicon and Si-XII at low scratch speeds and of amorphous silicon at high speeds. Transmission electron microscopy shows that Si nanocrystals are embedded in an amorphous matrix at low speeds, whereas at high speeds the transformed zone is completely amorphous as shown in Fig. 2 (b), taken from [1]. Furthermore, the extend of the transformed zone is almost independent of the scratching speed and is delimited by a dislocation rich area that extends about as deep as the contact radius into the surface.



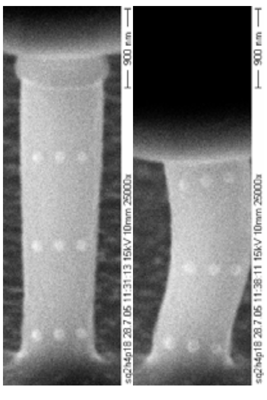


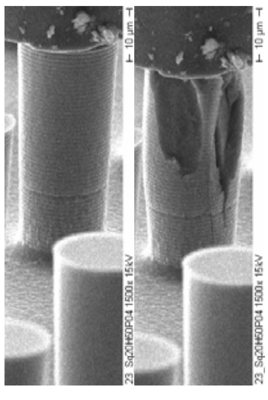
(a) **(b)**

Figure 2: (a) Typical scratch pattern of semiconductors generated by an increasing load along the scratch path and (b) Si scratched at 10 mN load and a speed of 100 µm/s where a platinum (Pt) layers has been deposited to protect the sample plane of the sample.

Task 2:

Fracture strength of silicon was studied dependent on the specimen volume. In model experiments compression tests on micromachined Si pillars with varying diameters have been performed inside the scanning electron microscope (SEM). Direct SEM-observation during the instrumented compression testing allows for very efficient positioning and assessment of the failure mechanism. Small pillars tend to buckle while larger ones tend to crack before failure as evident from Fig. 3, taken from [3]. Compressive strength increases with decreasing pillar size and reaches almost 9 GPa for sub-micrometre diameter pillars, compared to wafer strength values below 1GPa. This result is in agreement with earlier bending experiments.





(a) **(b)**

Figure 3: Frames extracted from the SEM video sequence recorded during the compression testing of the silicon pillars showing the first (left) and the last frame (right) just before failure of specimen with a diameter of (a) 0.7 and (b) 6 µm.

As mentioned in Task 1, it is well known that silicon undergoes a phase transformation during indentation and scratching. Since it is believed that during the sawing operation of silicon wafer with a MWSS a similar process happens, it is expected to find different silicon phases. But it was found no phase transformation at the surfaces of sawn wafers as shown in Fig. 4. In fact, it is obvious from this figure that only the Si I peak at more or less 520 cm^{-1} is observed. This raises the question about the deformation process occurring during the sawing operation and further investigation is required.

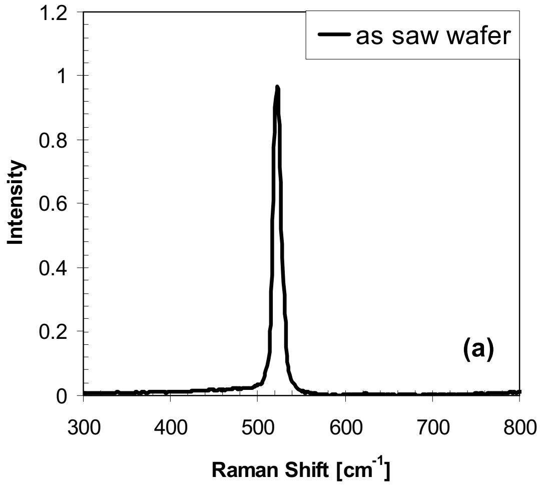


Figure 4: Raman spectra of a as saw silicon wafer

Task 3:

The preliminary results of roughness measurement of as sawn wafers showed that the roughness is dependent of the location on the wafer as evident from Fig. 5. Actually, the roughness decreases as the wire crosses the thickness of the wafer. On the contrary, the roughness does not depend on the sense of the ingot. Although, it is not yet known the real reason for such behaviour, it is due to either large particle are broken during their contact between the wire and the ingot or the large particle cannot stay between the wire and the ingot and are pushed elsewhere so that only small particles cuts the ingot close to the exit.

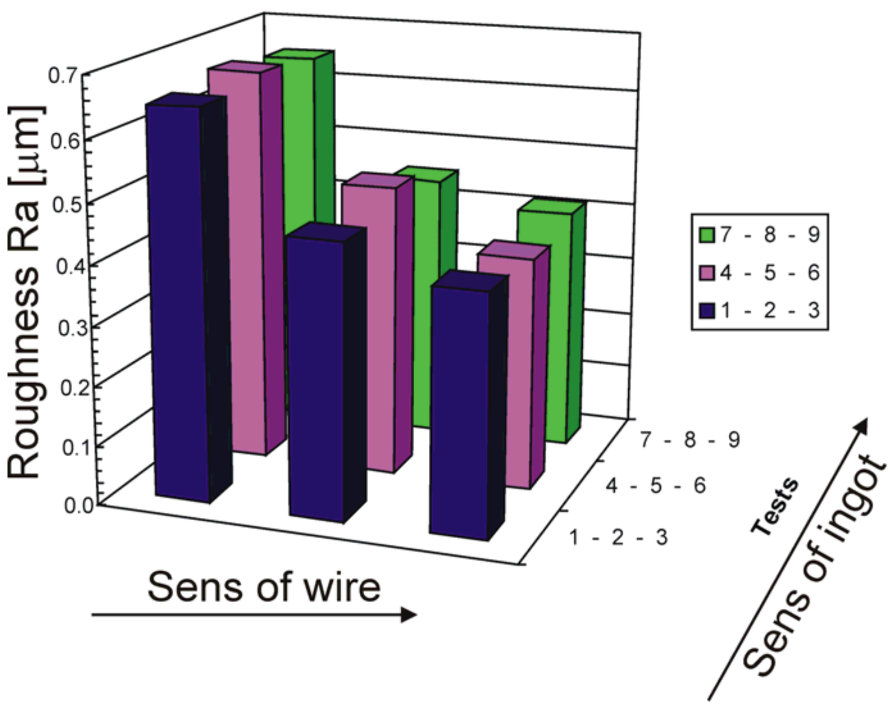


Figure 5: Roughness of a sawn wafer

Task 6:

In order to classify the sub-surface defects, the number of cracks as a function of their location in the depth has been measured for each sawing condition. The crack distribution can be accurately fitted by a exponential distribution of the form $p(x) = A \cdot e^{-b \cdot x}$ (see Fig. 6). These fits are then easier to compare and the influence of each sawing parameter can be studied by this mean.

The quality of a cut is defined by the quantity of cracks, particularly the deepest ones, because they have the biggest influence on yield stress. Thus, a cut with a lot of defects near the surface but fewer defects further deep than another cut will be said to be of better quality than the second one.

The quality of a cut is dependent of the position of measurement. Actually, a cut made near the exit of the wire will be of better quality than a cut made near the entrance also as in Fig. 5. Furthermore, the direction on which the cracks measurement is done also have an influence. If it is made in a direction parallel to the wire movement, the results will be worst than if the measurement is made perpendicular to it.

Apart from these positioning variations, the cutting parameters have an influence too. In fact, all the parameters studied have an influence on the depth of the deepest crack and / or on the quantity of cracks.

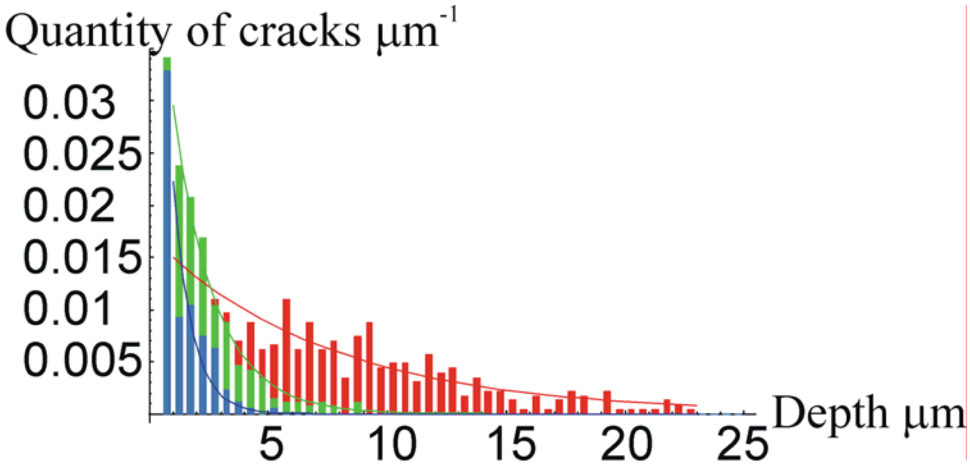


Figure 6: Distribution of cracks, depending of the sawing conditions

Task 7:

In order to analyse the different bending tests, various finite element models have been performed. Two examples of the geometries are presented in Fig. 7 and the results of the maximum principal stress are given in Fig. 8. As expected, the lines bending and point bending tests results are significantly different. Considering the point ring test in Fig. 8 (a), the area with the maximum stress is localised at the very centre of the wafer. Therefore, only the strength in the centre of the wafer and at the vicinity of the punch is tested. The 4-points test in Fig. 8 (b), the edges are also under stress and the strength value would also take into account defect at the edges. Hence, the final choice of the test will depend on the goal of the fracture test.

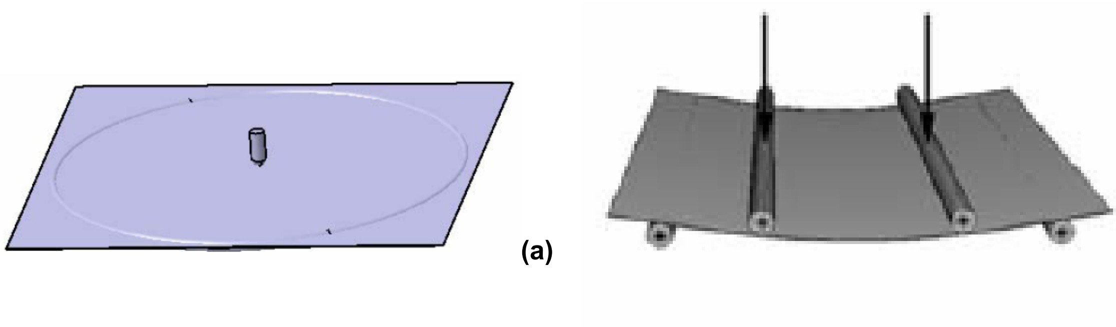
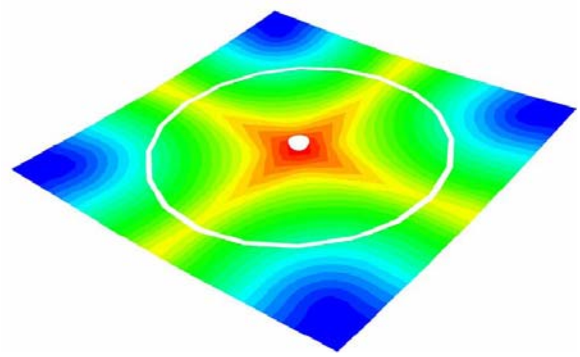
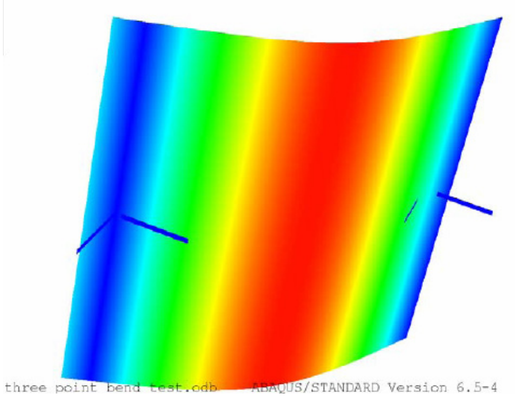


Figure 7: Example of 2 types of tested geometries (a) point bending test and (b) 4 points bend



(a)



(b)

Figure 8: Finite element results of the two examples of tested geometries (a) point bending test and (b) 4 points bend. In red the maximum of the maximal principal stress and in blue location were the stress is close to 0.

National Cooperation

Project Co-ordinator:
Empa – Materials Science and Technology, Materials- and Nanomechanics Laboratory

Partners: HCT Shaping Systems S.A, Cheseaux
Ideal Chimic S.A., Geneva
Institute of microtechnology, IMT, Neuchâtel
EPFL - Fluid Mechanics Laboratory (LMF), Lausanne

Evaluation 2006 and View 2007

During the first year of the project, a large number of experiments were conducted with various parameters. These experiments are the basis of the investigation, which will allow to correlate the surface roughness, the depth of the microcrack, the type of microstructure, the fracture strength to the sawing parameters. The set-ups banks to measure the mechanical wafer strength and scaled-up model of the wire saw were designed and built and are available. Based on the experiences gained through the work carried out and the results achieved so far, no modification to the initial description of work will be implemented in the remaining time of the project.

The performance of the consortium during the first half of the project was very good. Without the strong individual dedication of each partner and the collaborative spirit experienced, the achievements of the project to date would not have been possible.

HCT was, during the year 2006, under great pressure to build all multi-wire saws orders. Hence, in order to make the cuts with the various parameters on one single machine, HCT had to make some sacrifices, which were necessary for the good continuation of the project. This was due to the know-how and highly skills workers of the different, but complementary technical and/or scientific background of the different partners involved in this project. Furthermore, thanks to their hard work, the results presented here were obtained according to the initial schedule. The technical work revealed that the only major problem was to council the production of HCT for the costumers and to perform the necessary cuts for the project. Which was done with great flexibility.

To see the progress of each partner, monthly meetings are held. This allows as well the exchange of information and samples. Some slight delays occurred during the absence of the responsible person at HCT. The main reason is that it was thought to be of high importance to have the person responsible for the different cuts to be present to be certain of the cutting parameters.

Recognition

The success of this project depends largely on the professional commitment of the R & D teams within the different industrial partners and research institute as well as the financial support of CTI / KTI (Commission for Technology and Innovation).

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[4] Wasmer, K., Wermelinger, T., Spolenak, R. and Michler, J.***"In Situ Compression Tests on Micron Sized Silicon Pillars by Raman Microscopy – Stress Measurements and Phase Analysis"***, Submitted in *Scripta Materilia.*

Other reports and results are confidential

BIFACIAL THIN INDUSTRIAL MULTI-CRYSTALLINE SILICON SOLAR CELLS BITHINK

Annual Report 2006

Author and Co-Authors	Philippe Nasch & Stefan Schneeberger
Institution / Company	HCT SHAPING SYSTEMS SA
Address	Route de Genève 42, 1033 Cheseaux-sur-Lausanne
Telephone, E-mail, Homepage	+41(0)21 731 91 00, pnasch@hct.ch, sschneeberger@hct.ch
Project- / Contract Number	503105 / BBW 03.0086
Duration of the Project (from – to)	09.2004 – 09.2007
Date	13.12.2006

ABSTRACT

The main BiThink's objective is to reduce significantly the cost of industrial PV silicon solar cells and modules by developing new technologies based in bifacial cells and albedo modules.

The technology developed in BiTink project is yielding impressive numbers in low consumption of silicon: 3000 wafers can be get from a meter of silicon ingot and using a conservative 80% of final yield (yield after cleaning and handling) that means 1.06 m^2 of silicon wafers from a kilogram of silicon. Using the current BSF bifacial technology, with efficiency of 15%, 60% of bifaciality and using the lower albedo factor of 30% that gives to a consumption of 4.3 grams / Wp without taking account of the yield. Using the 80% of yield for the slicing process and 90% for the solar cell production this number is 5.9 g/Wp. Now, BiThink is running to 3.5 g/Wp.

Another technology has been developed in BiTink project, which opens the door to thin wafer handling. This has to be considered as a breakthrough in PV industrial processes, because the main challenge faced by industrial when going to thinner wafer is the concomitant increase in breakage rate due to handling.

Project goals

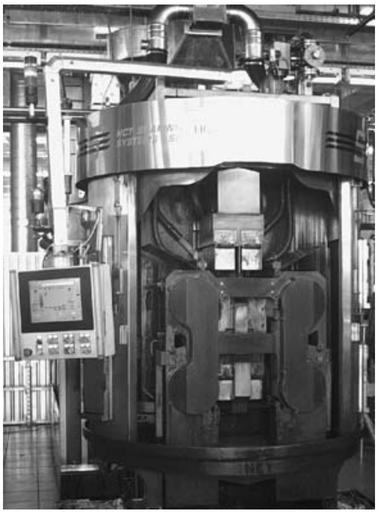
The main BiThink's objective is to reduce significantly the cost of industrial PV silicon solar cells and modules by developing a new technology based in bifacial cells and albedo modules. To get this objective, *HCT*'s work has been focused in the two following work packages:

1) ***Thin wafer slicing***: to increase the number of sliced wafers per linear meter of silicon ingot. The target of the project is to go from the current industrial value of 1800 wafers per linear meter of silicon ingot towards the range of 3500 – 4000 wafers per linear meter (w/m). An intermediate target of 2500 w/m has been reached from the very beginning of the project and current status is of 3000 w/m. A progression to 3500 w/m seems an achievable target, while 4000 w/m will require more dramatic changes.

2) ***Thin wafer handling***: to implement handling processes for freshly as-cut very thin silicon wafers. To detach the wafers freshly sliced from the ingot and the placement into standard cassettes or stack. The main objective is to develop wafer separation (singulation) and cleaning technologies applicable to process very thin solar wafers. Cleaning feasibility had to be demonstrated prior to singulation.

Thin wafer slicing

Thin slicing of ingots is carried out using HCT's technology of multi-wire slurry slicing (MWSS - Fig. 1) based on free-abrasive machining principles. Figure 2 depicts schematically the slicing principle of a high-efficiency multi-wire slurry saw. The MWSS consists of one single steel wire moving uni-directionally on the surface of the multi-crystalline silicon ingot. The single wire is wound on wire-guides carefully grooved with constant pitch forming a horizontal web of parallel wires. The wire-guides are rotated by drives, causing the entire wire-web to move at a relatively high speed (10-20 m/s; typically 12-13 m/s). High flow-rate nozzles feed abrasive slurry to the moving wires, which bring, on account of surface tension, a slurry (abrasive particles (e.g., SiC) suspended in a carrier liquid (e.g., polyethylene-glycol) into the cutting zone to produce a cut.



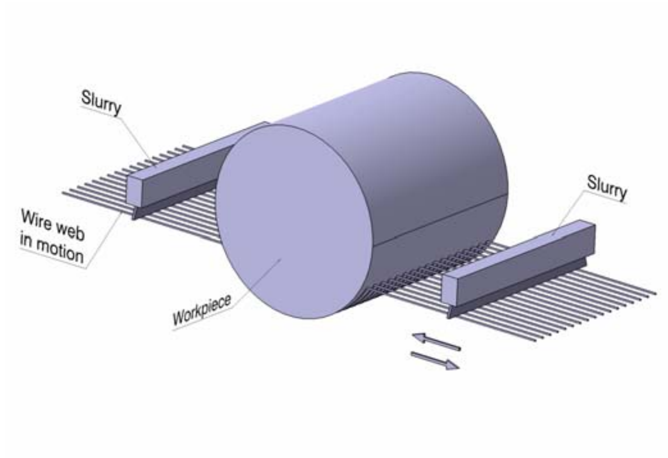


Figure 1: E500SD-B/5 HCT's MWSS model **Figure 2:** Principle

The silicon load is moved vertically. The wire tension is maintained constant (20-30 N) during the cutting process with state-of-the-art feedback control. A wire feed reel provides the new wire and a wire take-up reel stores the used wire.

HCT has improved the Multi-Wire Slurry Saw technique to obtain 4 to 6 wafers per linear millimeter of silicon ingot. Thickness of the obtained wafers have been as low as 90 micrometers.

Figure 3 shows the record of cuts in this project, ranging from over 250 μm thick to 90 μm, and Table I summarizes the progress of slicing technology in Bithink project. Wire diameters have been varied from 160 μm to 120 μm.

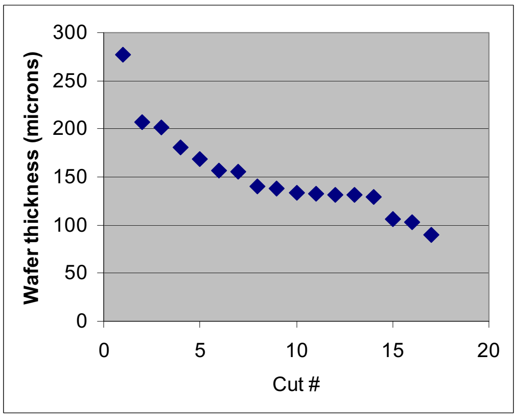


Figure 3: Cut summary

		In production	BiThink 1st milestone	BiThink 2nd milestone	BiThink 3rd milestone
Wafer thickness	µm	**250**	**200**	**135**	**100**
Wire diameter	µm	160	150	140	120
Grit size	µm	10	10	10	8
Slicing yield	%	98	>95	>90	>85

Table I: Progress of slicing technology in BiThink project

For 200µm-thick wafers and 200µm kerf-loss, one has 2.5 wafers per mm, or 2500 wafers per linear meter of Si. For 135µm-thick wafers and 200µm kerf-loss, one has 3 wafers per mm, or 3000 wafers per linear meter of Si.

Conclusion of thin wafer slicing

Technology developed in BiTink project is giving to impressive numbers in low consumption of silicon: 3000 wafers can be get from a meter of silicon ingot and using a conservative 80% of final yield (yield after cleaning and handling) that means 1.06 m^2 of silicon wafers from a kilogram of silicon. Using the current BSF bifacial technology, with efficiency of 15%, 60% of bifaciality and using the lower albedo factor of 30% that gives to a consumption of 4.3 grams / Wp without taking account of the yield. Using the 80% of yield for the slicing process and 90% for the solar cell production this number is 5.9 g/Wp. Now, BiThink is running to 3.5 g/Wp.

Thin wafer handling

In this workpackage, HCT has worked together with a German sub-contractor, the company Decker Anlagenbau GmbH, to develop an as-cut wafer separation technology. The technology makes use of an original principle based on molecular interactions (Van Der Waals forces). A patent is pending. A prototype bench unit was built and presented at the 21st European Photovoltaics & Solar Energy Conference and Exhibition held early September 2006 in Dresden (Germany).

A series of singulation tests with wafer thickness ranging from 140 microns to 200 microns were undertaken with continuous improvement of the unit. Just before the conference, the failure rate – on all account - was less than 15%, and has been since then improved to reach today less than 1% failure rate.

The unit is taking care of three steps of needed for wafer handling in real production environment.

1) The singulation (wafer to wafer separation after slicing)

2) Wafer Quality Control and Sorting

3) Cassetting or carrier loading or stacking

The prototype is a closed stand-alone unit (Fig. 4). An IP54 electrical cabinet (L x W x H: 0.60 x 0.60 x 2.10 m) hosts the power (400 VAC – 50Hz) and command (24VDC). The current maximum translation speed is 300mm/s. The dimensions in meters are (LxWxH): 1.80 x 1.20 x 2.25 (m). Empty weight is 1.8 tons. Water capacity is 257 liters.

Because the principle used in this singulation technology is inspired from biological behavior and in particular from the capability lizards have to stick to surfaces, the unit name was coined “GECKO”.

The exhibition in Dresden of the Demo unit has been extremely successful as indicated by the numerous visits to the booth and by established contacts amongst the market leaders. The project continues with focus on crystallizing an industrial partner for production scale joint development of the proven concept.

Figure 4: GECKO: a thin wafer singulation unit

Conclusion of thin wafer handling

A technology has been developed in BiTink project, which opens the door to thin wafer handling. This has to be considered as a breakthrough in PV industrial processes, because the main challenge faced by industrial when going to thinner wafer is the concomitant increase in breakage rate due to handling.

Final conclusion

BiThink is a project founded by the European Commission having transoceanic partners which target is to reduce the cost of PV silicon modules by developing new technologies based in bifacial cells and albedo modules. These bifacial cells are produced by an integral screen-printing process and using very thin silicon wafers. BiThink R&D activities cover from the slicing of silicon ingot to the lamination and testing of the module.

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Bundesamt für Energie BFE

FLEXIBLE CIGS SOLAR CELLS AND MINI-MODULES - FLEXCIM

Annual Report 2006

Author and Co-Authors	M. Kaelin, D. Rudmann, D. Bremaud, H. Zogg, A. N. Tiwari
Institution / Company	ETH Zürich
Address	Thin Film Physics Group, Technoparkstr. 1, 8005 Zürich
Telephone, E-mail, Homepage	+41 (0)44 633 79 49, tiwari@phys.ethz.ch, http://www.tfp.ethz.ch
Project- / Contract Number	100964 /151131
Duration of the Project (from – to)	01.03.2004 – 30.08.2005 (Extended: 30.04.2006)
Date	January 2007

ABSTRACT

Thin film $Cu(In,Ga)Se_2$ compound solar cells (also called CIGS) are well known for high efficiency, long term stability and the high potential for low cost solar electricity generation. While generally deposited on glass substrates, CIGS solar cells on metal and polymer foils offer obvious advantages: They are flexible, lightweight and can be manufactured with roll-to-roll deposition equipment. Roll-to-roll processes offer low cost production, while lightweight and flexible solar modules are attractive for a large variety of terrestrial and space applications. High efficiency solar cells on polymer and metal foils such as steel, Mo, Ti have been already developed by several groups.

Our group has been developing flexible solar cells on polymer and steel foils of 5 x 5 cm^2 size by using vacuum evaporated CIGS layers and applying a patented process, developed by ETHZ. Within this project we could report the development of 14.1% flexible solar cells on polyimide foil. This efficiency measured under AM1.5 illumination at ISE-FhG, Freiburg, Germany is a record for any kind of solar cell grown on polymer foil. Quantum efficiency and reflection measurements suggest that efficiencies exceeding 15% can be achieved by applying antireflection coating to reduce the reflection losses.

Aluminum is an interesting substrate material because of low cost and light weight, and it is used in several applications, especially in buildings. Development of CIGS cells on Al has remained a big challenge because of mismatch in thermo-physical properties. However, we have now developed for the first time CIGS solar cells on Al-foil. The photovoltaic properties of small area solar cells were characterized with I-V and quantum efficiency measurements. An efficiency of 6.6% was achieved with Na free CIGS absorber layers.

New cell concepts for semi-transparent solar cells and tandem solar cells require transparent back contact layers with good adhesion and suitable electronic properties for high efficiency CIGS solar cells. Indium tin oxide back contacts covered with a thin buffer layer of $MoSe_2$ yielded cells with efficiencies up to 11.8%.

We have started scaling up of deposition process to grow layers on 30 x 30 cm^2 size substrates by in-house assembly of a CIGS deposition system Development of large area flexible solar cells and mini-modules has started, and as a proof of concept flexible mini-modules to run small ventilator-fans have been developed. A mini-module with a 16cm^2 total area efficiency of 7.9% has been developed. During this preliminary development the factors for further efficiency improvements were identified although this result is already among the most efficient solar modules produced on polymer foil.

Introduction and project objectives

Flexible $Cu(In,Ga)Se_2$, called CIGS, solar cells are important for a variety of terrestrial applications, especially for integration in roofs and facades of buildings and as lightweight portable source of solar electricity. The overall project objective is to develop high efficiency solar cells and mini-module development strategies on commercial polyimide and metal foils with emphasis on improving the performance, process reproducibility and large area deposition capabilities. In addition, alternative electrical back contact to conventional Mo is to be evaluated based on application of a suitable buffer layer facilitating tunnelling of carriers across the CIGS-back contact interface.

Short description of the project

Polycrystalline thin film CIGS solar cells are important because of very high efficiency, long term stable performance, and their potential for low cost generation of solar electricity. The National Renewable Energy Laboratory, USA has reported a world record efficiency of 19.5% for the CIGS solar cells grown on glass substrates and several groups including ETHZ have achieved efficiencies exceeding 16% on glass substrates. Flexible and lightweight solar cells are interesting for a variety of terrestrial and space applications that require a very high specific power (kW/kg, defined as the ratio of output electrical power to the weight of solar module). Integration of such flexible CIGS solar modules in buildings (roofs and facades) is an emerging field with many attractive possibilities for the application of PV, and it offers an interesting commercial viability in future.

The processing of high efficiency solar cells requires deposition of a stack of polycrystalline layers of $ZnO{:}Al/ZnO/CdS/Cu(In,Ga)Se_2/Mo$ on a substrate (glass or metal or polyimide). A typical lightweight and flexible CIGS encapsulated solar module could be up to ten thousand times lighter than the module based on a 3 mm thick glass. In addition, the roll-to-roll manufacturing of flexible modules has certain other advantages leading to a significant cost reduction and expanding the applicability range of solar modules for diverse applications.

ETH group has been involved in the development of high efficiency flexible CIGS solar cells with low deposition temperature processes and incorporating controlled amount of Na in CIGS for efficiency enhancement. In this project the work is focused on the improvement of cell efficiency and process reproducibility on polyimide foils, and also to test the potential of the ETH invented process on steel and aluminium metal foils. We have been developing these solar cells on 5 x 5 cm^2 foils, but in this project proof of concepts are to be developed for scaling-up the deposition processes for larger area, up to 30 x 30 cm^2, size substrates. Strategies for large area solar cells and mini-modules are to be developed.

Mo is commonly used as a back electrical contact in CIGS solar cells. The damp heat tests of non-encapsulated or poorly-encapsulated modules quite often may show long term performance degradation because of contact corrosion. An important reason is the instability of Mo in moisture. Compared to some other possible contact materials Mo is an expensive material, and in case of flexible solar cells Mo layer can influence the stress and micro cracks in solar cell layers. Therefore, experiments are needed to investigate alternative strategies for ohmic back contact. First the role of $MoSe_2$ interface layer has to be understood for which CIGS solar cells need to be grown on metal or semi-metal like materials with a very thin “buffer layer” of $MoSe_2$.

Work and results

Flexible solar cells on polyimide foils

Our group has successfully developed flexible solar cells on polymer and metal foils of 5 x 5 cm^2 size by using vacuum evaporated CIGS layers and applying a patented process for controlled and reliable incorporation of Na in CIGS layers. This low temperature CIGS deposition and Na doping process offers several advantages for development of high efficiency solar cells on different substrates.

We have developed 14.1% efficiency (Voc = 649 mV, Jsc = 31.5 $mA.cm^{-2}$, FF= 69.1%, total area = 0.595 cm^2, no antireflection coating) flexible solar cell on polyimide foil (figure 1). This efficiency measured under AM1.5 illumination at ISE-FhG, Freiburg, Germany is the highest efficiency world record for any kind of solar cell grown on polymer foil. Quantum efficiency and reflection measurements (figure 2) performed on such samples suggest that efficiencies exceeding 15% can be achieved by applying anti-reflection coating to reduce the reflection losses. This value of 14.1% efficiency, achieved in December 2004, still remains the highest efficiency record for any kind of solar cell grown on polymer foil. Historical progress of efficiency of flexible CIGS cells of leading groups in the world is shown in figure 3.

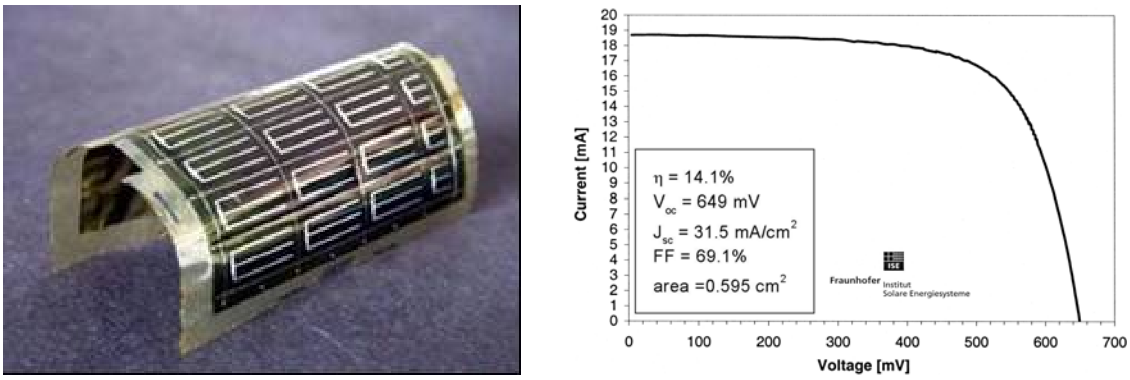


Figure 1: Flexible CIGS solar cells on a 5 x 5 cm^2 polyimide foil (left) and current-voltage characteristic of the 14.1% efficiency cell measured under simulated AM1.5 standard test conditions at ISE-Fhg Freiburg, Germany (right). This value still remains the highest efficiency record for any kind of solar cell grown on polymer foil.

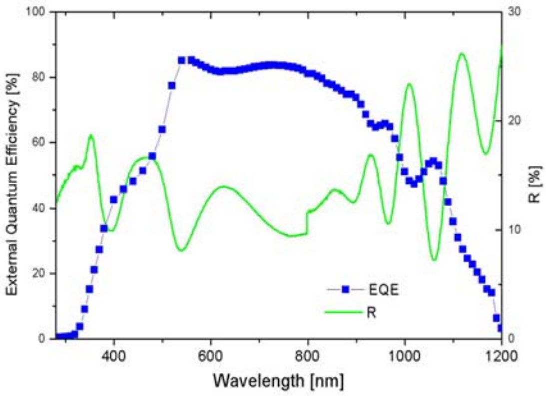


Figure 2, Quantum efficiency and reflection curves of 14.1% efficiency cell suggest that application of anti-reflection coating to reduce 13% reflection loss can further enhance the efficiency.

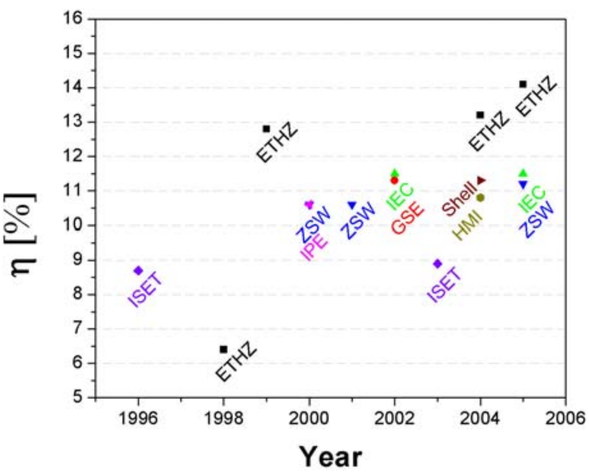


Figure 3: Progress in efficiency of flexible CIGS solar cells on polymer foils.

CIGS solar cells on Al foils

Development of CIGS solar cells on aluminum (Al) foils has to our knowledge was not reported by any other group despite that Al is an interesting substrate material because of its low cost and its light weight. In the industry, it is used in many applications, especially in buildings, where solar cells could be easily incorporated in facades. But Al can't be heated at the same temperature as the other metal foils, therefore a low temperature process has to be used for CIGS deposition.

One of the biggest challenges in deposing CIGS absorber on Al-foil is the large mismatch between the thermal expansion coefficient (CTE) of CIGS and Al. The mismatch causes stress between the different layers, which can create cracks in the absorber, and consequently shunt the cell. In the worst case this could even result in the complete delamination of the CIGS. The tension between the layers of course depends on the growth temperature. The higher the temperature the more tension is created during cooling down, therefore lower temperature results in better adhesion. On the other hand a minimal growth temperature is needed to obtain "device quality" CIGS layers and working solar cells.

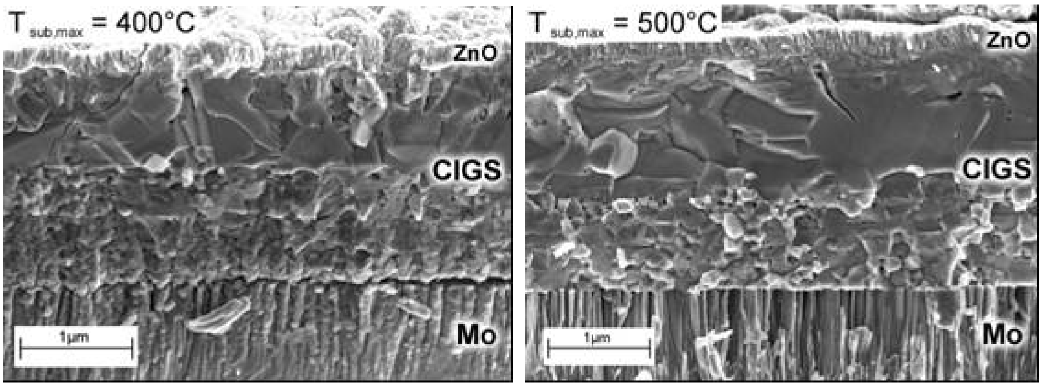


Figure 4: SEM cross-section images of solar cells on Al foils where CIGS layers were grown at a 400 °C (left) and 500 °C (right), the mentioned temperature is a reference value and not the exact substrate temperature.

The growth temperature has the most important impact on the structure and the quality of the absorber (figure 4). Solar cells grown at $T_{sub,max}$ = 400°C don't show photovoltaic conversion efficiency at all. It is important to note that we mention a reference temperature while the actual substrate may be quite different. As it can be seen in figure 5, the temperature was not high enough to permit the interdiffusion of the elements and it is inadequate for CIGS phase formation. One can distinctly see three different phase in the CIGS layer due to the 3-stage process and the insufficient temperature for a proper Cu-In-Ga diffusion. The top part shows "classical" CIGS with relatively small grains, whereas the bottom of the absorber has the typical structure of Cu-poor CIGS. A micro crack in the left upper part of CIGS and the separation between Mo and CIGS is due to the sample preparation for SEM measurement.

The photovoltaic properties of small area solar cells were characterized with I-V and quantum efficiency measurements (figure 6). An efficiency of 6.6%, measured under AM1.5 standard test conditions, was achieved with Na free CIGS absorber layers (V_{oc} = 434 mV, J_{sc} = 30.7 mA/cm^2, FF = 49.3 %, total area; no AR coating). While the short circuit current is reasonable, the open current voltage and the fill factor need to be improved. It is important to mention that Na was not added into the CIGS absorber layer, but it is known that addition of Na can significantly increase the efficiency by additionally up to 70% of the Na free value.

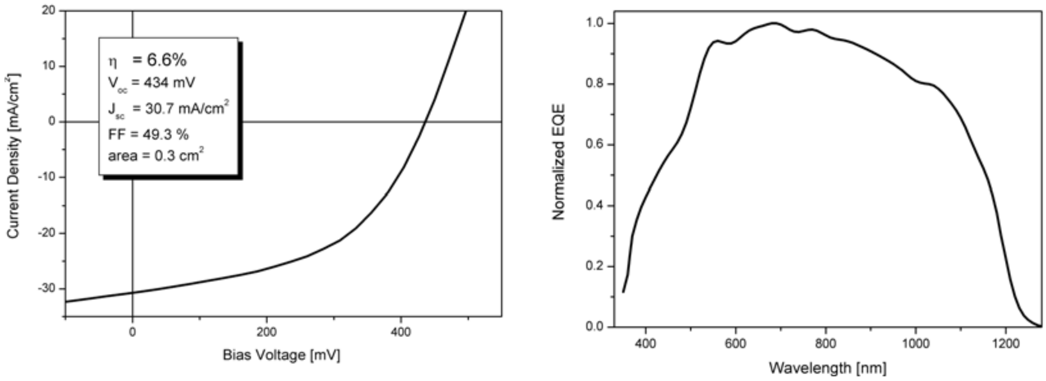


Figure 5: Current-voltage characteristic (left) and quantum efficiency (right) of a CIGS solar cell on Al foil. Neither Na was incorporated in CIGS absorber nor any AR coating was applied. This 6.6% efficiency is the highest value of efficiency reported to date for CIGS cell on Al foil. Addition of Na in CIGS will further increase the cell efficiency

Transparent back contacts

In order to either fully or partly replace the Mo contact in CIGS solar cells with a suitable back contact and buffer layer exploratory works were performed by developing CIGS solar cells on transparent conducting oxide (e.g. ITO) coated glass substrates. A buffer layer of $MoSe_2$ providing low resistance quasi-ohmic contact was obtained by selenization of a thin sputtered Mo layer on ITO. CIGS solar cells were grown on these substrates using conventional technology as described above. The purpose was to prove that $MoSe_2$ layer can facilitate a “quasi-ohmic” transport of carriers across the CIGS back contact.

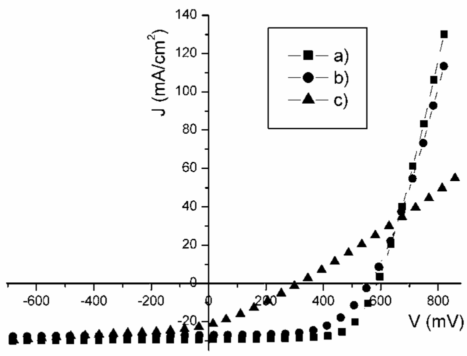


Figure 6: I-V characteristics under AM1.5 illumination of CIGS solar cells in substrate configuration with ITO/$MoSe_2$ back contact (a and b) and with ITO back contact (c). To form an intentionally grown $MoSe_2$ intermediate layer on ITO back contact, for cell (a) the Mo was selenized at 450°C, for cell (b) at 580°C for 30 min. Cell (c) was processed in the same run as cell (b), but covered during the selenization.

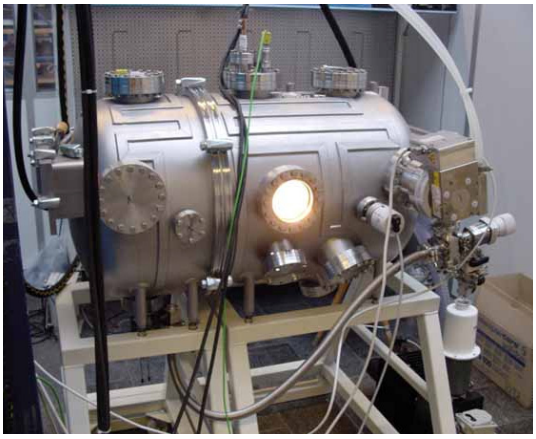
First solar cells on ITO back contact with intentionally grown $MoSe_2$ intermediate layer showed clearly a better photovoltaic performance than without the $MoSe_2$ intermediate layer, and efficiencies of up to 11.8% were achieved in substrate configuration (figure 6). The details of photovoltaic parameters are given in table I. These results prove that $MoSe_2$ layers can be used as buffer layer for quasi-ohmic contact and to develop high-efficiency CIGS solar cells on a variety of back contact materials.

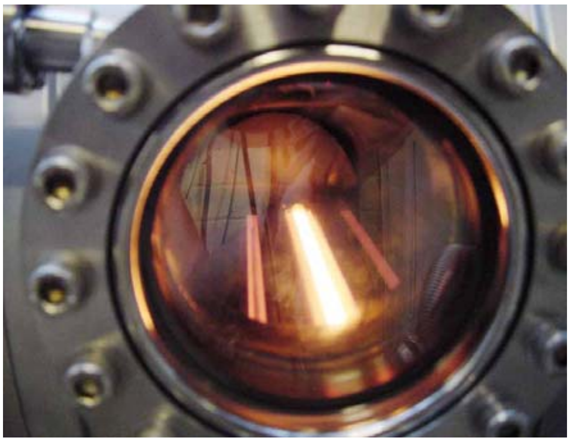
Table I: Photovoltaic parameters for solar cells with and without intermediate $MoSe_2$ layer between ITO back contact and CIGS; for specifications please refer to Fig. 9 and the text.

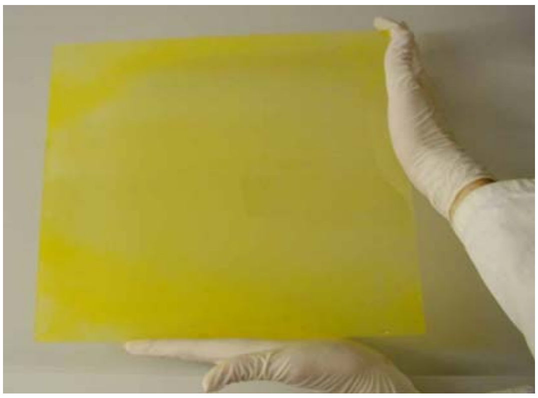
Sample, back contact	(a) ITO/$MoSe_2$	(b) ITO/$MoSe_2$	(c) ITO
selenization temp. [°C]	450	580	580
U_{oc}[mV]	585	559	314
I_{sc}[mA/cm^2]	29.3	27.1	21.6
FF[%]	68.9	60.8	29.6
η[%]	11.8	9.8	2.0

Large area deposition

As a first step towards industrial production of thin film CIGS solar cells and modules, up-scaling of all the processing steps to 30 x 30 cm^2 substrates should be done to in order to study critical problems of large area deposition. We have initiated this development with second-hand equipment due to the lack of investment funds for purchasing standard sputtering equipment for Mo and ZnO:Al/ZnO sputtering. Further work is needed for improvement of thickness uniformity and optimisation of layer properties and interfaces. Development of in-line CIGS deposition system is technically challenging and requires investment for various components of the evaporation system. During this project we have started assembly of an in-house developed CIGS evaporation system (figure 7a). An automated in-line movement mechanism of heated substrate in vacuum has been installed and tested to a satisfactory level. Furthermore, line-evaporation sources for Cu, In, Ga elements have been designed and constructed (7b). Experiments to evaluate thickness and composition uniformity have started. Figure 7c) shows a chemical bath deposited buffer layer on 30 x 30 cm^2 size substrate; further experiments are required to improve the thickness and composition uniformities.


a)


b)


c)


d)

Figure 7: (a) Picture in-house developed large area CIGS deposition system; (b) picture of 30 cm long evaporation sources in operation (c) chemical bath deposited buffer layer on 30x30 cm^2 glass substrate for uniformity tests; (d)encapsulated flexible large area CIGS solar cell without cell patterning on a roll.

We have been able to deposit Mo, ZnO/ZnO:Al layers on 30x30 cm^2 size substrates using a second hand refurbished sputtering equipment. Though the deposition equipment for CdS buffer layer and CIGS evaporation were installed during this project and several growth and characterisation experiments were performed to investigate thickness and compositional properties of layers, it turned out that the size of the CIGS evaporation chamber (already existing before the start of this project) is too small for 30x30 cm^2 size substrates. We developed substrate heating and in-line movement mechanism for large area size polymer foils for the deposition of all the required layers to form CIGS solar cell devices (figure 7d).

However, further work is needed for improvement of evaporation sources and design of a new CIGS deposition system is necessary; such a system should have in-situ diagnostics for process monitoring and control of evaporation fluxes and layer properties.

Mini-module development

Strategies to develop solar modules were evaluated considering the options of monolithically interconnected cells (obtained through laser scribing and patterning) or connection of large area solar cells with metal grids. We could develop mechanical scribing for Mo layers on polymer foils, but optimisation of the scribed layers as a function of sputtering condition is not completed. Processes for application of metal-grids by evaporation on large are solar cells has been developed. In our preliminary experiments we have already achieved 8% efficiency (V_{oc} = 1.075 V, J_{sc} = 12.3 mA/cm², FF = 59.4%) mini-module of 16 cm^2 size by connecting two large area cells on 25 cm^2 foil (figure 8). The technology for serially connecting solar cells can contribute to important efficiency losses and requires careful optimization after gaining some experience. Therefore a further increase of efficiency can be expected although the obtained result is already among the best results for solar cells on plastic foils.

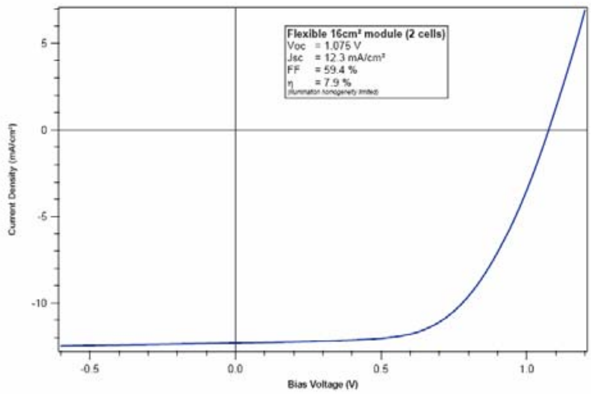


Figure 8: J-V curve of 16cm^2 mini-module obtained by connection of two large area cells with metal grids.

Flexible mini-modules to run small ventilator-fans have been developed to demonstrate an application possibility (figure 9).

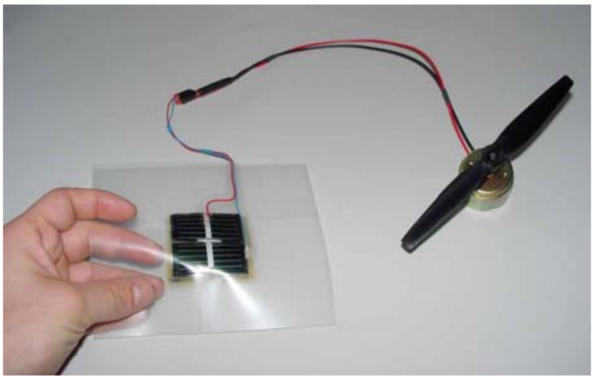


Figure 9: flexible mini-module to run a ventilator-fan.

National and international collaboration

This project has benefited from our participation in EU projects METAFLEX, PROCIS and collaboration with IAP-ETH Zurich.

Conclusions

The project has been completed and several milestones of this ambitious project have been successfully met, while more work, especially on up-scaling of CIGS deposition and further increasing the efficiency of flexible solar modules is needed. This project has contributed towards the achievements of: i) Improvement in the efficiency world record of flexible CIGS solar cells to 14.1%; ii) prospects for >15% efficiency cells by reduction of reflection losses; iii) development of large area cells with grids and 8% efficiency on 16 cm^2 in the preliminary development; iv) in-house development of large area in-line deposition system for CIGS layers; v) 6.7% efficiency CIGS solar cells on Al foils and prospects for efficiency improvements; vi) CIGS solar cells on transparent back contact (ITO) by application of $MoSe_2$ layer which improves the efficiency from 2% to >10%. Unfortunately, resources and project duration were inadequate for improving the large area deposition system and processes. Further work is needed for improving the large evaporation sources and to apply process diagnostic tools for monitoring of in-line growth on large area. Module development on foils is another challenging area requiring technical developments. It is hoped that further support will facilitate the development of highly efficient large area flexible CIGS modules based on the innovate concepts of ETH for “low temperature” processing of CIGS cells and their interconnection on flexible substrates.

Publications and conference presentations

[1] D. Brémaud, D. Rudmann, H. Zogg, A. N. Tiwari, ***Towards the development of flexible CIGS solar cells on polymer films with efficiency exceeding 15%,*** Proc. 31st IEEE Photovoltaic Specialist Conference, Orlando, 3-8 January 2005, USA, p. 223-226.

[2] D. Rudmann, D. Brémaud, H. Zogg and A.N. Tiwari, ***Na incorporation into $Cu(In,Ga)Se_2$ for high efficiency flexible solar cells on polymer foils***, D. Rudmann, D. Brémaud, H. Zogg, A.N. Tiwari, **J. Appl. Phys.** 97, 084903 (2005).

[3] D. Rudmann, D. Brémaud, M. Kaelin, H. Zogg and A.N. Tiwari, ***Band-gap grading in low-temperature-grown CIGS absorbers,*** Proc. 20th European Phototovoltaics and Solar Energy Conference, June 2005, Barcelona.

[4] D. Brémaud, D. Rudmann, M. Kaelin, G. Bilger, H. Zogg, A. Tiwari, ***Flexible and lightweight $Cu(In,Ga)Se_2$ solar cells on aluminum foils, Proc. 20th European Photovoltaic Solar Energy Conference,*** June 2005, Barcelona.

LARGE-AREA CIS BASED THIN-FILM SOLAR MODULES FOR HIGHLY PRODUCTIVE MANUFACTURING (LARCIS)

Annual Report 2006

Author and Co-Authors	D. Brémaud, M, Kaelin, A. Chirila, R. Verma, H. Zogg, A. N. Tiwari
Institution / Company	ETH Zürich
Address	Thin Film Physics Group, Technoparkstr. 1, 8005 Zürich
Telephone, E-mail, Homepage	+41 44 633 79 49, tiwari@phys.ethz.ch, http://www.tfp.ethz.ch
Project- / Contract Number	SES66-CT-2005-019757 / FP6-019757
Duration of the Project (from – to)	01.11.2005 – 31.10.2009
Date	February 2007

ABSTRACT

This European collaborative project within the FP-6 EU program involves 6 universities and 4 industries working together towards the development of large area $Cu(In,Ga)Se_2$ (CIGS) based thin film solar modules for highly productive manufacturing. The project will improve the device performance and manufacturing technologies for low-cost, more stable, more efficient solar modules. In this project vacuum evaporation and electrodeposition approaches are used for absorber deposition and other components of the solar cells are improved. Two important objectives of the overall project are:

(1) Very high-quality modules manufactured by co-evaporation of CIGS and applying cost-effective methods with target efficiency > 13.5 % on 0.7 m^2.

(2) Development of alternative buffer layers for large are CIGS modules of up to 0.7 m^2 with efficiency > 12 %.

To meet the above mentioned objectives, research and development (R&D) work of the ETH group is directed on the improvement of Mo and development of alternative back contacts for improvement of efficiency, stability and to explore the possibility of reducing the CIGS absorber layer thickness. Another R&D activity of the ETH group is to transfer the so-called “3-stage” CIGS growth process from “static-mode” to an “in-line” moving substrates, and modify the CIS absorber in such a way that a separate deposition of the buffer layer could be avoided.

In order to develop alternative (to Mo) electrical back contacts providing multi-functionality, we have investigated TiN as a possible candidate because of its physical and chemical properties. A thin layer of $MoSe_2$, which is known to facilitate ohmic transport of carriers between CIGS and back contact, was applied prior to the CIGS deposition. Growth kinetics and properties of the $MoSe_2$ layers were investigated. We have successfully developed cells of 10-12% on TiN coated glass substrates and observed that the post-deposition Na incorporation in CIGS method developed at ETH is effective to significantly increase the cell efficiency to 13.8%. This efficiency is comparable to the achieved efficiency with conventional 1 micron thick Mo layer, however, higher efficiencies should be achievable with further optimization of the processes.

Introduction and project objectives

The objective of this project is to develop advanced manufacturing technologies for $Cu(In,Ga)Se_2$ (CIGS) thin-film solar modules both for the electrodeposition and coevaporation approach. This technology transfer from laboratory scale enables large area industrial production.

The project will improve the manufacturing techniques for low-cost, stable, efficient CIGS thin film solar modules on large area. This includes work on the molybdenum back contact, the buffer layer, the CIGS absorber and the quality and process control. Special emphasis is placed on the development of cadmium-free large-area modules and of electrodeposition methods for CIGS absorbers. Results of the work will be transferred from the laboratory scale to the operating (pilot) manufacturing plants in Germany, Sweden and France.

The work in the project will improve the average and peak efficiency of the modules produced in the manufacturing plants of the industrial partners Würth Solar, Solibro and EDF. Modifications of the back contact (process and composition) and doping of the absorber will contribute to these improvements. Existing uncertainties concerning the stability of modules with alternative cadmium-free buffers will be eliminated and the transfer of the processes to the manufacturing plant will be prepared.

To fulfill the conditions for rapid entrance in the industrial production there is a need to consolidate and extend the results on one side and to increase the acceptability of the process on the other side. The project will contribute significantly to this objective by giving a frame for knowledge development, know-how exchange and cross-fertilizations between the groups and technologies involved in the project, i.e. between co-evaporation and electrodeposition methods of CIGS formation.

Short description of the project

In order for the commercial production of large $Cu(In,Ga)Se_2$ based modules on the multi-megawatt scale to be successful, the processes must still be streamlined and optimized taking both economical and ecological aspects into consideration. This project aims to support the development of this material- and energy-saving thin-film technology so it can gain a foothold in the free photovoltaic market. Promising laboratory results will be transferred to large-scale production, where the availability of appropriate production equipment and very high material and process yields are of decisive importance. Six universities and research centers and four companies are working closely together in order to merge the physical understanding of the processes and the engineering know-how, both of which are necessary for up-scaling the CIGS technology to a marketable multi-megawatt production volume.

The project tasks are focused on:

- very high-quality modules manufactured by coevaporation of CIGS and applying cost-effective methods, efficiency > 13.5 % on 0.7 m^2.
- the development of cadmium-free buffer layers for cadmium-free CIGS modules on an area of up to 0.7 m^2, efficiency > 12 %.
- and the development of a mid-term alternative: electrodeposition of low-cost CIS modules with efficiency ≥ 10 % on 0.1 m^2.

The consortium is transfering the molybdenum back contact sputtering know-how to provide substrates for both the coevaporation and the electrodeposition approaches. All process developments such as modifications of the back contact, wet- or vacuum-deposited buffer layers, the multi-stage coevaporation of CIGS, or improved gallium incorporation in electrodeposited absorbers are first being tested and evaluated on the laboratory scale. Successful approaches will be up-scaled and transferred to three independent commercial CIGS pilot lines. Novel process and quality control techniques are also being developed and applied to reach these ambitious goals.

The R&D contributions of the ETH group in this project cover following topics:

- Investigation of Mo pre-solemnization and Na doping methods and mechanisms
- Investigation of TiN as back contact layer
- Introduction of a novel MoX/Mo back contact to enhance Mo stability
- Enhancement of large-area efficiency: ETH will fabricate highly efficient absorbers by the 3-stage process and support the ZSW for transferring the 3-stage process to 30x30cm^2
- ETH will develop a modified absorber without the need for a buffer layer for reduction of production costs
- Correlation of I/V results of heated and light-soaked samples with growth process in order to increase the device stability

Work and results

Growth of $MoSe_2$

$MoSe_2$ has been grown by selenization of dc sputtered Mo single-crystals and thin films under variation of the substrate temperature, the selenization duration, the Mo crystal orientation, and the Na concentration.

The $MoSe_2$ thickness dependence on selenization temperature and time was investigated to understand the formation kinetics of $MoSe_2$. For substrate temperatures lower than about 550°C, the $MoSe_2$ layers reach a rather small thickness of about 10-30 nm, whereas the $MoSe_2$ layer thickness increases strongly for substrate temperatures higher than about 550°C. Fig. 1a shows the BF-TEM image of the sample produced at 450°C. The layered structure of the $MoSe_2$ covers the Mo substrate uniformly and has a thickness of about 10 nm. The sheaths of the layered structure are oriented preferentially parallel to the Mo surface. Direct comparison of the orientations of the *c*-axes of $MoSe_2$ layers grown at 450°C (Figs. 1a and b) and at 580°C (Fig. 1c) reveals a change from perpendicular to parallel with respect to the Mo surface.

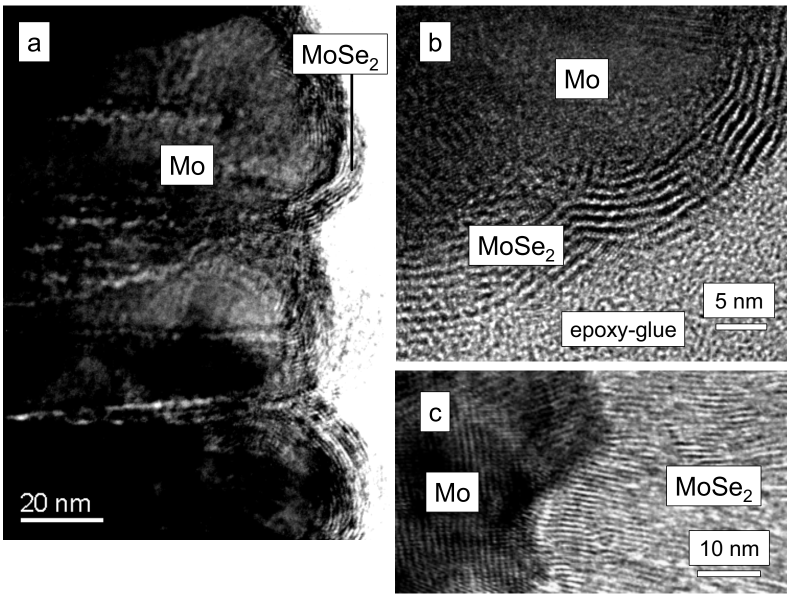


Figure 1: (a) BF-TEM image of the interface between $MoSe_2$ formed at 450°C and Mo. (b) HR-TEM image of the same interface. (c) HR-TEM image of the interface between $MoSe_2$ and Mo selenized at 580°C.

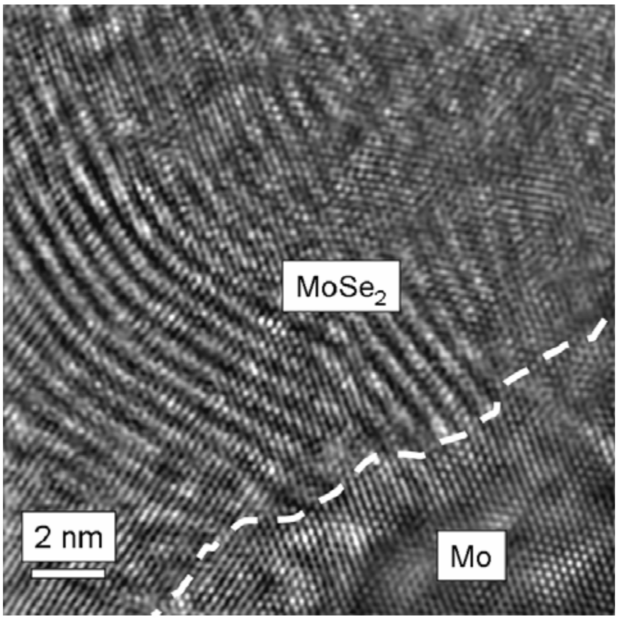


Figure 2: HR-TEM image of the interface between MoSe2 and Mo oriented in [110]; the interface is indicated by a dashed line.

X-ray diffraction patterns of $MoSe_2$ layers grown on Mo single crystals oriented in [100], [110] and [111] reveal a pronounced texture of $MoSe_2$ in [11.0] orientation. Also, it is clear from these measurements that the $MoSe_2$ orientation is independent from the orientation of the Mo single crystals. The interface between the $MoSe_2$ and the single crystal Mo is abrupt, as revealed by the HR-TEM micrograph shown in Figure 2.

Thin $MoSe_2$ as interface layer

In order to use thin $MoSe_2$-layers as an interface layer between the CIGS absorber and alternative (to conventionally used Mo) back contacts, we have also tested two different selenization methods of a DC sputtered 10nm thick Mo-layer on ITO / soda-lime glass (SLG) substrates. The first method consisted of evaporating Se on the Mo in a high vacuum chamber followed by heating at high temperature. The second method used a Se-oven, where the evaporated Se was flown over the substrate along with the N_2 carrier gas (few mbar pressure). In both cases the substrates were heated at different temperatures. At substrate temperatures above 450°C the formation of $MoSe_2$ could be clearly demonstrated as shown in the Fig. 3. For lower substrate temperatures and for the first method not all of the 10nm of Mo converted to $MoSe_2$. It should be mentioned, that those tests and measurements were done without growing CIGS layer on the Mo layers.

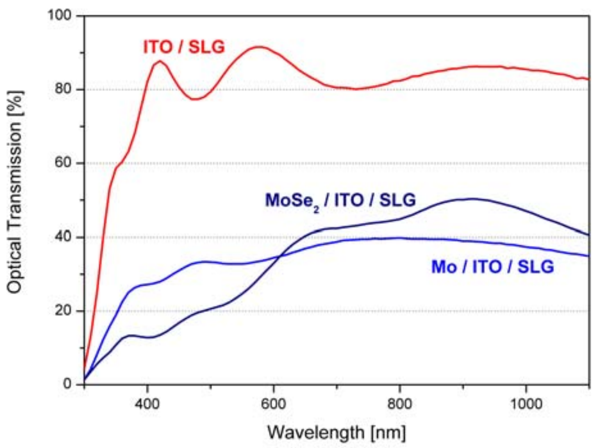


Figure 3: Transmission of light through transparent conductive oxide (ITO) back contact and coated with Mo and $MoSe_2$.

CIGS solar cells on TiN back contacts

We have developed CIGS solar cells on soda lime glass substrates with TiN back contacts. The TiN layers were deposited by reactive sputtering. A thin (10nm) Mo film was deposited with dc sputtering (in tables: "Mo (10 nm)" for high vacuum method, "$MoSe_2$ (10 nm)" for Se-oven method). The CIGS absorber layers were grown using the 3-stage process. Since some electrical back contact layers (like TCO) can not be heated to high temperatures (e.g. 550 °C) without degrading their conducting properties, the max. temperature was kept at 450°C for the samples, in order to be able to compare the results with other back contacts. The solar cells were completed by depositing CBD-CdS buffer, RF sputtered ZnO:Al/i-ZnO and an Al/Ni-grid.
TiN act as diffusion barrier for Na. Therefore we have also compared the effects of Na on some samples, by adding Na with a post-deposition treatment (PDT).

The results (Table 1) show that a thin Mo-layer is enough to ensure same photovoltaic properties as with "usual" thicknesses: The sample "Mo (1μm)/TiN" was used as references to compare the properties of solar cells, whereas TiN act as Na barrier and electrical back contact layer.

The presence of the $MoSe_2$ layer seems to be essential to get higher V_{oc} and FF, as can been seen by comparing the cells grown directly on TiN with those with Mo-layer. On the other hand it is still unclear, which selenization method gives better results. Without addition of Na, the complete selenization in the Se-oven leads to higher efficiencies. The behavior is exactly the opposite with presence of Na. It seems that Na has an influence on the properties at the interface and that there could be a correlation between those two effects. We will need further investigations to confirm and understand the correlations.

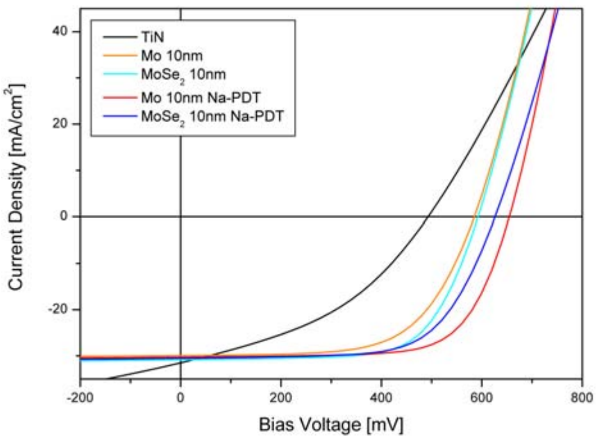


Figure 4: IV-measurements show that efficient solar cells can be grown on alternative electrical back contacts such as TiN by using a thin $MoSe_2$ layer between CIGS and back contact

Back Contact	Na	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
TiN	-	493	31.5	39.8	6.2
Mo (1μm) / TiN	-	546	31.0	64.3	10.9
Mo (10 nm) / TiN	-	585	29.9	62.8	11.0
$MoSe_2$ (10 nm) / TiN	-	592	30.9	67.1	12.3
Mo (10 nm) / TiN	PDT	655	30.3	69.7	13.8
$MoSe_2$ (10 nm) / TiN	PDT	626	30.5	65.6	12.5

Table 1: Photovoltaic properties of CIGS solar cells grown on TiN back contacts.

The overall conclusions are:

(i) Efficient solar cells can be grown on alternative electrical back contacts such as TiN;

(ii) a thin layer of Mo to facilitate the formation of $MoSe_2$ layer is adequate for quasi-ohmic tunneling contact between CIGS and back contact;

(iii) Addition of Na is necessary for cells on alternative contacts even on SLG substrates;

(iv) Further experiments are needed for improved solar cell performance.

National and international collaboration

This project is realized in collaboration with the following industrial partners and scientific institutes:

- Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)
- Uppsala Univ., Angström Solar Center (UU-ASC)
- Solibro
- Würth Solar (WS)
- Hahn-Meitner-Institut (HMI)
- Electricité de France (EDF)
- Centre National de la Recherche Scientifique (CNRS)
- Univ. Barcelona, Electronic Materials & Engineering (UB-EME)
- Saint Gobain Recherche (SGR)

TEM work of Daniel Abou-Ras is gratefully acknowledged.

Outlook

R&D work will further continue on the process improvement of CIGS on alternative back contacts; more work will be required to investigate the properties of metal nitrides and multilayer stacks. Investigations of the $MoSe_2$ formation and controlled Na incorporation in CIGS will be carried out. Different stages of the "3-stage" CIGS grown layers on an in-house developed in-line deposition system will be investigated.

Publications and conference presentations

[1] D. Brémaud, D. Rudmann, M. Kaelin, C. Hibberd, A.N. Tiwari: ***"Alternative Back Contacts and $MoSe_2$ Interface Layer on Cu(In,Ga)Se_2 Solar Cells"***, 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4 - 8 Sep 2006.

ADVANCED THIN-FILM TECHNOLOGIES FOR COST EFFECTIVE PHOTOVOLTAICS (ATHLET)

Annual Report 2006

Author and Co-Authors	M. Kaelin, D. Bremaud, A. Chirila, R. Verma, H. Zogg, A. N. Tiwari
Institution / Company	ETH Zurich
Address	Thin Film Physics Group, Technoparkstr. 1, 8005 Zürich
Telephone, E-mail, Homepage	044 633 79 49, tiwari@phys.ethz.ch, http://www.tfp.ethz.ch
Project- / Contract Number	FP6-2204-Energy-3
Duration of the Project (from – to)	01.01.2006 – 31.12.2009
Date	February 2007

ABSTRACT

The ATHLET project is an integrated project of the European Union involving 24 partners consisting of universities, research institutions and industries working on the topic of $Cu(In,Ga)Se_2$ (called CIGS) and Si based thin film solar cells. The project is divided in several work packages covering diverse topics of solar cells and modules. The Thin Film Physics Group (TFP) of ETH Zurich is participating in two work packages within the integrated EU project:

- Development of high efficiency lightweight and flexible CIGS solar cells on polymer foils and improvement in processes for highest record efficiencies.
- Buffer layer deposition by spray technique for CIGS solar cells.

R&D work of flexible CIGS solar cells has been carried out to understand the influence of deposition conditions and processes on the properties of layers and solar cells. The ETH group still holds the highest (14.1%) efficiency record of flexible solar cells on polymer foil. In order to develop flexible solar cells with evaporated buffer layers we have started installation of the deposition system for In_xS_y buffer layers by vacuum evaporation method. Another vacuum deposition system for the growth of CIGS layers on in-line moving substrates is currently under development stage. CIGS solar cells on ITO transparent conducting oxide (TCO) coated glass substrates were developed for their future application in tandem solar cells. We have developed 8% to 12% efficiency CIGS solar cells where both the front and back contacts are TCOs.

A new spray technology incorporating ultrasonic fine and condensed mist forming method has been developed for the growth of buffer layers on CIGS solar cells. Initial testing of different wide band gap buffer materials was started and later on the focus was placed on In_xS_y layers. An ultrasonic spray equipment for $5x5cm^2$ substrates was established; growth and properties of ultrasonic sprayed In_xS_y layers were investigated and 9.5% efficiency cells were developed.

Introduction and project objectives

Polycrystalline thin film CIGS solar cells are important because of very high efficiency, long term stable performance, and their potential for low cost generation of solar electricity. The National Renewable Energy Laboratory, USA has reported a world record efficiency of 19.5% for the CIGS solar cells grown on glass substrates and several groups including ETHZ have achieved efficiencies exceeding 16% on glass substrates. Flexible and lightweight solar cells are interesting for a variety of terrestrial and space applications that require a very high specific power (kW/kg, defined as the ratio of output electrical power to the weight of solar module). Integration of such flexible CIGS solar modules in buildings (roofs and facades) is an emerging field with many attractive possibilities for the application of PV, and it offers an interesting commercial viability in future.

Prior to the start of this project, research and development work on flexible solar cells was conducted in the EU-METAFLEX project and our own internal project from the national funds. There is some overlap of the objectives and the research work of the METAFLEX and ATHLET project to maintain continuity of development. Near the beginning of the project the ETH group succeeded in developing 14.1% efficiency solar cell. The CIGS layers were grown by a vacuum evaporation process on static substrates. The ETH group had plans to start development of low temperature CIGS deposition process on in-line moving substrates.

The processing of high efficiency solar cells requires deposition of a stack of polycrystalline layers of ZnO:Al/ZnO/CdS/Cu(In,Ga)Se_2/Mo on a substrate (glass or metal or polyimide). A typical lightweight and flexible CIGS encapsulated solar module could be up to ten thousand times lighter than the module based on a 3 mm thick glass. In addition, roll-to-roll manufacturing of flexible modules has certain other advantages leading to a significant cost reduction and expanding the applicability range of solar modules for diverse applications. The objectives of the first work package include:

- Development of high efficiency lightweight and flexible CIGS solar cells on polymer foils and improvement in processes for highest record efficiencies.
- Development of alternative processes towards simple and low cost manufacturing of high efficiency flexible solar cells.
- Development of critical cell components of CIGS tandem solar cells for next generation of more efficient solar cells.

Preliminary work on the pneumatic spray deposition of ZnO and ITO layers on glass substrates was already performed with emphasis on a low temperature deposition process suitable for application of buffer layers in CIGS solar cells. One outcome of the preliminary investigation, prior to the start of the project, was that it is important to minimize the solution droplet size for low temperature deposition of the very thin buffer layer on CIGS in order avoid the chemical damage (oxidation) of the CIGS surface and to control the layer thickness. For this reason ultra-sonic spray was identified as a suitable low cost large area scalable process. Initial plans were made to set-up the ultra sonic spray set-up for deposition of buffer layers for the ATHLET project.

The objectives of the second work package is the development of a new spray technology incorporating ultrasonic fine and condensed mist forming, initial testing of different wide band gap buffer layer materials (InS_xO_y, ZnS_xO_y, SnS_xO_y) on small area cells, followed by more detailed work on the best suited buffer material.

A set up for homogenous deposition of various buffer layer materials by ultrasonic spraying is to be developed and optimized for solar cells with an area up to 10x10 cm^2. Pneumatic spraying of the buffer layer with alternative materials is a promising and easy scalable technique to replace the common chemical bath deposition (CBD) process of the CdS buffer layer. Nevertheless solar cell efficiency is still lacking behind the common CBD-CdS approach and more experience has to be gained with the new materials in order to get similar results or even outperform the conventional buffer layer. This project should help to understand the potential of the novel ultrasonic spraying technique for thin compound layer deposition.

Work and results

Flexible solar cells on polyimide: We have grown CIGS solar cells on different commercially available polyimide (PI) Upilex-S foils. An approximately 1 μm-thick Mo back contact was directly deposited by dc sputtering without application of any additional intermediate layer. CIGS absorber layers were grown by evaporation of elemental Cu, In, Ga and Se and using 3-stage process. Na in CIGS was incorporated in-situ by a post-deposition treatment (PDT) method. This consists of evaporation of about 30 nm NaF on CIGS, without substrate heating, and then annealing the sample at 400°C for 20 minutes.

Experiments have shown that the in-diffusion of Na significantly improves the efficiencies. Typical consequence of the presence of Na during CIGS growth on the cell parameters are substantial improvements in V_{oc} and FF, but hardly in J_{sc}. Since PDT Na incorporation gives rise to corresponding changes in the cell parameters, it is likely that the dominating Na mechanisms responsible for the improvements are the same, although CIGS growth kinetics, grain size and crystallographic orientation are not affected with PDT Na incorporation. Absorber depositions at different $T_{sub,max}$ have shown that best efficiencies are obtained at $T_{sub,max}$ = 450-460 °C (this is a reference temperature, actual substrate temp might be different).

The cross-section scanning electron microscope (SEM) images of solar cells with CIGS absorbers show small grains of CIGS near the Mo back contact, but larger grains of dimensions approaching 1 μm are observed in the upper half of the CIGS layers. Although solar cell component layers and substrate have different thermal expansion coefficients no cracks have appeared on the samples, even after high temperature deposition and/or after CBD-CdS and ZnO/ZnO:Al depositions. This required optimization of Mo sputtering and CIGS deposition processes.

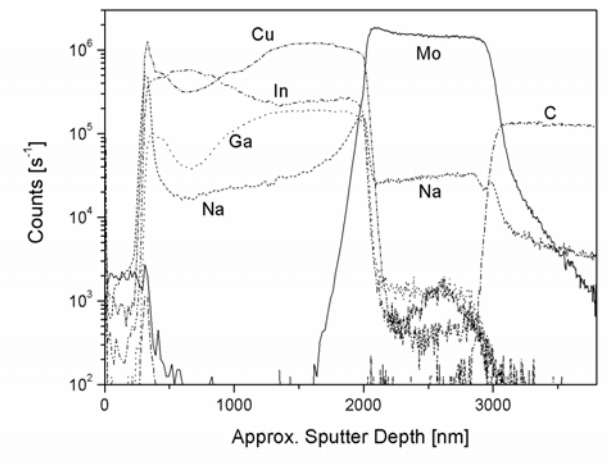


Figure 1: SIMS depth profile of CIGS/Mo layers in solar cells on PI. No C diffusion into absorber is detected. The Ga-dip/In-hill is due to low In-Ga interdiffusion at low temperature. The Cu-dip is a matrix effect and not real.

Secondary ion mass spectrometry (SIMS) measurements (thanks to G. Bilger, Stuttgart University) do not show (fig. 1) carbon contamination from the substrate into the absorber layer. Na diffuses, as expected, through the whole absorber layer and can be observed even in the Mo layer and in the polyimide. Due to the low interdiffusion of Ga and In at low substrate temperature a Ga dip and In peak in composition profiles appear near the absorber surface, this results in a band-gap grading in the absorber layer. The band-gap grading (or composition profiles) depends on CIGS deposition temperature and it leads to high efficiency solar cells.

Our CIGS deposition process was optimised for efficiency improvement and 14.1%-efficiency cell on PI were achieved (V_{oc} = 649.4 mV, FF = 69.1 %, J_{sc} = 31.48 mA/cm², total area = 0.595 cm²; no AR coating, measured under AM1.5 standard test conditions at the Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany). Since no anti-reflection coating was applied to the solar cells the external quantum efficiency (EQE) does not exceed 80-85 %. An average reflectance loss of about 13 % was measured in the visible-near IR spectral region for these solar cells. Deliverable of >14% efficiency cell on polymer foil was due for 18 month but it was achieved just in the beginning since this activity is a continuity of the METAFLEX project. For all these experiments CIGS layers were grown on substrates at a fixed position with respect to the evaporation sources during growth (static deposition).

In-line CIGS deposition of flexible solar cells: Deposition of CIGS layers with in-line evaporation method requires construction of a new evaporation system. With investment support from our federal grant we have started development of a new CIGS deposition system where different type of substrates and growth processes could be used. Construction of such a system requires lot of technical and time consuming assembling work and a multitude of basic experiments to test evaporation sources, substrate heating and movement mechanisms before starting the CIGS growth experiments. Several iterations are needed for a satisfactory operation of the deposition system. Obviously, the quality of layers in the initial phase of the development of such system would be inferior to the static-deposition system. We are hopeful that during the next reporting of progress results from the new system on in-line CIGS deposition will be available.

Flexible cells with PVD buffer: For the development of flexible solar cells with PVD grown buffer layers an evaporation system has been installed and initial experiments on the growth of InxSy buffer layers for calibrations have started. Detailed results will be available during the next six months.

Table 1: Photovoltaic properties of CIGS solar cells grown on ITO back contacts.

Back Contact	**Na**	**V_{oc}** [mV]	**J_{sc}** [mA/cm^2]	**FF** [%]	**η** [%]
ITO	-	496	30.9	47.6	7.3
Mo (1μm) / ITO	-	529	29.1	65.5	10.1
Mo (10 nm) / ITO	-	524	29.2	61.4	9.4
$MoSe_2$ (10 nm) / ITO	-	544	30.6	57.2	9.5
Mo (10 nm) / ITO	PDT	603	31.4	63.1	11.9
$MoSe_2$ (10 nm) / ITO	PDT	562	30.4	48.6	8.3

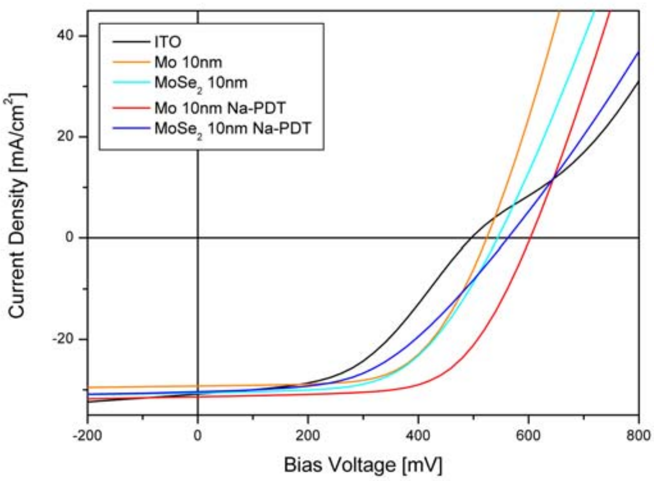


Figure 2: IV-measurements show that efficient solar cells can be grown on alternative electrical back contacts such as Indium Tin Oxide (ITO) by using a thin $MoSe_2$ layer between CIGS and back contact

Advanced concepts and tandem solar cells: Development of CIGS solar cells on transparent conducting oxide (TCO) coated substrate is essential for the development of tandem and bi-facial solar cells. Different TCOs are to be evaluated in terms of their compatibility with the device structure and processing conditions, we started with ITO layers. CIGS solar cells grown directly on ITO coated glass substrates exhibit very low efficiency of 2-3%, but application of a very thin MoSe2 interface layer, obtained by selenisation of a thin Mo layer, enhanced the cell efficiency to 8% - 12% range depending on processing conditions.

Alternative buffer layer with ultrasonic spray deposition method

Ultrasonic spray pyrolysis (USP) equipment for 5x5cm^2 samples was assembled and various configurations (spray-up, spray-down) were tried. The final and most promising configuration is shown in Figure 3. In_2S_3 thin films were deposited on soda lime glass (SLG) substrates by spraying an alcoholic solution containing different concentrations of $InCl_3$ and $(NH_2)_2CS$ (TU). SLG substrates were cleaned with soapy water, double deionised water and isopropanol. Various heater temperatures were used to produce layers for spraying times of 30 minutes. For the description of results in this paper we use heater temperature (T_H) values of: 310, 345 and 380 °C, but corresponding measured average substrate temperature (T_S) values during the spray were: 200, 220 and 245 °C.

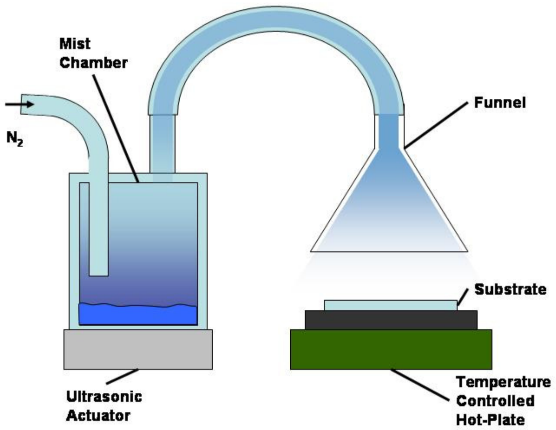


Figure 3: Schematic of the USP system; mist of the solution generated by the ultrasonic actuator is transported through a tube and the funnel for a spray

The nitrogen carrier-gas flow rate was kept at 1.5 l/min, corresponding to an average solution spray rate of 40 ml per 30 minutes. The formation of In_2S_3 results from the chemical reaction:

$$2InCl_3 + 3(NH_2)_2CS + 4CH_3OH + 2O_2 \rightarrow In_2S_3 + 6NH_4Cl + 3CO_2 + 2H_2O.$$

The thickness of the In_2S_3 layers was measured with a stylus profilometer and the optical properties were measured over the wavelength range of 280 – 1100 nm. A X-ray Photoelectron Spectroscopy (XPS) was used to calculate changes in S:In ratios in the films and Scanning Electron Microscopy (SEM) was used to evaluate the uniformity, morphology and structural properties of the In_2S_3 layers. X-ray Diffraction (XRD) was used to determine the chemical and structural phases of different In_2S_3 films.

USP-In_2S_3 properties: As can be seen in Table II, the USP-In_2S_3 film growth rate is dependent on the T_H and precursor concentrations in the spray solution. At higher T_H and [$InCl_3$] concentration the growth rate is higher if the [TU]:[$InCl_3$] ratio is kept constant in the solution at the same deposition time. The effects are less pronounced for lower concentration of $InCl_3$.

The average optical transmission of the films decreases when T_H and [$InCl_3$] increase, mainly due to greater film thicknesses. The values of average transmission and the thicknesses given in Tables I and II have statistical distribution due to experimental limitations, the values are therefore indicating only the trends.

Table II: $InCl_3$ concentration and heater temp. (T_H) influence on the USP-In_2S_3 film thickness (d), optical transmission in wavelength region 700-1100 nm ($T_{700-1100}$), S:In ratio in the films and dominating chemical phases. The [TU]:[$InCl_3$] concentration ratio was 4 and spray duration was 30 minutes.

T_H (°C)	[$InCl_3$] (M)	d (nm)	$T_{700-1100}$ (%)	S:In	In_2S_3 phase α-c	β-c	β-t
310	0.005	40	97				
310	0.01	70	94	0.79	+	+	
310	0.1	115	83				
345	0.005	45	95				
345	0.01	85	87	0.77	+	+	
345	0.1	120	82				
380	0.005	50	94				
380	0.01	120	75	0.74		+	+
380	0.1		180	81			

The dominating phases in layers deposited at lower T_H are α-cubic In_2S_3 and β-cubic In_2S_3 (Fig. 4). But at higher T_H the dominating phase is β-tetragonal In_2S_3, accompanied with weak β-cubic In_2S_3 peaks. According to Gödecke et al (T. Gödecke, K. Schubert, Z. Metallkd. 76 (1985) 357), the α-cubic phase forms in this T_H region only if [S] = 59.7 – 60.0 at% in In_2S_3, while for β–phase [S] value is slightly lower (58.6 – 59.4 at%). XPS measurements detected slightly lower S:In conc. (change within the sensitivity range) in the USP-In_2S_3 films for layers grown at higher T_H, the values of exact conc. have not been calculated, because standards were not available, therefore the relative change is given.

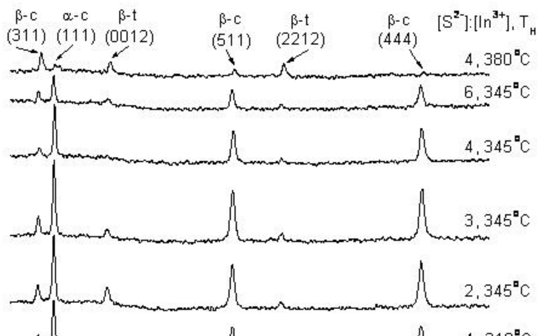


Figure 4: XRD patterns of USP-In_2S_3 films, deposited at different heater temp. (T_H) and [TU]:[$InCl_3$] ratio, show α-cubic (α-c), β-cubic (β-c) and β-tetragonal (β-t) In_2S_3 phases.

The [TU]:[$InCl_3$] concentration ratio influences the growth rate, transmission and chemical composition of the deposited layers (Table III). If the conc. ratio is 2 and 6, the film growth rate is slightly lower than for films with ratio 3 and 4. The films transmission decreases when the TU concentration in the solution was decreased. This can be also due of changes in crystal structure and chemical phase of the layers.

Table III: Influence of [TU]:[InCl$_3$] ratio on the USP-In_2S_3 film thickness (d), optical transmission between 700 and 1100nm (T) and dominating phases when [InCl$_3$] = 0.01 M, T_H = 345°C and the spray duration is 30 minutes.

[TU]:[InCl$_3$]	d	$T_{ransparency}$	In_2S_3 phase		
	(nm)	(%)	α-c	β-c	β-t
2	55	69.4	+	+	+
3	88	77.3	+	+	+
4	85	85.7	+	+	
6	65	92.5	+	+	

Figure 5 displays optical transmission curves. In the absorption region 350 – 500 nm, the shape of the curves is similar for the films with [TU]:[InCl$_3$] = 3, 4 and 6. Layers with [TU]:[InCl$_3$] = 2 have different growth rate probably because of a dominant β-tetragonal phase and a change in crystal structure can influence the growth rate of the layer. With increasing [TU]:[InCl$_3$] concentration ratio the presence of the β-tetragonal phase decreases as measured from XRD peak intensities. It is probable that the layers may contain small concentration of oxygen, which is not detected by the XPS or XRD measurements.

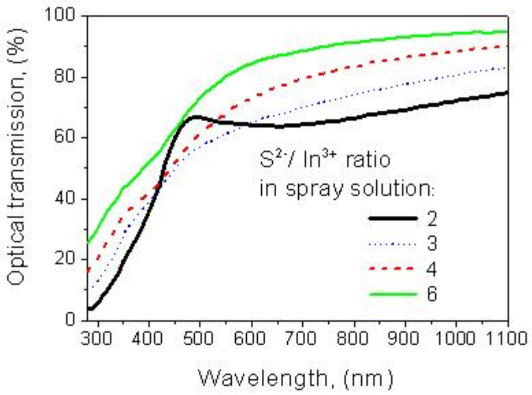


Figure 5: Optical transmission curves for USP-In_2S_3 films deposited with different [TU]:[InCl$_3$] ratios as given in Table II.

Figure 6 shows SEM images of an In_2S_3 layer sprayed on SLG with solution containing 0.05 M InCl$_3$, [TU]:[InCl$_3$] = 3, T_H = 345°C and spray duration 60 minutes. It can be seen that the layer is continuous and that the thickness is approximately 170 nm (Fig. 6b). The surface of the film appears clean and polycrystalline with grain size of 100 – 150 nm (Fig. 6a).

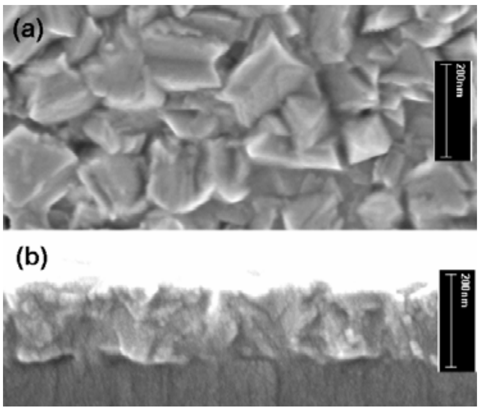


Figure 6: SEM image of USP-In_2S_3 surface a) and cross-section b) on the SLG indicates 100 – 150 nm grain size.

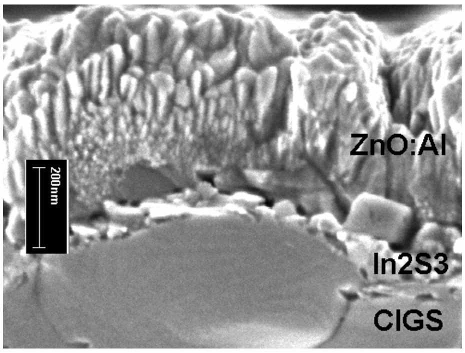


Figure 7: SEM cross-section image of the CIGS solar cell with USP-In_2S_3 as a buffer-layer

Solar cells with USP-In_2S_3 and CBD-CdS: For solar cell development USP-In_2S_3 was sprayed using solution containing 0.005 M $InCl_3$, [TU]:[$InCl_3$] = 3, T_H = 310°C and spray duration was 20 minutes. Reference solar cells were prepared with CBD-grown CdS on CIGS. The SEM cross-section (Fig. 7) shows the presence of about 30 - 50 nm thin granular In_2S_3 layer between CIGS and ZnO layers. The grain size of USP-In_2S_3 (Fig. 6a) is larger then that of CBD-CdS, but the conformal coverage of CIGS surface appears rather poor.

Figure 8 shows the I-V curves of solar cells with different buffer. Solar cells with USP-In_2S_3 show light soaking effect, e.g. after a continuous light illumination for 14 hours 8.9 % efficiency (V_{OC} = 0.523 V, FF = 60.9 %, J_{SC} = 27.9 mA/cm^2) increases to 9.5 % efficiency (V_{OC} = 0.552 V, FF = 61.8 %, J_{SC} = 28.1 mA/cm^2). The corresponding reference cell with CdS has 12.7 % efficiency (V_{OC} = 0.609 V, FF = 73.2 %, J_{SC} = 28.4 mA/cm^2). The reason for light-soak induced improvement is the decrease of the defects during the illumination (persistent photoconductivity). Although the USP-In_2S_3 has a wider band gap than CdS and thus absorbs less light in short wavelength region, the current densities are comparable. The cells with In_2S_3 buffer-layer have lower V_{OC} and FF. The characteristics of the absorber-buffer interface and their influence on the recombination mechanisms are not clear and need further investigation.

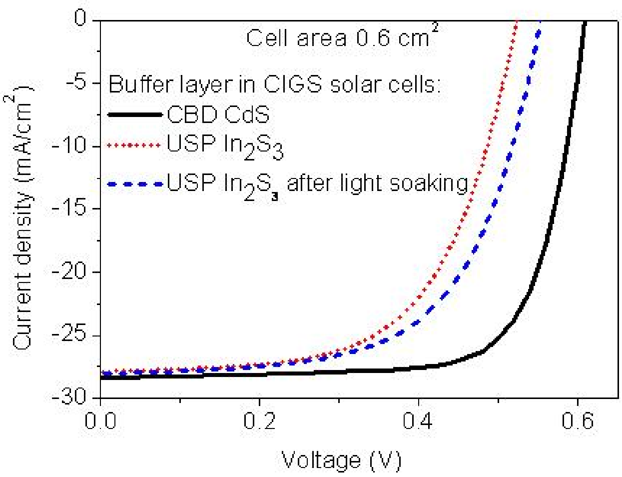


Figure 8: I-V curves for solar cells with CBD-CdS and USP-In_2S_3 before and after light soaking.

Outlook 2007

First focus was placed on In_2S_3 deposition. Instead of exploring other buffer materials more focus is put in the optimization of a promising buffer layer. Observed difficulties with thickness uniformity and reproducibility associated with the random turbulence of the solution mist arriving at the substrate will be addressed with a better protected spray chamber and improved experimental set-up for better control of the mist profile which influences the homogeneity of the layers. The deposition setup will have to be up-scaled from 5 x 5 cm^2 to 10 x 10 cm^2 size substrates. CIGS solar cells with evaporated buffer layers will be developed and eventually the process will be applied to flexible solar cells. Further development of solar cell devices for tandem solar cells will be carried out. Our work on in-line CIGS deposition has an overlap with a project from the Federal Office of Energy and further a deposition system is developed for layer growth and characterization which is used to perform towards optimization of a process for high efficiency solar cells.

National and international collaboration

This project is realised in collaboration with the following industrial partners and scientific institutes:

- Centre national de la recherche scientifique
- Hahn-Meitner-Institut GmbH
- Energy research Centre of the Netherlands
- Shell Solar (AVANCIS)
- Solarion GmbH
- Free University of Berlin
- Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg

Several activities of this project benefit from the projects sponsored by Swiss agencies, especially the work on flexible and tandem solar cells have some overlap from the projects supported by the Swiss Federal Office of Energy and ETH.

Publications and conference presentations

[1] K. Ernits, M. Kaelin, D. Brémaud, T. Meyer, U. Müller, A.N. Tiwari, ***Ultrasonically sprayed In_2Se_3 films for $Cu(In,Ga)Se_2$ solar cells,*** Proceedings 21st European Photovoltaic Solar Energy Conference, Dresden, 2006, p. 1853-1856.

[2] D. Brémaud, D. Rudmann, M. Kaelin, C. Hibberd, A.N. Tiwari, ***Alternative Back Contacts and $MoSe_2$ Interface Layer on $Cu(In,Ga)Se_2$ Solar Cells,*** 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4 - 8 Sep 2006.

[3] K. Ernits, D. Brémaud, S. Buecheler, M. Danilson, C.J. Hibberd, M. Kaelin, U. Mueller, D. Rudmann, E. Mellikov, A.N. Tiwari, ***Characterization of Ultrasonically Sprayed In_2S_3 Buffer-Layers for Cu(In,Ga)Se2 Solar Cells,*** E-MRS 2006 Spring Meeting, Nice, France, 29 May - 2 Jun 2006.

DYE-SENSITISED NANOCRYSTALLINE SOLAR CELLS

Annual Report 2006

Author and Co-Authors	Michael Grätzel, Augustin McEvoy
Institution / Company	Laboratory for Photonics and Interfaces LPI, Faculty of Basic Sciences
Address	Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne
Telephone, E-mail, Homepage	+41 21 693 31 12, michael.graetzel@epfl.ch; http://isic.epfl.ch/graetzel_e.htm
Project- / Contract Number	Project EPFL
Duration of the Project (from – to)	January – December 2006
Date	January 2007

ABSTRACT

Sensitised photoelectrochemical devices are a significant technical and commercial alternative to the conventional solid-state junction photovoltaic devices for solar energy applications. The standard photovoltaic devices developed and now widely applied are solid state devices, with semiconductor layers absorbing light and thereby producing electron-hole pairs, which are subsequently separated to provide a photovoltage by junctions, either with other semiconductors or Schottky contacts with metals. In the photoelectrochemical system the contacting phase is an electrolyte. However standard semiconductors with absorption properties compatible with visible light are in general unstable in contact with electrolytes. Widebandgap semiconductors are suitable, if sensitised to the visible spectrum by electroactive dyes. In the dye-sensitised system the recombination loss mechanism is minimised since the processes of optical absorption and charge separation take place on distinct phases within these photovoltaic cells. In consequence oppositely charged species are restricted to separate phases. Therefore device photoconversion efficiency is maintained even at low light levels. Recent results on enhanced device stability are particularly significant for future commercial applications.

A hybrid variant is also under investigation, the dye-sensitised solid state heterojunction, where the electrolyte phase is replaced by an organic charge transport medium. A further implementation of the dye-sensitised cell is as a component in optical-series tandem cells for photoelectrolysis.

Introduction

The objective remains the advancement of the technical status of sensitised photovoltaic devices, so that the materials and processes involved, as developed over the past decade by LPI-EPFL and protected by patents, can be effectively transferred to industry under license and become part of the established photovoltaic market. Effort has been directed towards the advancement of the scientific understanding, materials base, stability, compatibility and practical applicability for these devices. To that end, better spectral matching of dyes, confirmation of materials stability particularly at more elevated temperatures, improved electrolytes using ionic liquids, and attention to variants such as the sensitised solid state heterojunction have been pursued during the year. There is attention to increased efficiency and device reliability, use of diverse substrates, interconnection procedures and applications.

Technical summary

The fundamental principles of the dye-sensitised solar cell are well establishment and reported (1,2). As is evident from the nanoscale structure of such a cell as presented in Fig. 1, the fundamental operating unit is the organometallic dye molecule chemisorbed on the surface of a crystallite of a wide bandgap semiconductor, in this case titanium dioxide. Long experience of semiconductor photoelectrochemistry has established that the narrow-gap materials, with optoelectronic properties best adapted to solar energy conversion, are in general unstable incontact with electrolytes under illumination. The optical absorption properties of the dye molecule permit a sensitivity to visible light, with consequent electron transfer to the substrate, a stable wide-gap material. Regeneration of the uncharged dye complex is by reaction with the contacting redox electrolyte, which in turn recovers electrons through the external circuit and the counter-electrode. The overall reaction – the absorption of a photon leading to charge separation and the passage of an electron in an external circuit – therefore functionally replicates the operation of a conventional photovoltaic cell. Fig. 2 is a schematic of the optical excitation and charge transfer sequence.

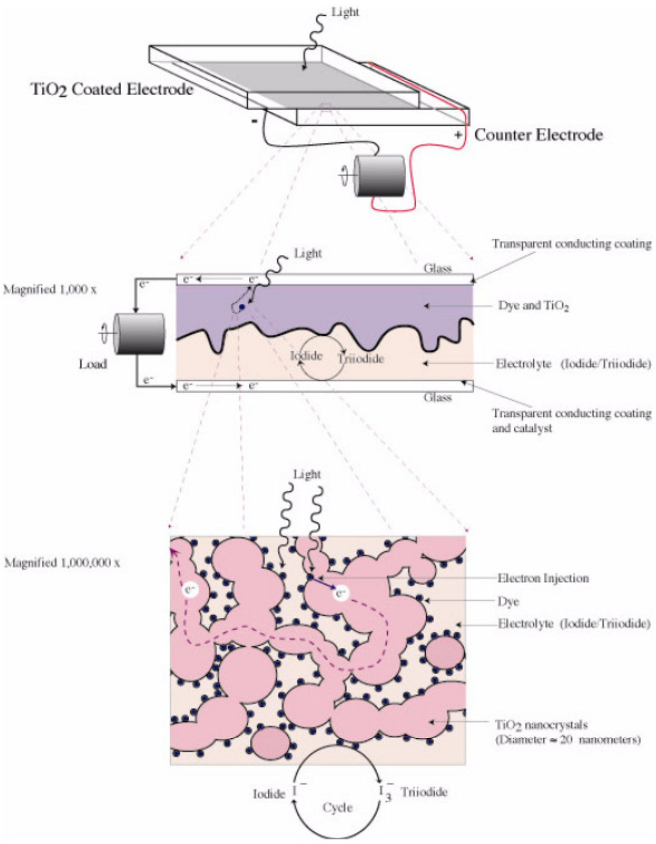


Fig. 1: Structure of dye-sensitised photo-electrochemical cell on different scales.

(Top): a complete cell (centimeter scale).

(Centre): electrodes and electrolyte, micron scale.

(Bottom) nano-scale semiconductor inter-connected porous layer, with adsorbed monolayer of dye and entrained electrolyte.

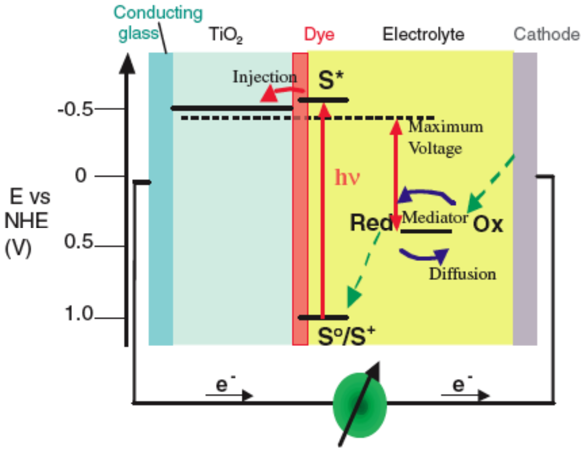


Fig. 2: Principle of operation of the dye-sensitised nanocrystalline solar cell. Photoexcitation of the sensitizer (S) is followed by electron injection into the conduction band of an oxide semiconductor film. The dye molecule is regenerated by the redox system, which itself is regenerated at the counter electrode by electrons passed through the load. Potentials are referred to the normal hydrogen electrode (NHE).

Practical realisation of the cell on an industrial scale requires a manufacturing procedure to interconnect cells electrically in series, as well as to seal adjacent cells to prevent interaction of their electrolytes. Sealing is less problematic if the electrolyte is in gel form, or otherwise more viscous and less mobile. Another alternative is the sensitised heterojunction concept already mentioned, in which the contacting phase to the n-type titania photoelectrode is a p-type material, specifically an organic hole conductor. A known material with the required properties is the spiro- structured compound shown in Fig. 3. The structure of the solid-state dye-sensitised heterojunction cell appears as Fig. 4.

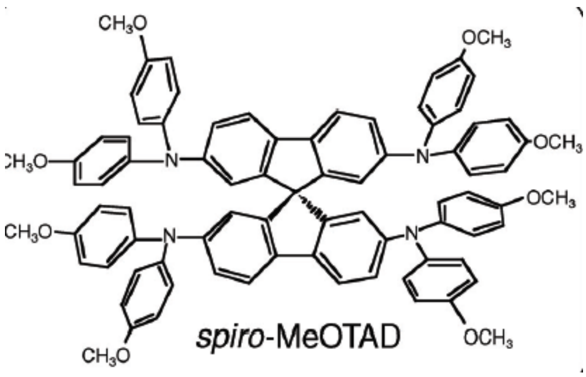


Fig. 3: structure of spirobifluorene hole-conducting p-type organic semiconductor. The fluorene structures are perpendicular, conjoined through a carbon site common to both.

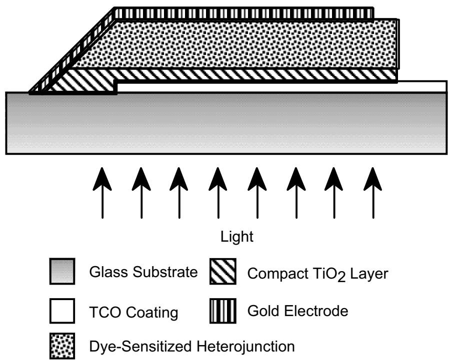


Fig. 4: Schematic of the dye sensitized heterojunction PV cell.

The application of a dye-sensitised component within a tandem cell for photoelectrolysis has also been investigated. The oxide photoanode itself, of course does not provide the potential difference of about 1.23 volts necessary for electrolysis of water so a complementary DSC is added in electrical series to achieve the required voltage. It is also convenient that the cells be in optical series and have complementary optical absorption spectra in order to maximise the energy drawn from sunlight. The cell with the larger bandgap semiconductor is effectively transparent for longer wavelengths, which can be harvested by a second cell whose sensitivity extends towards the red.

For the oxide semiconductor photoanode, iron or tungsten is favoured. A schematic of the energetics of this system is shown in Fig. 5.

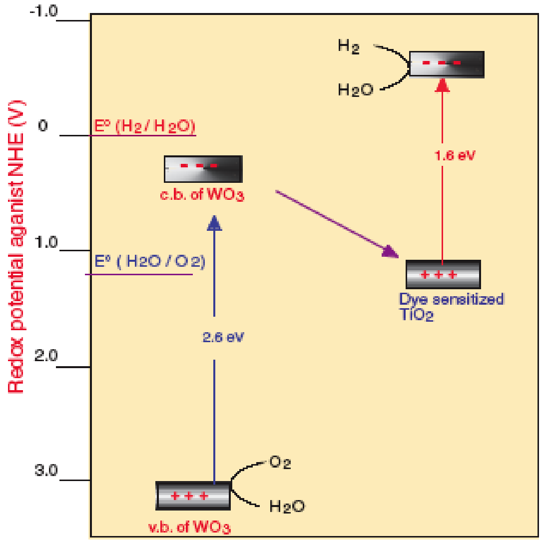


Fig. 5: schematic of energy levels and electrical series connection of a tandem arrangement for solar photoelectrolysis. As stated in the text, the two photosystems are also in optical series.

Ongoing Work and Results 2006

Dye development is particularly important, with attention to molecular engineering for improvement of stability, particularly at higher temperatures. Noteable is the substitution of hydrophobic chains on the dye molecule, so that traces of water in the ionic liquid electrolytes are not deleterous for cell performance. The optical absorption spectrum and molecular structure of the first of the “K-series” dyes with these side chains is shown in fig. 6. The high optical absorption and its favourable match to the solar spectrum should be noted, as well as the improvement with respect to the prototype dye N3 (3).

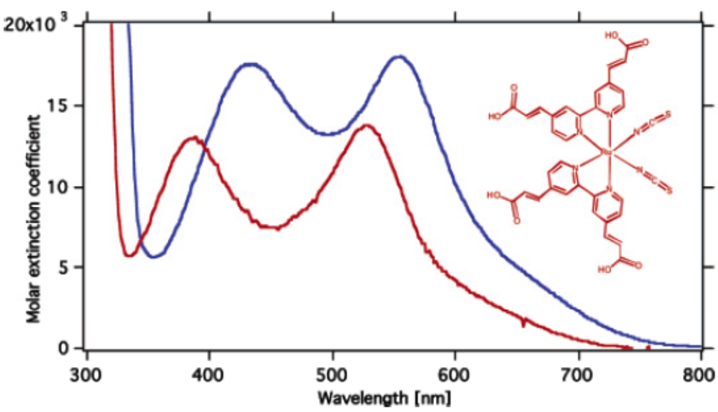


Fig. 6: Molecular structure and optical properties of the dye K8.

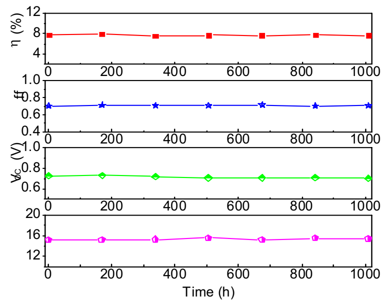


Fig. 7: Cell stability over 1000hr, AM1.5, after thermal aging at 80 °C

Electrolyte performance has also been enhanced in the recent past (4). The particular objective is the long-duration stability of cells in full sunlight operation, since the temperature on the photoactive surface may reach 80°C. Ionic liquid electrolytes which are normally less volatile are explored for their applicability for nanocrystalline dye-sensitized solar cells with an acceptably high current density of over 15 mA/cm^2. The mass transport of triiodide had been previously considered a limiting factor because of its lower diffusion coefficient and lower concentration in electrolytes compared with that for iodide. Initial results obtained by simply replacing the organic solvent with some ionic liquids were disappointing. However 6% efficiency under AM 1.5 full sunlight was achieved by employing an amphiphilic sensitizer in conjunction with an ionic liquid containing very high iodine concentration, i.e., by loading pure 1-propyl-3-methylimidazolium iodide (PMII) having a viscosity of about 880 cP with 0.5 M I_2. At an iodine concentration below 0.2 M, mass transport of triiodide does become the main limitation in this type of thin-layer electrochemical cell. For comparison a device employing the same sensitizer and an acetonitrile-based electrolyte gave a conversion efficiency of 9.5% in full AM 1.5 sunlight, the short-circuit photocurrent density (*J*sc), open-circuit photovoltage (*V*oc), and fill factor (*ff*) of this being 16.7 mA/cm^2, 753 mV, and 0.75, respectively. Replacing part of the iodide in the PMII by some weakly coordinating anions can lower the viscosity of the ionic liquid. Thus, mixtures of PMII with

1-ethyl-3-methylimidazolium dicyanoamide and 1-ethyl-3-methylimidazoliumthiocyanate achieve conversion efficiencies above 6.0% in full sunlight. However a high mole fraction of PMII is required in these binary systems to maintain photovoltaic performance even if the triodide concentration is sufficient to avoid diffusion limitation of the photocurrent.

Obtaining long-term stability for DSCs at temperatures of 80~85°C had remained a major challenge for over 10 years and has only recently been achieved. Stabilization of the interface by using self-assembly of sensitizers in conjunction with amphiphilic coadsorbents has been particularly rewarding. Stable operating performance under both prolonged thermal stress (at 60 and 85°C) and AM 1.5 light soaking conditions has been possible. These devices retained 97.7% of their initial power conversion efficiency after 1,000 hr ageing (Fig.7). An analysis on DSC stability shows that in principle, DSCs can function in a stable manner for over 20 years, if the macro-engineering issues are rightly addressed (5). The characteristics of a state-of-the art cell are presented in fig. 8.

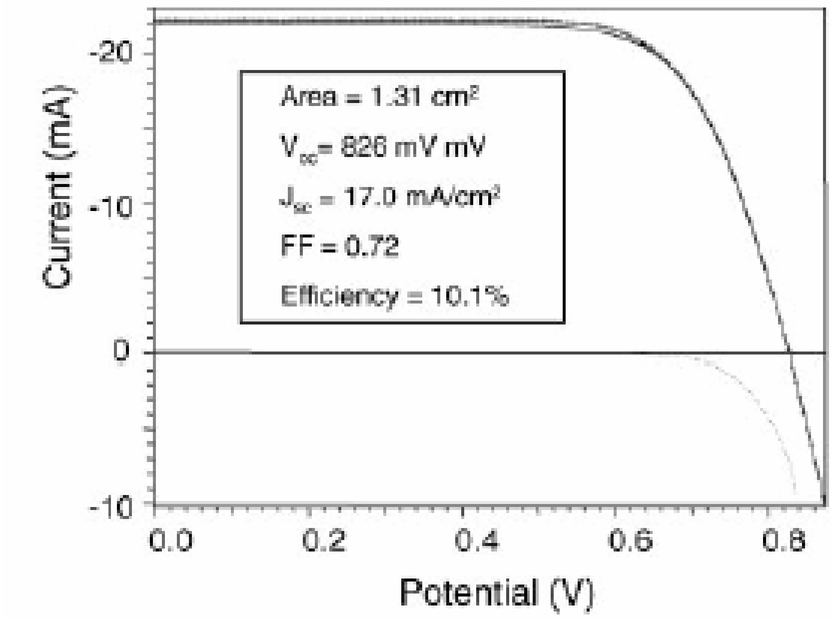


Fig. 8: I-V characteristics of a 1 31 cm2 DSC top-cell prepared at EPFL; Dye: N719 (from Greatcell), 4 times purified; Electrolyte: 0 6M butyl,methyl imidazolium iodide (BMII), 0 1M GuSCN, 0 03M I2, 0 5M tert-butylpyridin (TBP) in acetonitrile/valeronitrile 85:15 volume ratio. High transmission FTO-glass (Nippon Sheet Glass, 10 Ohm/square) was used provided with an antireflector coating. nc-TiO2: 16 micron TiO2 (20 nm particle size) +4 micron scattering TiO2 scattering layer (400 nm particle size)

It is should also be noted that investigations into improved semiconductor substrates have continued. Zinc oxide in nanostructured form is not yet competitive with the standard titania material,especially when scattering layers for improved optical performance have been added (6).

For a more technical report on the status of DSC development, a recent review is of interest (7).

National Cooperation

The primary national cooperation is with Swiss industries which have taken up licenses on the dye-sensitisation photovoltaic concept.

International Cooperation

An ongoing cooperation on the European level within the research programme of the Commission of the European Communities is the object of a separate report. Outside Europe, cooperation continues with licenses to industrial partners in Australia (below), North America and Japan. Academically there are ongoing contacts with India, China and Korea.

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VOLTAGE ENHANCEMENT OF DYE SOLAR CELLS AT ELEVATED OPERATING TEMPERATURES

Annual Report 2006

Author and Co-Authors	Michael Grätzel, Augustin McEvoy
Institution / Company	Laboratoire de la photonique et des interfaces LPI, Faculté des Sciences de Base
Address	Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne
Telephone, E-mail, Homepage	+41 21 693 31 12; michael.graetzel@epfl.ch; http://isic.epfl.ch/graetzel_e.htm
Project- / Contract Number	7019.1
Duration of the Project (from – to)	01.01.2004 – 01.01.2006
Date	January 2006

ABSTRACT

The recently concluded action with the industrial partner, Greatcell Solar SA (GSA) followed on a previous cooperation, also supported by KTI/CTI (project nos. 5815.1 & 5480.3), "Highly Efficient Nanocrystalline Solar Cells for Indoor Applications". The GSA product concept is a dye-sensitised electrochemical photovoltaic cell also adapted for indoor use. As a result the environmental restrictions are less severe, but the requirement for sensitivity to low light levels is an imperative. The reported project action at increased stability, particularly at elevated operating temperatures, with enhanced efficiency, in dye-sensitised PV cells fabricated in accordance with the Greatcell Solar SA product concept. It has been recognised that recombination losses are inhibited by the specific characteristics of this type of solar cell, rendering it more suitable for operation over a wider range of incident light intensities, indoor and outdoor. Cell fabrication requires the preparation of nanoparticulate semiconductor powders, and methods of preparing mesoporous layers from these materials on transparent conducting oxide coated substrates. The layers are then sensitized to visible light by chemisorbed electroactive dyes. This photoanode is associated with a redox electrolyte and cathode to form an electrochemical photovoltaic cell. During 2006 attention was given to formulation of improved electrolytes, molecular engineering of suitable dyes which by their physicochemical effects enhance stability at a higher output voltage, and the interface engineering particularly of the photoanode semiconductor material. This project is a key contribution to the development of the company Greatcell Solar, providing relevant information and technology for its intended product.

Introduction

The objectives of the project were to enhance the performance, particularly the voltage characteristics, of dye solar cells for indoor applications. The typical light level indoors is 500 lux. In addition, the spectrum of light depends on the light source. Consequently, it has been necessary to develop electochemistry that can perform in a wider range of light conditions and sources, as well as sustaining higher operating temperatures. The result of this work has been to demonstrate that DSC can compete advantageously with other photovoltaics under incandescent, fluorescent and pseudo-sunlight conditions at low intensities. In order to achieve the required results, several aspects of the DSC electrochemistry have been adapted. The nanoparticle surfaces have been modified with other cations as dopants, with certain output voltage enhancement effects; similarly surface modification by use of coadsorbents with the dye has been investigated. Formulations for dye deposition and for the support of the electrolyte redox system have been evaluated, particularly for synergetic effects, and a robust electrolyte with improved long-term performance is employed. Lifetime tests at elevated temperatures were reported to the industrial partner.

Technical Summary

The fundamental principles of the dye-sensitised solar cell are well established and widely reported; an outline of the state of the art was presented at the European Photovoltaic Solar Energy Conference, Dresden, 2006 (1). Whereas in conventional solid state junction PV cells optical absorption takes place within a single phase of a solid material, followed by charge separation at the junction, in the dye-sensitised device the absorption is by a monolayer of chemisorbed molecular dye, followed by electron injection into an underlying semiconductor substrate, so that two separate phases are involved. In consequence the recombination process limiting the efficiency of solid-state photovoltaic cells, particularly at low light levels, is inhibited in the dye-sensitised device, enhancing its relative performance under those circumstances. Basic patents on the concept are held by EPFL; Greatcell Solar S.A. is a licensed under those patents to exploit DSC concepts.

Ongoing Work and Results 2006

The goals of this project were an improved performance, particularly higher output voltages maintained over a wider temperature regime, and technology transfer of key nanoparticle-based technologies for the production of dye solar cells as developed in LPI EPFL, to Greatcell Solar SA which has a novel design for a cell module suited for indoor diffuse light application. At EPFL a systematic evaluation of the photovoltaic power output under different light conditions has been made. The analysis shows that under typical indoor conditions (500 lux) the electric power obtained can be about 40 % higher than the initial output of commercial amorphous silicon cells. The photovoltaic yield of dye-sensitised devices in comparison with amorphous silicon cells is presented in the accompanying Fig.1.

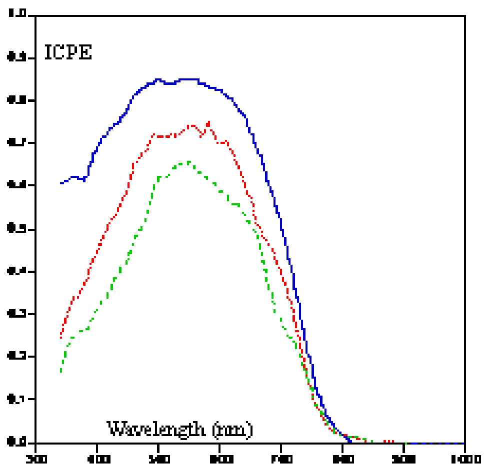


Fig. 1: spectral response, given as incident photon conversion efficiency against wavelength, of a dye-sensitised cell (——) in comparison with a new (·········) or used (6 hrs., 800 W/m^2) amorphous silicon cell.

For efficiency, there has been an emphasis on the chemisorption process for the attachment of the dye molecules to the titania film substrate. Amphiphilic dye molecules had been identified as significant for cell performance and stability (2); further structural engineering of these dye molecules has been carried out.

During an earlier phase of the cooperation (TopNANO contracts 5815.1 & 5480.3) dye development work concentrated on partial deprotonisation of the N719 dye in order to increase cell voltage and also on optimization of solvent system chemistry. These were achieved and the results transferred to the industrial partner. However EPFL stability tests had shown permanent degradation of the cell performance at very high storage temperatures (e.g. 85°C). Consequently, even though trials had shown that there was full recovery of performance after 60°C storage, it was considered desirable to offer an alternative dye system. This system is based on the EPFL Z907 dye, described in parallel reports to OFEN and in the literature (2, 3). The structure of this dye is shown in Fig. 2. This is a hydrophobic dye due to the presence of longer hydrocarbon chain branches on the molecule. Consequently, degradation by trace contaminant water in the ionic liquid electrolyte is reduced. A further enhancement of this system involved additions of self-assembling molecules to the dye solution that co-adsorb with the dye to reduce the free titania surface (4). A typical additive is decylphosphonic acid. Treatment with trivalent cations is also known. The electrolyte utilized with the previous dye had to be modified for the Z907 dye because it was desorbed by the solvent, butyrolactone. A particular advantage of the new dyes is compatibility with gelled ionic liquid electrolytes, which enhance thermal stability without deterioration of photovoltaic efficiency.

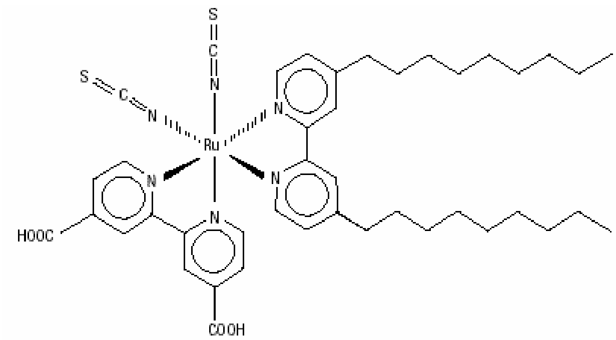


Fig. 2: structure of dye Z907 (3)

The more recent work on dye structure has targeted the hydrophobic "tail" in the molecule, shown in the Z907 case as aliphatic. Aromatic or olefin species have been introduced, and when appropriately disposed they demonstrate a resonant characteristic. This has given rise to the "K" series of dyes, the molecular structure of one of these being given in Fig. 1 (5). They have a distinct extension of the absorption spectrum towards the red, with a higher molar extinction coefficient and a good match to the visible spectrum.

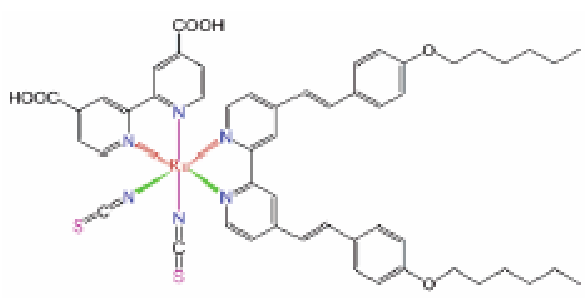
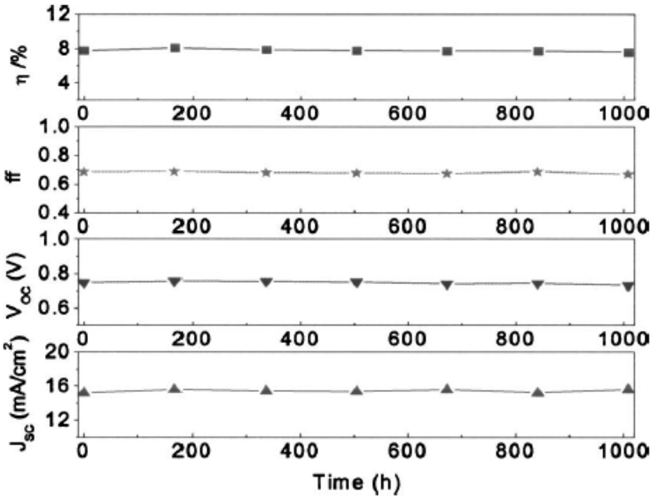


Fig.3: Structures of K19 (left) recent member of the "K" series of dyes.

The project has supported transfer of critical technologies for the production of dye PV devices from EPFL to GSA, the industrial partner, through constant interaction with GSA personnel. The production methods for the nanometric titanium dioxide material and its fabrication into semiconductor films on transparent conducting substrates, developed jointly at EPFL and GSA, is being applied and upscaled to meet the needs of the company.

Of particular interest is the increased stability under realistic operating conditions. Accelerated degradation tests by light-soaking (4) at an ambient temperature of 60°C have been carried out (Fig. 4). These demonstrate a negligible loss of any of the performance-related parameters over a period of 1000 hrs.



Temporal evolution of photovoltaic parameters - J_{sc}, V_{oc}, fill factor and efficiency - under continuous AM 1.5 simulated sunlight using K19 sensitiser during continued one sun visible-light soaking at 60 °C.

Perspectives

The prospect of industrial application of the results of the present research is greatly enhanced by the announcement in December 2005 by an associate company of Greatcell Solar SA, Dyesol (Australia) of a project for a manufacturing facility in Greece, with a local partner, Solar Technologies AE (http://www.dyesol.com/). The plant, to be built in Ioannina, in northern Greece, is planned by Solar Technologies to be the forerunner of a volume manufacturing facility.

International Cooperation

Both participants took part in the NANOMAX action, part of the European Union Research Framework 5 program. NANOMAX was managed by ECN, the Netherlands Energy Research Centre. Greatcell Solar S.A. has a close relationship with Sustainable Technologies International Ltd. and Dyesol Ltd. (Australia).

Recognition

Success in this program is obviously dependent on the professional commitment of the R&D teams within both participant organizations, and the financial support of CTI/KTI (Commission for Technology and Innovation).

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MOLYCELL - MOLECULAR ORIENTATION, LOW BANDGAP AND NEW HYBRID DEVICE CONCEPTS FOR THE IMPROVEMENT OF FLEXIBLE ORGANIC SOLAR CELLS

Annual Report 2006

Author and Co-Authors	Michael Grätzel, Ravindranathan Thampi, Augustin McEvoy
Institution / Company	Laboratory for Photonics & Interfaces, Faculty of Basic Sciences (LPI-FSB-EPFL)
Address	Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne
Telephone, E-mail, Homepage	+41 21 693 31 12; michael.graetzel@epfl.ch, http://isic.epfl.ch/graetzel_e.htm
Project- / Contract Number	SES6-CT-2003-502783
Duration of the Project (from – to)	01.01.2004 – 30.06.2006
Date	January 2007

ABSTRACT

Organic solar cells promise a strong reduction of photovoltaics (PV) costs if rapid improvements of the solar conversion efficiency and the lifetime can be achieved. There are still some crucial obstacles to overcome before a large-scale production of polymer- and organic-based solar cells can be considered. The latter is the clear aim of all industrial partners here involved. The feasibility of this approach will be proven with a new generation of organic PV having better efficiency (≥ 5% on 1cm^2 glass substrates and ≥ 4% on 1cm^2 flexible substrates), longer lifetime and a production cost far below those of competing technologies based on silicon.

The programme is a multinational specific targeted research/innovation project (STREP) within the 6th. Framework Programme of the European Union.

Introduction

Organic solar cells promise a strong cost reduction of photovoltaics (PV) but require improvements in efficiency and lifetime. The MOLYCELL action programme was a multinational specific targeted research/innovation project (STREP) within the 6th. Framework Programme of the European Union for research and development of these organic solar cells since 2004 which is now terminated. The clear aim of the industrial partners in the MOLYCELL consortium was to address some crucial obstacles to a large-scale production of plastic-based solar cells. The target was a new generation of organic PV having better efficiency (≥ 5% on $1cm^2$ glass substrates and ≥ 4% on $1cm^2$ flexible substrates) with lifetime and production cost competitive with those of competing technologies based on silicon. To reach this goal, the following issues were simultaneously addressed:

1. Design and synthesis of new materials to overcome the large mismatch between the currently available polymer materials' optical absorption characteristics and the solar emission spectrum and also to improve their charge transport properties.
2. Development of two device concepts to improve efficiencies: all-organic solar cells and nanocrystal/organic hybrid solar cells.
3. Materials and fabrication costs determined to be consistent with projected production costs < 1 €/Wp
4. Fabrication methodologies compatible with large-scale reel to reel production on flexible substrates.
5. 3000 hours of stable operation under indoor conditions defined in consultation with end-users, with roadmap for establishing stability required for outdoor operation.
6. Fabrication from non-toxic materials.

Devices

All-organic solar cells

Devices are based on donor-acceptor bulk heterojunction built by blending of two organic materials serving as electron donor (hole semiconductor, low band gap polymers) and electron acceptor (*n*-type conductor, here soluble C_{60} derivative) in the form of an homogeneous blend and sandwiching the organic matrix between two electrodes. One of these electrodes is transparent and the other is usually an opaque metal electrode. In addition to the incorporation of polymers with improved light harvesting and charge transport properties, two concepts were developed to improve efficiencies:

i) an innovative junction concept based on the orientation of polar molecules and

ii) a multi-junction bulk donor-acceptor heterojunction concept.

Nanocrystalline metal oxides /organic hybrid solar cells:

Devices are based upon solid-state heterojunctions between nanocrystalline metal oxides and molecular/polymeric hole conductors. Two strategies were addressed for light absorption: the sensitization of the heterojunction with molecular dyes, employing transparent organic hole transport materials and the use of polymeric hole conductors having the additional functionality of visible light absorption.

In order to achieve these targets, the consortium brought together established experts from both the polymer and dye sensitised solar cell communities, with expertise in the design and synthesis of new organic hole-conducting polymers or p-type semi-conductors, low temperature fabrication of nanocrystalline metal oxide films, the sensitisation of such films by light absorbing polymer and molecular dyes, the development and solution processing of organic optoelectronic materials, the fabrication of all-organic blend structures, the fabrication of nanostructured inorganic/organic heterostructures, and the photophysical and photochemical characterisation of such materials and heterostructures. Reel to reel fabrication expertise was also available where necessary within the consortium.

Project activities and results

The project was managed as a series of 6 linked work packages, covering a large field of research from the development of new materials, their characterization, the elaboration of solar cells and their evaluation. The results of each work package will be outlined.

- **WP1: Design, Synthesis and Basic Chemical Analysis of Novel Organic Hole Conductors**

The objective of reducing the band gap of conjugated polymers to 1.8 eV in a first time and then to 1.6 eV have been achieved, through the development of efficient synthetic strategies. The charge carrier mobilities of these polymers are in line with expectations and hole mobilities above 10^{-4} $cm^2/V.S$ have been demonstrated.

- **WP2: Metal Oxide Development**

New low temperature processes for the deposition of mesoporous, nanorystalline metal oxide films on flexible substrates have been developed, for the elaboration of solid-state nanocrystalline metal oxide / organic hybrid solar cells. Due to accelerated recombination of injected electrons, the efficiencies of cells built on these films remain low compared to benchmark devices, and further studies should reveal the exact origin of this behaviour. To overcome this difficulty, an alternative strategy based on the elaboration of cells on flexible Ti foils was developed leading to an inverted structure which shows highly promising initial results. Alternative methodologies for the fabrication of mesoporous, nanocrystalline metal oxide films have also been studied. Among these, evaluation of mesoporous films made by supramolecular templating has led to promising results and a novel approach has been developed in which the porous metal oxide layer is replaced by a blend of TiO_2 nanorods with a conjugated polymer

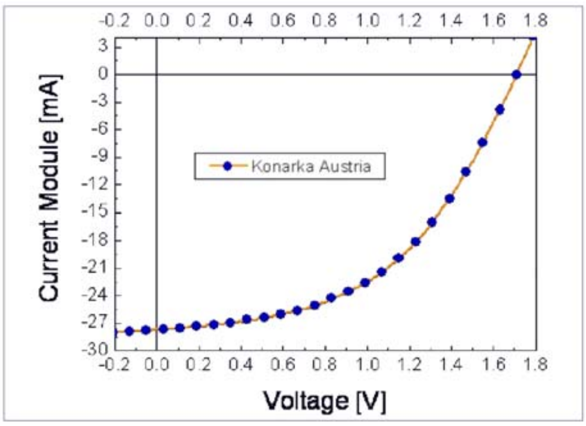
- **WP3: Advanced Characterization and Modelling**

A detailed understanding of the fundamental properties and behaviour of the novel materials developed in WP1 and WP2 was necessary to check their mutual compatibility and suitability for improved solar cells (increased energy conversion efficiency). For that, quantitative models of device function have been developed and validated by a range of experimental data, leading to:

a) Identification of parameters limiting device performance.

b) Identification of specific design improvements.

c) Prediction of optimum device efficiencies achievable with each device concept.



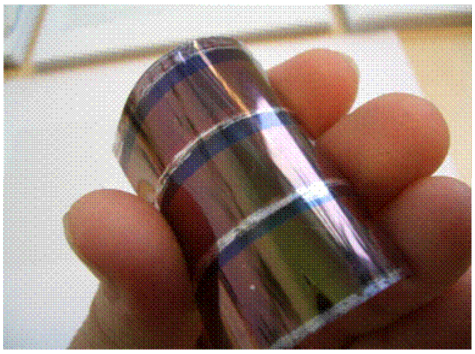


Fig. 1: Current / voltage characteristics of a 3% all organic device on flexible substrate (right) and picture of a stripe module with an active area of 930 mm^2

- **WP4: All-Organic Device Development**

Based on the donor-acceptor bulk heterojunction concept, two innovative principles were explored in parallel and low band gap polymers issued from WP1 were tested. The two innovative principles explored are one based on a junction induced by the orientation of polar molecules, and one based on a multijunction bulk donor-acceptor heterojunction concept. Proof of concept studies for the innovative devices have shown progress. The first 2-terminal multi-junction solar cells, in particular, have shown near doubling of the open-circuit voltage as compared to the single junction device. A prototype device with a certified efficiency of 4% on a 1 cm^2 glass substrate has been realised, and an efficiency of 3% on a 10 cm^2 flexible substrate has also been demonstrated (Fig.1).

- **WP5: Metal Oxide / Organic Hybrid Device Development**

Solid-state metal oxide / organic solar cells on glass and flexible substrates, have been elaborated following two distinct routes consisting in the use of optically transparent organic hole conductor or of organic material that serves the functions of both hole transport and light absorption. Using different organic or inorganic dyes in combination with a transparent molecular hole conductor, efficiencies up to 4% have been reached (fig.2).

Fig. 2: Various solid-state dye-sensitised solar cells with solar efficiencies up to 4%. Top left: blue dye, η = 1.5%; top centre and right: zinc porphyrin dyes, η = 2.5 - 3%; bottom left: perylene dye, low η = low; centre: Z-907 dye, η = 4%; right: indoline dye, $\eta \rightarrow$4%.

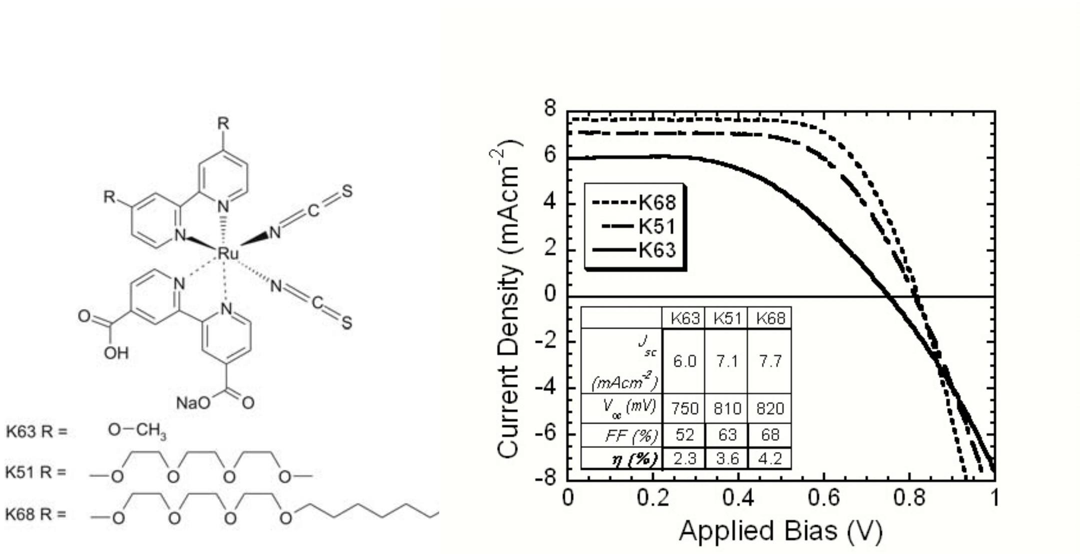


Fig. 3: a) The sensitizer molecules used in this study; b) current-voltage characteristics under simulated AM 1.5 solar conditions at 100 $mWcm^{-2}$ for solid-state dye-sensitized solar cells incorporating K63 sensitizer (solid line), K51 sensitizer (dot-dashed line) and K68 sensitizer (dotted line). The inserted table shows the device performance values.

- **WP6: Device Evaluation / Cost Assessment**

An initial evaluation of device processing and stability for metal oxide / organic and all-organic devices has been carried out, leading to the identification of critical stress factors. A definition of the specifications requested for a 4% flexible solar cell (5% on glass substrate) has also been established. Characteristics of an LPI cell are given in Fig.3.

Technical Summary

Making of low cost solid state organic PV with efficiencies >5% on glass and > 4% on flexible substrates was the main aim of this project. Two different device concepts, namely all-organic solar cells and nanocrystalline – organic hybrid solar cells, have been followed. Metal oxide and organic hole conductor syntheses, characterization and application of suitable new materials for making solid state solar cells, and device evaluation and cost assessment were the key tasks. Minimization of interfacial recombination losses, modelling and interfacial engineering of cell structures and low temperature processing routes were studied. EPFL was a key partner of this project consisting of 13 partners located in different parts of Europe. EPFL was the activity leader of work package 5. At the start of the project itself, both benchmark materials and a cell design had been adopted for further investigations. The status and the future requirements of materials have been also established. In addition to the adopted benchmark design and a standard cell making protocol, a new cell design suited to the declared objectives of the project has been also developed by EPFL during this work. Through this project, several soluble low bandgap PTV derivates and grafted polymers were synthesized and tested for solar cell applications by the consortium. Similarly, an excellent new low temperature fabrication procedure for dense metal oxide blocking layers yielding a shunt resistance > 160 kohms (only 30 kohms was the target) has been developed. This produced cells with low dark currents. Also, mesoporous nanocrystalline metal oxide (TiO_2) films giving 30% improvement in device performance over benchmark materials have been developed for hybrid cell application. Specially prepared commercial low temperature metal oxide pastes have been evaluated for their application potential in this field. In the area of modelling, a prototype model of device function has been established, which allowed confirmation of the direct relationship between material properties and device J-V behaviour. The model led to the identifiaction of key factors limiting the efficiencies on the basis of the use of materials close to the actual references. For both the device concepts, performances up to 10% seem to be attainable in the near term. The objectives in terms of power conversion efficiencies have been approached by EPFL both on glass and flexible substrates. On glass, a conversion efficiency reaching 4.2% was achieved under AM 1.5 illumination (100mW/cm^2). Under reduced light intensities, the solid state cells showed >6% efficiency. These improved performances go to the credit of MOLYCELL, when one considers the efficiency of solid state dye sensitized solar cells at the beginning of the project was only 3%. Even when using a novel metal foil flexible substrate of 1 cm^2 area, 3.6% conversion efficiency was achieved under AM1.5 illumination. In the case of all-organic PV, the project objectives in terms of power conversion efficiencies have been attained on both glass and flexible substrates (certified efficiencies of 4.8% and the best laboratory efficiencies of 5.5% have been achieved under AM1.5 light). Raw material costs for the state-of-the-art polymer solar cells were determined and it was concluded that costs < 1€/W_p can only be achieved by attaining a substantial reduction in the material costs and further improvement of power conversion efficiencies. After discussions with EU and the different stakeholders, it was agreed that the roadmap for the way forward to attain 1€/W_p will be best served by a CA action. It is pleasing that this will materialise through the newly approved CA, OrgaPVNET. Workshops and training sessions have enabled the transfer of practical research expertise between research groups. The efficiency advancements of both organic and solid state hybrid devices have been impressive under this programme. For all organic PV, device efficiencies and stabilities are already approaching levels sufficient for niche applications. They are compatible with fabrication on ITO-plastic substrates. Furher improvement in efficiencies require new lower bandgap materials. For dye solar cells, extensive commercialisation programmes are already ongoing. Unlike with the metal foil substrates, for plastic substrates low temperature processing methods need to be developed. Glass and flexible substrate mounted devices continue to have distinct merits and hence cater to distinct applications and markets. Both should be developed further. The project produced a large number of publications, presentations and a few patent applications. A scientific conference (ECHOS 06) was held in Paris in 2006 for the dissemination of knowledge acquired through the MOLYCELL project.

National and International Cooperation

Cooperation was of course primarily with the Swiss and European partners within the research programme of the Commission of the European Union, with the Swiss participation fiunded through OFES/BBW (Federal Office for Education and Science). Participation of partners from Austria, Czech Republic, England, France, Germany, Netherlands, Sweden and Turkey was the key element in the MOLYCELL multinational specific targeted research/innovation project (STREP) of the 6th. Framework Programme of the European Union

Pubilication 2006

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FULLSPECTRUM

A NEW PV WAVE MAKING MORE EFFICIENT USE OF THE SOLAR SPECTRUM

Annual Report 2006

Author and Co-Authors	Dr. Toby Meyer & Andreas Meyer
Institution / Company	Solaronix SA
Address	Ouriette 129 CH-1170 Aubonne
Telephone, E-mail, Homepage	+41 (0)21 821 22 80, toby@solaronix.com, www.solaronix.com
Project- / Contract Number	SES6-CT-2003-502620 / SER N° 03.0111-2
Duration of the Project (from – to)	1.11.03 – 31.10.08
Date	01.03.2007

ABSTRACT

FULLSPECTRUM is an EU integrated project whose primary objective is to make use of the FULL solar SPECTRUM to produce electricity. The necessity for this research is easily understood, for example, from the fact that present commercial solar cells used for terrestrial applications are based on single gap semiconductor solar cells. These cells can by no means make use of the energy of below bandgap energy photons since these simply cannot be absorbed by the material. The achievement of this general objective is pursued through five strategies: a) the development of high efficiency multi-junction solar cells based on III-V compounds, b) the development of thermophotovoltaic converters, c) the research on intermediate band solar cells, d) the search of molecules and dyes capable of undergoing two photon processes and e) the development of manufacturing techniques suitable to industrialize the most promising concepts.

Project goals

The aim of FULLSPECTRUM is the development of photovoltaic (PV) concepts capable of extracting the most of every single photon available [1]. At this respect, each of the five activities envisaged in this project to achieve this general goal confront its own challenges. The multijunction activity pursues to develop solar cells that approach 40 % efficiency as much as possible. For that, it faces the challenge of finding materials with a good compromise between lattice matching and bandgap energy. The thermophotovoltaic activity bases part of its success in finding suitable emitters that can operate at high temperatures and/or adapt their emission spectra to the gap of the cells. The other part relies in the successful recycling of photons so that those that cannot be used effectively by the solar cells can return to the emitter assisting in keeping it hot. The intermediate band solar cell approach defy the challenge of proving its principles of operation to an extent in which these have not represent only marginal effects in the performance of the cells. The molecular based concept activity devoted to search of new molecules encounters the challenge of **identifying molecules capable of undergoing two photon processes**, that is, molecules that can absorb two low energy photons to produced a high energy excited state or, for example, dyes that can absorb one high energy photon and re-emit its energy in the form of two photons of lower energy. An other aim is investigating the **"flat-plate concentrator"** (FPC) concept, which is based on thin polymers sheets colored with special dyes capable of absorbing high energy photons and re-emit them as low energy photons, that ideally match the gap of the solar cells. This emitted light is trapped within the concentrator usually by internal reflection and, if the losses within the concentrator are small, can only escape by being absorbed by the cells put on the edges of the concentrator plate. Among all the above concepts, the multijunction approach appears to be the most readily available for commercialization. For that, the manufacturing techniques and pre-normative research activity is devoted specifically to speed up its path to market is developing trackers, optics and manufacturing techniques that can integrate these cells in commercial concentrator systems.

Short description of the project

The multijunction solar cell approach pursues the better use of the solar spectrum by using a stack of single gap solar cells to be incorporated in a concentrator system in order to make it cost effective (Fig. 1) . Within this approach, the project, at its start, aimed to cells with an efficiency of 35 %. This result has already been achieved by FhG-ISE in the second year of the Project and the Consortium aims now to achieve efficiencies as close as possible to 40%.

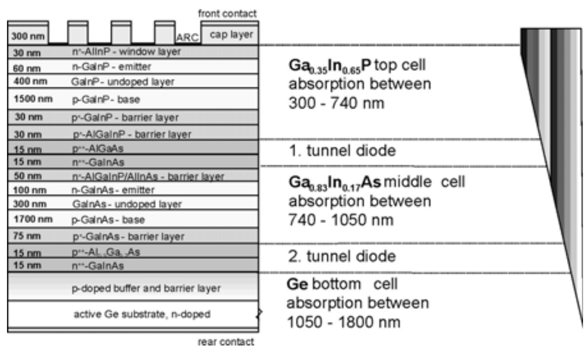

Fig. 1. Example of a structure of a monolithic triple-junction solar cell made of $Ga_{0.35}In_{0.65}P$ -, $Ga_{0.83}In_{0.17}As$ - and Ge-junctions interconnected by internal tunnel diodes.

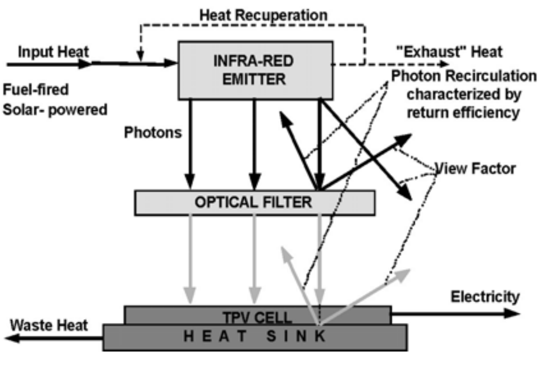

Fig. 2. The principle of TPV conversion

In the thermophotovoltaic approach, the sun heats up, through a concentrator system, a material called “emitter” leading it incandescent (Fig. 2). The radiation from this emitter drives an array of solar cells producing electricity. The advantage of this approach is that, by an appropriate system of filters and back reflectors, photons with energy above and below the solar cell bandgap can be directed back to the emitter assisting in keeping it hot by recycling the energy of these photons that otherwise would not be optimally converted by the solar cells. By the end of the project, it is expected that the system, composed basically by the concentrator, emitter and solar cell array can be integrated and evaluated.

The “intermediate band” approach pursues a better use of the solar spectrum by using intermediate band materials (Fig. 3). These materials are characterised by the existence of an electronic energy band within what otherwise would be a conventional semiconductor bandgap. According to the principles of operation of this cell, the intermediate band allows the absorption of low bandgap energy photons and the subsequent production of enhanced photocurrent without voltage degradation. The Project expects also to identify as much intermediate band material candidates as possible as well as to demonstrate experimentally the principles of operation of the intermediate band solar cell by using quantum dot solar cells as workbenches.

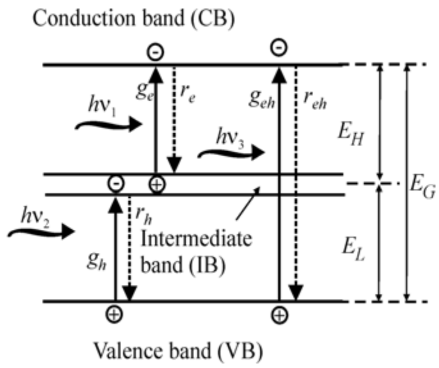

Fig. 3. The principle of the IBC.

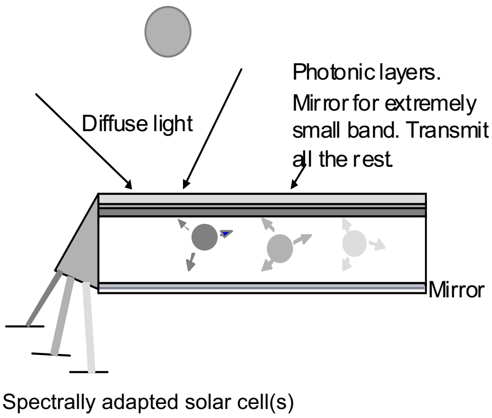

Fig. 4. Luminescent concentrator with photonic crystal.

As mentioned, under the “molecular based concepts” heading, it is expected to find dyes and molecules capable of undergoing two-photon processes. Dyes -or quantum dots- suitable to be incorporated into flat concentrators are also pursued. Flat concentrators are essentially polymers plates, that by incorporating these special dyes to their structure, are capable of absorbing high energy photons and re-emit them as low energy photons that ideally match the gap of the solar cells. This emitted light is trapped within the concentrator usually by internal reflection and, if the losses within the concentrator are small, can only escape by being absorbed by the cells.

Within the activity involving manufacturing, it is expected to clear the way towards commercialization for those most promising concepts. This is the case of the multi-junction solar cells and within this activity it is expected to develop, for example, trackers with the necessary accuracy to follow the sun at 1000 suns, “pick and place” assembling techniques as to produce concentrator modules at competitive prices as well as to draft the normative that has to serve as the framework for the implementation of these systems.

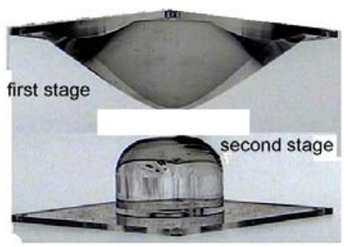

Fig. 5. An example of novel concentrator lenses.

Project Structure: The Project is coordinated by Prof. Antonio Luque (Instituto de Energía Solar) assisted by Projektgesellschaft Solare Energiesysteme GmbH (PSE). The Consortium involves 19 research institutions listed at the side of this text. As mentioned, to make the better use of the solar spectrum declared above, the project is structured along five research development and innovation activities:

1) Multijuntion solar cells. The activity is leaded by FhG-ISE with the participation of RWE-SSP, IES-UPM, IOFFE, CEA-DTEN and PUM.

2) Thermophotovoltaic converters. Is headed by IOFFE and CEA-DTEN. IES-UPM and PSI participate also in its development.

3) Intermediate band solar cells. The activity is leaded by IES-UPM. The other partners directly involved are UG, ICP-CSIC and UCY.

4) Molecular based concepts. The activity is leaded by ECN. The other groups involved are FhG-IAP, ICSTM, UM and Solaronix.

5) Manufacturing techniques and pre-normative research. The activity is leaded by ISOFOTON. IES-UPM and JRC are involved also in the activities.

In addition, every two years, the Project sponsors a public Seminar about its public results and grants students worldwide in order to assist this Seminar as part of its dissemination activities. Proper announcements are made in FULLSPECTRUM web page (http://www.fullspectrum-eu.org).

Work and results

Solaronix is involved in the Molecular based concepts sub-project, which consists of 4 workpackages

WP4.1: Flat Plat Concentrator (FPC)– Practical Devices

WP4.2: Ultimate Light Concentrator Performance

WP4.3. FPC stability assessment

WP4.4: Dye & Quantum dots assessment (as sensitizer and/or "two-photon" absorber)

Our works in WP4.1 are focusing in providing the high efficiency (> 15 %) Si-solar cell being only 2-3 mm wide and up to 12.5 cm long with or without front coating , provide complete assemblies of Flat Plate Concentrator polymer sheets (provided by the Project partners) fitted with solar cells and vacuum evaporated aluminum or silver back / edge mirrors, provide III-V multijunction solar cells (provided from the "Multijunction solar cell" Sub-project) being YAG-Laser cut into 2 to 4 mm diameter cells able to fit on the edges of the thin polymer sheets.

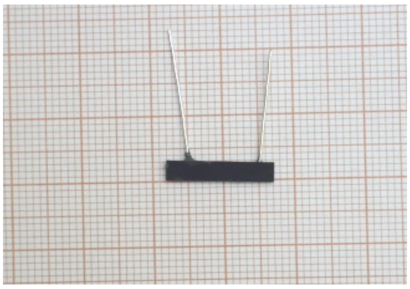

Fig. 6: High-efficiency miniaturized Si-solar cell cut out with YAG-Laser

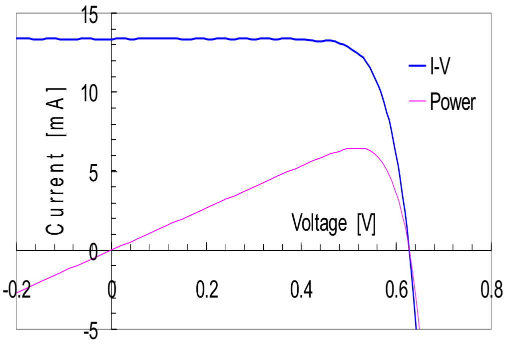

Fig. 7: I-V plot at 1000 W/m^2 Xe-light of the 5 x 15 mm miniature Si-cell employed for Flat Plate Cencentrators (measured with the **Solaronix** SR-IV spectrometer)

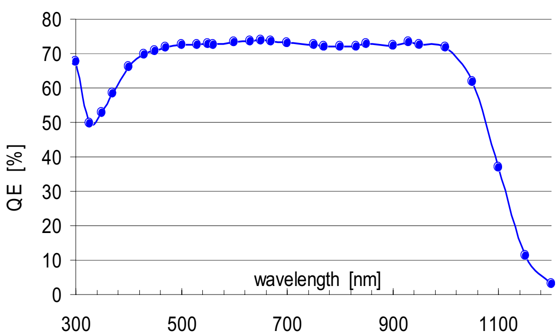

Fig. 8: Quantum efficiency plot of the miniture Si-cell, this plot was measured with the filter-wheel based „SR-IV-Spectrometer" built at **Solaronix** for the Project, the same spectrometer was also delivered to ECN, one of the Project partners

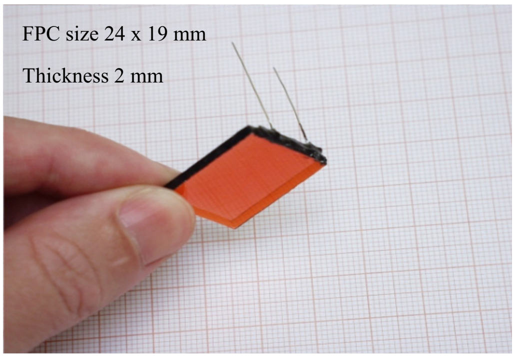

Fig. 9: Evaporated aluminum mirror back coated concentrator plate fitted with 15 x 3 mm Si-cell White edge reflector on sides witjout cells (covered in black)

For the works related to WP4.2 (Ultimate Light Concentrator Performance) **Solaronix** is in charge of the economical modelling of the Flat Plate Concentrator concept – no data yet as the typical design used for cost estimation is not yet fixed. **Solaronix** provides current-voltage (I-V) and spectral response (SR, quantum efficiency) plots of actual FPC devices, these data being used to confirm the calculated output coming from the Project partners dealing with optical modelling of the FPC devices.

In the workpackage WP4.3 related to stability of the Flat Plate Concentrators, **Solaronix** built a high power monochromatic light source based on LED arrays. These stability testing lamps have an active area of 12 x 12 cm with an intensity homogeneity of better than 5 %. The selected LED wavelengths are 470 nm (blue), 528 nm (green), 589 nm (amber), 618 nm (red) with a FWHM of ~ 30 nm.

The achieved light intensity at 470 nm corresponds to 15 times the intensity provided by the sun in this wavelength range (7.5 times the sun's radiation at 589 +/- 15 nm).

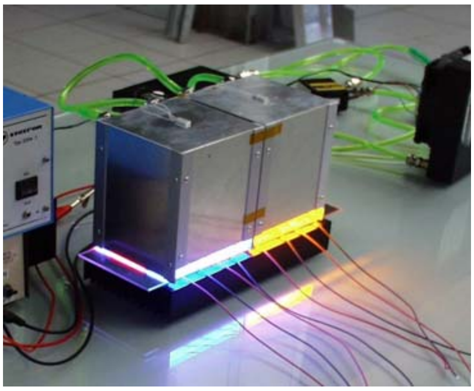

Fig. 10: Blue (470 nm) and amber (589 nm) high power LED lamps built by **Solaronix** irradiating 2 sets of Flat Plate Concentrators fitted with solar cells to follow the electrical performance. The FPC having each a different being dye investigated for its light stability.

Using the high intensity LED lamps (blue and amber), FPC's were irradiated to investigate the light stability of the fluorescent dyes. One set of plates contain only the red dye Lumogen F Red 305, the other set a mix of 2 dyes, Fluorescence Yellow CRS040 + Lumogen F Red 305

Each set plates were exposed to either blue (470 nm) and amber (589 nm) light for a period of 700 hours. The UV-Vis spectrum and the electrical caracteristics (I-V & S-R plots) were monitored during the light exposure time.

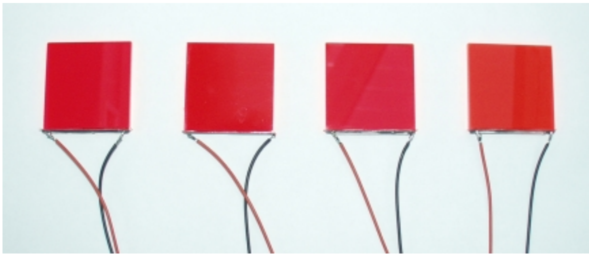

Fig 11: Flat Plate Concentrators prepared for stability testing, half of the samples contain 2 dyes, the other only ond red dye (the difference is practically imperceptible by the naked eye).

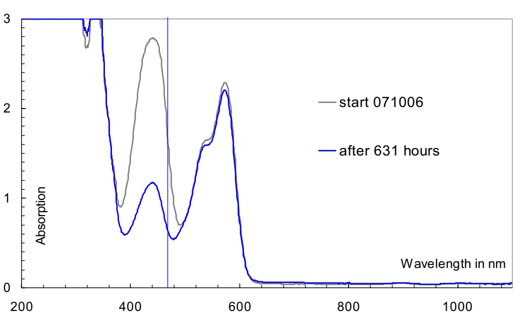

Fig. 12: UV-Vis spectrum of a FPC containing the two dyes Fluorescence Yellow CRS040 + Lumogen F Red 305 being irradiated for 700 hours in the blue LED light at 470 nm, the degradation occured in the 450 nm region, where the Fluorescence Yellow CRS040 dye absorbs – the same FPC didn't show such a degradation when irradated in the amber LED light (589 nm).

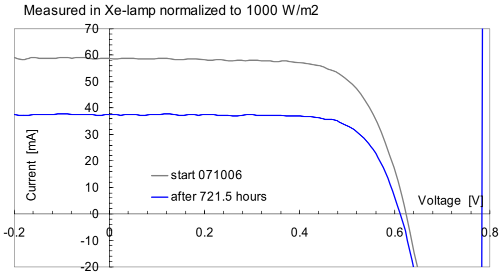

Fig. 13: Current-Voltage (I-V) plot of a FPC containing the two dyes Fluorescence Yellow CRS040 + Lumogen F Red 305 being irradiated for 700 hours in the blue LED light at 470 nm. Manifestly, the electrical perfermance dropped after the irradiation test as the contribution of the yellow dye Fluorescence Yellow CRS040 vanished due to molecular degradtaion.

The following table indicates the results obtained during this monochromatic light irradiation test of the four Flat Plate Concentrator having either only one dye (the red Lumogen F Red 305) and two dyes (Fluorescence Yellow CRS040 + Lumogen F Red 305). Selective irradation shows that the yellow dye (absorbing at ~450 nm) is degraded after a few hundred hours, the same dye remains stable after being irradiated at 589 nm, where it has no absorption band.

	Blue LED ~ 700 hr irradiation time				Amber LED ~ 700 hr irrad. time			
Sample name	Isc vs time LED light	I-V Xe-lamp	IPCE	UV-Vis spectrum	Isc vs time LED light	I-V Xe-lamp	IPCE	UV-Vis spectrum
FPC020506A2 Lumogen F Red 305	Isc – 31.3 %	Isc – 2 % Voc = cte FF drop	- 12 %	minor drop at 575 nm				
FPC020506A3 Lumogen F Red 305					Isc – 31.3 %	Isc - 7.5 % Voc = cte	- 9 %	practically unchanged
FPC100205A2 Fluorescence Yellow CRS040 + Lumogen F Red 305	Isc – 4.6 %	Isc - 35 % Voc – 10 mV	- 33 %	major drop at 444 nm, minor drop at 575 nm				
FPC020506A6 Fluorescence Yellow CRS040 + Lumogen F Red 305					Isc + 6.1 %	Isc – 14.7 % Voc - 150 mV	- 9 %	unchanged at 444 nm, minor drop at 575 nm

In the WP4.4 related to the dye & quantum dots assessment, Solaronix provided to synthesis related Project partners chemical building blocks (several grams of each), such as 4,4'-dimethyl-2,2'-bipyridine and the difficult to make 2,2':6',2"-terpyridine-4,4',4"-tricarboxylic acid and its precursor material 4,4,'4”-trimethyl-2,2':6',2”-terpyridyl, serving as ligands for new ruthenium based dyes.

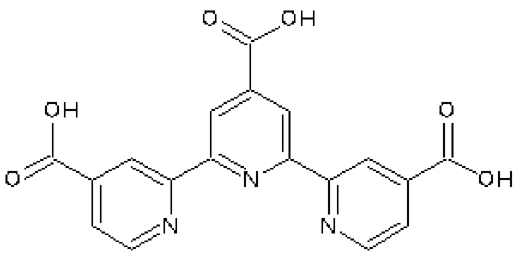

Fig 14: molecular structure of 2,2':6',2"-terpyridine-4,4',4"-tricarboxylic acid, used as a ligand in new Ruthenium sensitizers

National and international collaboration

In the framework of the sub-project « Molecular Based Concepts », where **ECN** (Petten, NL) is the sub-project leader, collaboration is essentially with **Imperial College of Science, Medicine and Technology** (London, UK) regarding the special Si-solar cell supply, the **Fraunhofer-Institut fuer Angewandte Polymerforschung** (Golm, DE) provides the PMMA-polymer based flat plate concentrator sheets in sizes up to 10x10 cm (ca 3 to 5 mm thick), the **University of Utrecht** (Utrecht, NL) provides the quantum dots & new dyes to the partners and **RWE-SSP** (Heidelberg, DE) provided the multijunction solar cells to be built on the edges of the flat-plate concentrators.

National collaboration: as an alternative to the cut-out Si-cells, we are investigating the use of Dye Solar Cells such as the ones developed by Prof M. Graetzel at the **EPFL** (Lausanne) and **Solaronix**. Dye Solar Cells have the advantage of delivering a higher voltage than the Si-cells and they can be tailored to the emission spectrum of the fluorecent dye employed in the Flat Plate Concentrator.

Results 2006 and outlook for 2007

During 2006, the demonstration of the Flat Plate Concentrator was achieved using a high-efficiency Si-cell and a combination of 2 dyes (Fluorescence Yellow CRS040 + Lumogen F Red 305) in 5 x 5 cm sized devices. The light to electricity conversion efficiency was around 1.8 % [2,3] (compared to the aperture area of the FPC i.e. 25 cm^2), corresponding well to the preduction of the models made by the **Imperial College of Science** and by **ECN** using a statistic « Monte-Carlo » ray tracing model. This means that the loss factors are identified such as scattering losses in the PMMA matrix, dye absorption & fluorescence efficiency, Si-cell efficiency, quality of side and bottom mirrors, size effects, etc. Improving of materials such as the PMMA, liquid cristal based selective reflecting mirrors on the bottom (and top ?), dyes molecules & quantum dots acting as dye having broader absorption spectra and usage of high bandgap solar cells (multijunction cells, dye solar cells ?) are key to achieve a flat plate concentrator setup with 4 % overall efficiency till the end of the project (2008).

The stability testing of the first flat plate concentrators with fluorscent dyes showed rapid degradation within days of light irradiation, but the purification of the MAA monomer done at the **Fraunhofer-Institut fuer Angewandte Polymerforschung** and careful casting afforded high quality plates, which showed way better stability. Selective high intensity monochromatic irradation using LED lamps indicated which types of dyes are prone to degradation (wavelength dependent) and the upcoming molecular investigation done at the **University of Utrecht** will eventually help to explain the observation and lead to improved molecules. Better and easier to contact cut-out Si-cells were important for building functional FPC devices emplyed in the stability investigation. In 2007, even less scattering and purer PMMA (or other types of polymers) are expected to improve the light concentration efficiency, combined with high bandgap solar cells and maybe wider absorbing fluorescent dyes. Degradation mechanisms will further be investigated with LED lamps, where a UV-version is in preparation (ca. 390-400 nm probably). Specially adapted Dye Solar Cells will be built and tested in FPC devices to take advantage of their higher output voltage, improving thus the overall efficiency.

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PHOTOVOLTAIC TEXTILE

PHOTOVOLTAIC FIBERS AND TEXTILES BASED ON NANOTECHNOLOGY

Annual Report 2006

Author and Co-Authors	J. Ramier[1], C.J.G. Plummer[1], Y. Leterrier[1], J.A.E. Månson[1], K. Brooks[2], B. Eckert[2], R. Gaudiana[2]
Institution / Company	[1] Laboratoire de Technologie des Composites et Polymères (LTC) [2] KONARKA Technologies AG
Address	[1] Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 12, CH-1015 Lausanne, Switzerland [2] Lowell, MA-USA
Telephone, E-mail, Homepage	+41 21 693 48 48, yves.leterrier@epfl.ch, http://ltc.epfl.ch/
Project- / Contract Number	CTI 7228.1 NMPP-NM
Duration of the Project (from – to)	01.11.2004 – 31.03.2006
Date	January 2007

ABSTRACT

The goal of this project is to develop a woven, flexible photovoltaic (PV) device. Photoactive wires were produced by depositing layers of photoactive material onto a conductive filament. The PV cell was then assembled from two wire electrodes, the photoactive wire and a titanium-coated platinum wire. The PV efficiency of a lab-scale fiber is averaging 5.5%. The mechanical integrity of the functional coatings on working electrodes, and their PV behavior under mechanical stress was investigated, from which critical tensile load and radius of curvature for loss of PV efficiency were determined. Two different textile prototypes, namely encapsulated non-woven with reflective backside, and satin, were produced.

Main results and achievements

Production of photovoltaic fibers

The PV fiber comprised two wires embedded in a cladding: the photoactive wire and a titanium-coated platinum wire, which acts as the counter-electrode (Figure 1). The photoactive wire was produced by depositing layers of photoactive material onto a conductive filament. TiO_2 was coated using a T-shaped taper glass applicator, dried and sintered. Dying of the TiO_2 coating was accomplished by immersion of the TiO_2 coated wire in a tube filled with dye solution followed by rinsing in a tube filled with ethanol. The full fibers were coated by passing the dyed, TiO_2 coated wire and the PEDOT counter electrode wire simultaneously through a two layer coating applicator in which the electrolyte and the photopolymer were applied simultaneously. The photopolymer was immediately cured by passing through a nitrogen filled chamber. The efficiency of the PV cells in their initial state was improved from 2% at the start of the project to an average of 5.5%.

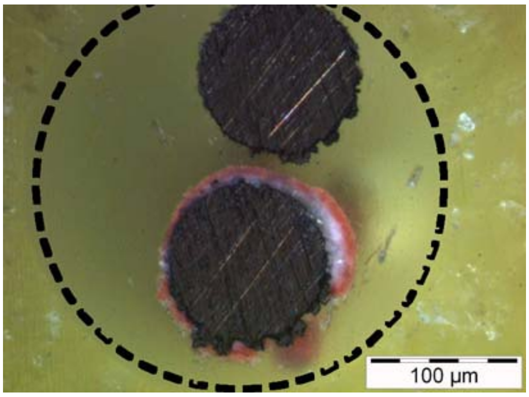

Figure 1. Cross section of PV fiber with two electrode wires.

Mechanical integrity analysis

Textile processes such as weaving imply solicitation in tension and bending, so that a key issue is the extent to which the efficiency of the PV fibers is maintained during the fabrication step. Test on the photoactive fibers, using techniques developed *in house*, showed cracks to appear at about 0.3% tensile strain in the TiO_2 coating, followed by a loss in adhesion at about 1% strain. The crack density increased up to 6.7% tensile strain, reaching roughly 20 per mm of fiber, and continued to grow with increasing strain until total destruction of the coating. *In situ* tests of the PV efficiency of a complete cell during deformation showed a relatively small initial decrease in the power developed at constant illumination in the elastic regime, as shown in Figure 2. However, in the regime corresponding to loss of adhesion between the coating and the substrate (from 0 to 70% of the total surface area), the electrical power fell sharply from 80% to less than 10% of its initial level. At higher strains the electrical power tended to zero.

In a simple woven textile, the principal mode of solicitation of the fibers is three-point bending about the points of contact with neighboring fibers. To evaluate the effect on the PV efficiency of localized damage of the TiO_2 coating, the fibers were submitted to either successive impacts regularly spaced along their length (impact diameter 2 mm), or successive impacts at two fixed locations with an increasing impact diameter. The results of these two types of test were similar (Figure 2): the decrease in PV efficiency was strongly correlated with the extent of fiber damage, with a loss of 35% being observed at 40% loss of adhesion between the TiO_2 and the substrate, for example. This contrasted with the results from the tensile tests, for which a 60% loss in efficiency was observed at 40% loss in adhesion, which implies that localized impacts are less detrimental to the electrical efficiency than a loss in adhesion distributed along the fiber.

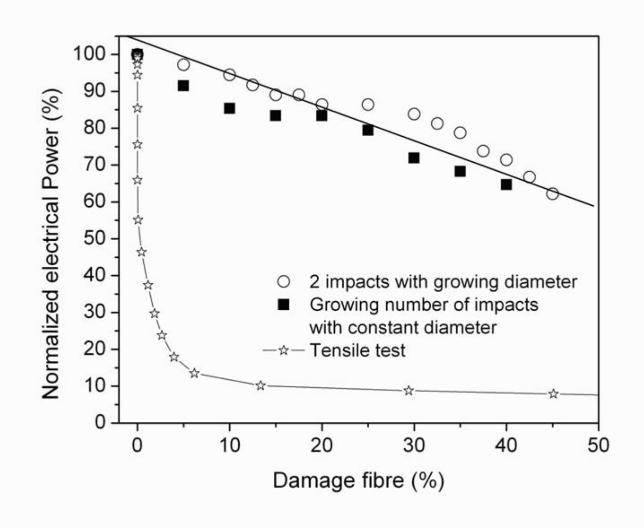

Figure 2. Evolution of the normalized PV power output versus fiber damage expressed as the fraction of the surface that had undergone loss in adhesion

By winding the working electrode around cylindrical cores with different radii it also was possible to use SEM to investigate delamination and crack initiation in more detail. In this case the TiO_2 was simultaneously in compression (inner surface) and in tension (outer surface). Crack growth and loss in adhesion were observed at and below a radius of curvature of 1.5 mm. In the case of a textile, however, these curvatures are shown to be localized and will hence provoke localized damage, which, on the basis of the indentation tests, is not expected to have large influence on the global performance. With proper control of the tension of the weft and in the warp, therefore, high PV efficiency woven textures are concluded to be feasible using the present technology.

Development of prototype PV textiles

The production of prototype PV textiles was done based on the mechanical integrity analysis, which permit one to eliminate a variety of possible textile structures, and in fact to choose different textile structures so as not to damage the functional fiber during processing and weaving. These include the following two main textile architectures.

Encapsulated non-woven textiles: A thermoformed encapsulated non-woven textile is thought to be a particularly promising solution, since it reduces stresses during manufacture. This approach offers the possibility for insertion of a reflective backing film to increase the quantity of absorbed light.

Satin textiles: A second solution shown in Figure 3, which also allows one to reduce stress in the fibers, is based on a combination of PV fibers and transparent low modulus fibers in the warp and the weft respectively. These satin-like structures will maximize the surface area exposed to the light source. Knitted structures represent a further type of textile architecture, which could be attractive thanks to its inherent excellent drapability compared to the above structures.

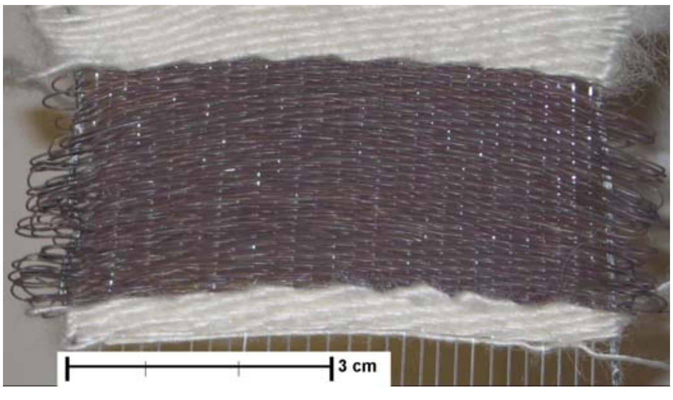

Figure 3. Prototype satin weave

Applications and Advantages

The present technology is aimed at a wide variety of application areas:

- Home automation and protection
- Autonomous energy sources (lap-tops, mobile communications systems, etc)
- Industrial equipment (floating sensors in storage tanks)
- Clothes, awnings, vehicle covers, tents, etc

Among the main advantages of DSC PV cells with respect to batteries are their reduced size and weight. They are also more flexible and cheaper than solar cells based on traditional silicon semiconductor technology, and unlike these latter, can be formed into non-planar shapes. Use of a thermoformed encapsulated non-woven textile is a particularly promising way to produce PV cells with complex geometries. This approach permits use of a reflective backing film to increase the quantity of absorbed light. Another possibility is to use a satin weave, which optimizes surface exposure of the functional fiber.

Acknowledgements

The Swiss Commission for Technology and Innovation is gratefully acknowledged for funding this work (Discovery project n°7228.1 NMPP-NM), and the EPFL center for electron microscopy (CIME) is acknowledged for technical assistance.

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ORGANIC PHOTOVOLTAIC DEVICES

Annual Report 2006

Author and Co-Authors	F. A. Castro, H. Benmansour, J. Heier, R. Hany, T. Geiger, M. Nagel, F. Nüesch
Institution / Company	Labortatory for Functional Polymers / Swiss Federal Laboratories for Materials Testing and Research-Empa
Address	Überlandstrasse 129, CH-8600 Dübendorf
Telephone, E-mail, Homepage	+41 (0) 44 823 47 40, frank.nueesch@empa.ch, http://www.empa.ch/plugin/template/empa/901/*/---/l=1
Project- / Contract Number	Empa project
Duration of the Project (from – to)	January - December 2006
Date	22.3.2007

ABSTRACT

Organic solar cells offer the advantage of low-cost production and mechanical flexibility. Quite recently the 5% power efficiency benchmark has been achieved in the laboratory and photon-to-current efficiency at a given wavelength of up to 85% was obtained. New impetus for improved efficiencies requires a) novel low-band gap materials chemically tuned to the maximum of the solar photon flux, and b) a better understanding and control of the nanoscale arrangement of the electron acceptor and donor materials.

Little synthetic work has been done to replace the most popular materials, such as buckminsterfullerene, polythiophene, poly(p-phenylene vinylene) or poly(fluorene) derivatives, which absorb primarily in the visible and near ultraviolet region. Much more effort has been devoted to the nanoscale arrangement of the electron donor and acceptor material. The present research effort contributes to both, synthesizing new photovoltaic materials and developing new approaches to nanostructured biphasic films.

Introduction

Organic solar cells need very different device concepts as compared to classical semicoductor p-n junction cells (see Figure 1). This is due to the particular properties owned by soft materials being composed of dyes or polymers with conjugated p-electron systems. Most compelling for optoelectronic applications are electrical and optical properties. The low charge carrier mobility in organic semiconductors limits the thickness of the photoactive layers to about 100 nm. Due to the extremely high absorption coefficients however, thickness is not a limiting factor for harvesting solar light. When photons are absorbed a tightly bound electron-hole pair (exciton) is formed that can be dissociated at a heterogeneous interface formed between an electron donor and an electron acceptor material. Since excitons have a limited diffusion length of the order of 10 nm, only excitons produced close to the hetero-interface will generate free charge carriers. Efficient devices therefore have a large internal donor-acceptor interface with a typical length scale of 20 nm. Since the diffusional component of charge transport is not directional, the device performance is improved if selective charge injection layers are present at anode and cathode. These layers can in principle be composed of the electron donor and acceptor material, respectively.

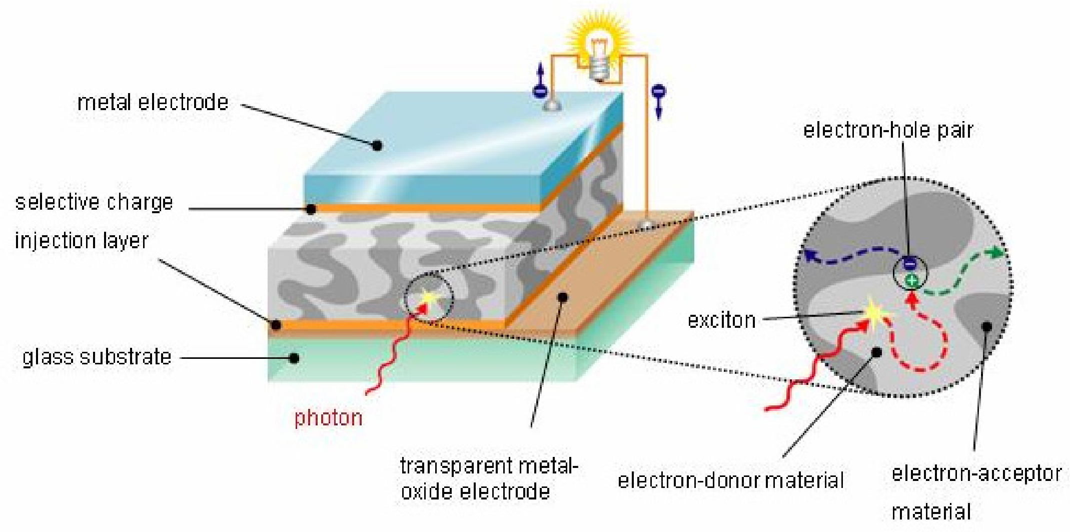

Figure 1: Working principle of an organic bulk-heterojunction solar cell. Photons are absorbed by the organic semiconductor, where excitons are produced. The latter diffuse to the heterogeneous donor-acceptor interface, where free charge carriers are produced. Finally the charge carriers are collected at the electrodes

Objectives

a) Potential of cyanine dyes for photovoltaic applications

Improved efficiencies of organic solar cells require novel low bandgap materials tuned to harvest near infrared photons, while still providing a sufficiently large open circuit voltage. In third generation devices such low bandgap materials are also necessary to construct efficient tandem cells. Cyanines benefit from high light extinction coefficients and thus allow the fabrication of highly absorbing thin films. They can be spin-coated from solution, which is of considerable technological interest. Furthermore, we demonstrated the possibility to synthesize polymers with cyanine chromophores in the main chain. It was shown that this strategy can lead to polymers with absorption maxima up to 1000 nm. Despite these promising pre-conditions, the photon-to-current efficiencies achieved so far are somewhat disappointing. The reasons are unknown at the moment, and further studies are necessary to investigate charge carrier mobility, photophysics as well as counter-ion effects that are specific to cationic cyanines. The results will form a basis for future synthetic work where use cyanines are used as building blocks in polymers and donor-acceptor block copolymers.

b) Nanostructuring of polymer layers for interface-enhanced organic cells

State-of-the-art organic solar cells make use of a combination of an electron-donor and electron-acceptor material, sandwiched as a thin (< 100 nm) film between a hole-accepting and electron-accepting electrode. To maximise the charge generation efficiency and the charge transport to the electrodes at the same time, the morphology of the donor-acceptor materials and the degree of phase separation at the nanometer scale is a critical point. The best organic solar cell devices reported so far use a blend of regioregular polythiophene (P3HT) with a soluble C_{60} derivative (PCBM). With a view to develop other material systems a general approach to nanostructured biphasic thin films would be very useful. We demonstrated a simple method allowing the sequential fabrication of bilayer polymer cell devices with large nanostructured heterointerfaces using poly(p-phenylenevinylene) derivative MEH-PPV as donor and C_{60} as acceptor. Other methods based on polymer demixing are being developed to achieve optimized device architectures for a variety of material combinations.

Work performed and results obtained

a) Cyanine dyes and polymers

Cyanine dyes were developed at the beginning of the 20th century, mainly for the photographic industry. Today cyanine dyes are used as fluorescent markers in biomolecules as well as absorbers in recording technology. Very few scientific works report on the use of cyanines in solid-state optoelectronic devices. In previous work we showed that cyanine dyes can be used as donors and acceptors in heterojunction organic solar cells. Recently, we demonstrated that the cyanine film is also photosensitive when used as an acceptor (see Figure 2). This offers the possibility to improve the spectral response width by choosing complementary absorption spectra for the donor and acceptor.

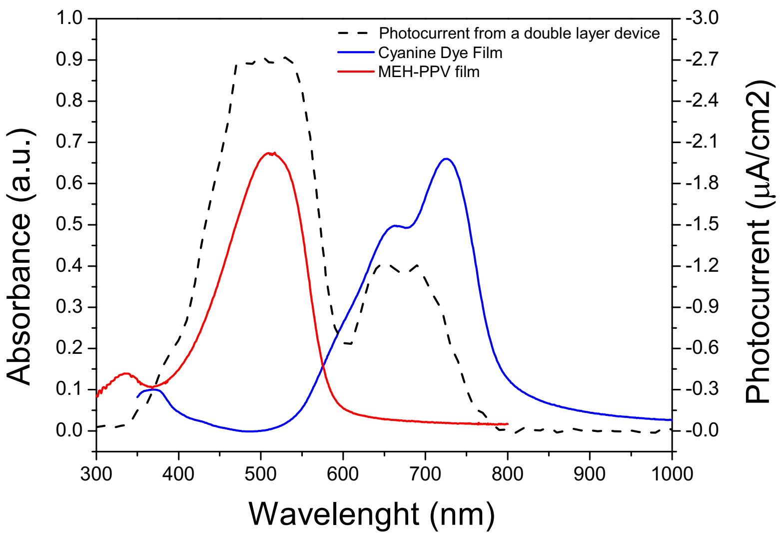

Figure 2: Absorption spectra of MEH-PPV and cyanine dye films (colored lines). Photocurrent spectrum of the heterojunction solar cell device using MEH-PPV as donor and the cyanine film as acceptor (dashed line).

Of major interest in this context are organic semiconductors absorbing in the near infrared (NIR) domain from 700 nm to 1000 nm. We have investigated the fabrication of cyanine polymers, where the individual cyanine chrompophores are coupled in a linear way to each other. For a particular cyanine dye, polymerization gave rise to an impressive absorption shift in solution of 0.5 eV (Figure 3). A similar approach using a different cyanine building block led to a polymer absorbing at 1000 nm.

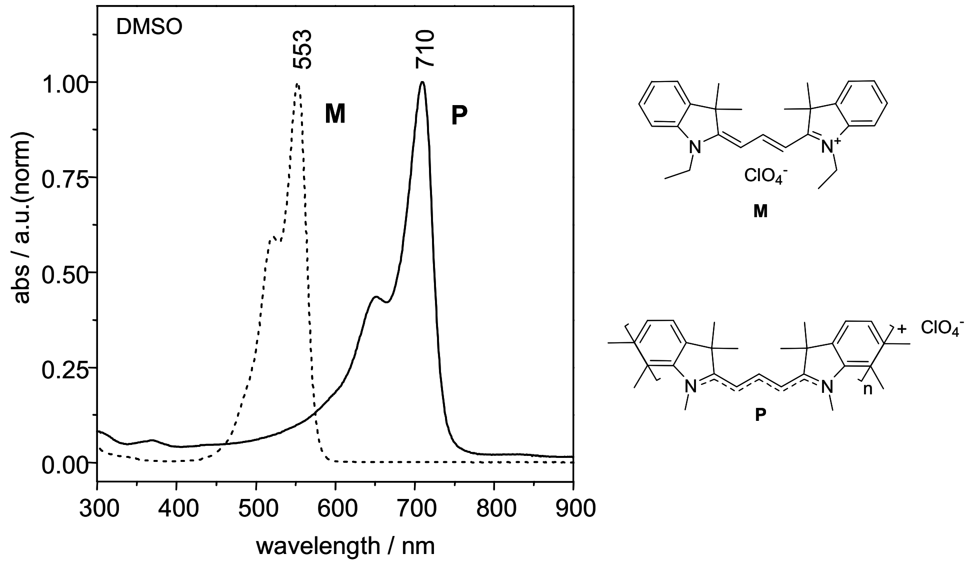

Figure 3: Absorption spectra of cyanine dye (M) and related polymer (P). The corresponding chemical structures are also indicated.

b) Nanostructured layers for organic photovoltaic devices via polymer demixing

In a planar bilayer heterojunction solar cell, the donor and acceptor materials are deposited one after the other and contact the respective electrodes selectively. The planar geometrical interface is not optimized for charge generation, since light not absorbed within the exciton diffusion distance of the interface will not create free charge carries. However, those carriers created at the donor-acceptor interface are largely confined to the acceptor and donor sides of the heterointerface and benefit from recombination-free transport. A bulk-heterojunction cell consists of an interpenetrating network of donor and acceptor material. This architecture is optimized for charge generation within the exciton diffusion length, however, the collection efficiency is critically dependent on percolating paths for the hole and electron transport to the respective electrodes. Combining the advantages of the planar bilayer with the bulk heterojunction concepts yields, in theory, a most favourable arrangement of the two components as shown in Fig. 4:

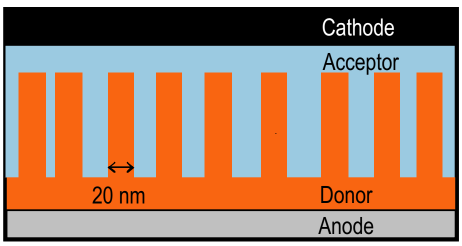

Figure 4: Sketch of an idealized (experimentally not yet realized) organic heterojunction solar cell. The thickness of the semiconducting layer is ~ 200 nm to absorb the entire incident light. The electron donor and acceptor interdigitate on a 10 – 20 nm length scale to enable efficient charge generation within the diffusion length (~ 10 nm) of the photo-excited electron-hole pair. At the same time, the active components wet their respective electrode completely, to provide conduction paths for the selective extraction of charges. The nature of the organic materials dictates the solar cell design criteria, which implies aspect ratios (height : width) of >> 1 for the nanostructured interface topography.

Our initial work towards an interdigitated morphology employed a guest polymer and polymer demixing during spin-coating to produce a rough interface: surface directed spinodal decomposition lead to a 2-dimensional spinodal pattern with submicrometer features at the polymer-polymer interface. We then removed the guest polymer phase and covered the rough surface with a second active component (Figure 5). Although typical aspect ratios of the interface topographical features were far below 1 (heights ~ 10 nm, widths ~ 30 nm), solar cell efficiencies already increased by a factor of 3 compared to the planar bilayer configuration, demonstrating the proof of concept. The amplitude of features in the spinodal demixing process is limited by interfacial tension between the active and guest polymer. To further amplify these ripples and to improve the cell performance, we will use external forces (such as electric fields) that can overcome dispersive forces and allow control over the instabilities, because the magnitude of the force can be varied.

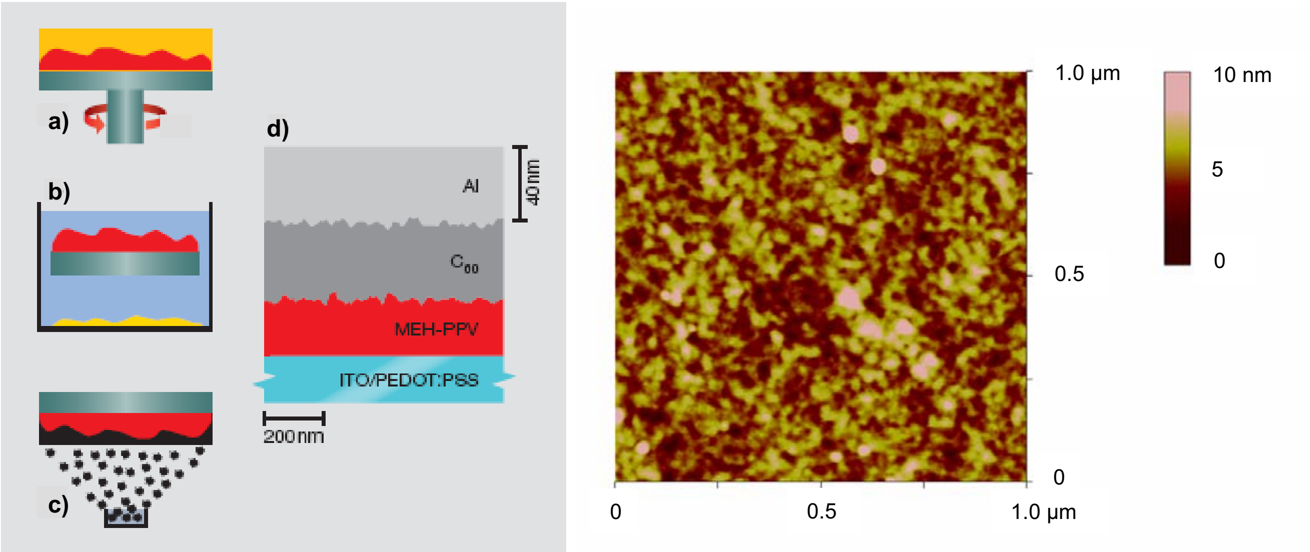

Figure 5: Left: Diagram describing the fabrication process of an interface-enhanced bilayer film, and the final photovoltaic device. (a) An immiscible semiconducting polymer/guest polymer mixture is spin-coated from a common solvent. Polymer demixing results in a vertically segregated bilayer film with a rough, nanostructured interface. (b) Subsequently, the guest polymer is removed using a selective solvent. (c) The remaining semiconducting polymer is covered with a layer of a second, active component via thermal evaporation. (d) Cross-section of the actual device structure. The guest polymer was polystyrene, which was selectively removed with cyclohexane. Interfaces are represented as experimental cross-sections from atomic force microscope images. Right: Atomic force microscope image of semiconducting film after polystyrene removal.

National / International collaborations

Prof. D. Schlüter (ETHZ, Zürich): Cyanine polymers

Prof. J. Moser (EPFL, Lausanne): Photophysics of cyanine films

Dr. C. Winnewisser (CSEM, Zürich): Charge carrier mobility

Center of Competence in Energy and Mobility (CCEM) of the ETH domain. This project will be coordinated by F. Nüesch and includes 9 partners in Switzerland (see http://ccem-ch.web.psi.ch/documents/Projektbeschriebe/Beschrieb_ThinPV.pdf)

C.F.O. Graeff (UNESP, Brazil): Organic photovoltaic devices

Prof. R. Zentel (Johannes Gutenberg Universität, Mainz): block co-polymers based on conjugated dyes

Evaluation of 2006 and perspectives for 2007

In 2006 the build-up of our thin-film organic device laboratory was pursued. Chemical synthesis laboratories were further developed. Doctoral students and scientists in the field of chemical synthesis, polymer physics and organic optoelectronic devices were recruited. A new concept was proposed for the construction of interface-enhanced bilayer organic solar cells. Cyanine polymers absorbing in the NIR and block-copolymers containing cyanine dyes were synthesized. The results were published in scientific journals and at conferences.

We have also been active in project acquisition. A two year COST project on the nanostructuring of polymers was granted. A thin film photovoltaic project (ThinPV) coordinated by us was recently granted within the Competence Centre for Energy and Mobility (CCEM). Furthermore, we have extended our national and international network in the field of organic photovoltaic devices.

In 2007 we intend to intensify the characterisation and tuning of cyanine based semiconductors. In particular charge carrier mobility, absorption and electrochemical properties will be investigated. The photophysical properties of these materials in the solid state will also be addressed. The promising work on polymer nanostructuring will be pursued and the polymer demixing approach extended.

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PHOTOELEKTROCHEMISCHE UND PHOTOVOLTAISCHE UMWANDLUNG UND SPEICHERUNG VON SONNENENERGIE

Jahresbericht 2006

Author and Co-Authors	Dr. Prof. Gion Calzaferri
Institution / Company	Departement für Chemie und Biochemie, Universität Bern
Address	Freiestrasse 3, CH-3012 Bern
Telephone, E-mail, Homepage	031 631 42 36, gion.calzaferri@iac.unibe.ch www.dcb.unibe.ch/groups/calzaferri/
Project- / Contract Number	76645 / 36846
Duration of the Project (from – to)	Januar 2003 – Dezember 2006
Date	24. Januar 2007

ABSTRACT

Three important problems could be solved:

The first antenna system which manages the unidirectional electronic excitation energy transport on macroscopical level could be built (via near field interaction, not optical).

In order to absorb the strong dispersion in the visible part of the spectrum a dye-loaded zeolite L nano crystal could be successfully inserted in a polymer matrix. It has also been shown that fluorescent solar concentrators could be built with those materials, and that previous problems related to the appropriate absorption and stability have been largely eliminated.

Organic Zn-Phthalocyanin solar cells are very attractive, but they do not absorb enough light in the 400 nm - 500 nm range of the spectrum, this is the reason for the low efficiency of this kind of solar cell. It has been demonstrated that this problem could be solved with the help of the antenna materials.

Two US patent have been granted in 2006.

Projektziele

Entwicklung einer Dünnschicht-Antennen-Solarzelle basierend auf Farbstoff-Zeolith L Antennen

Es wird angestrebt, brauchbare Vorrichtungen für die Speicherung von Sonnenenergie in Form von Wasserstoff, bzw. für den Einsatz als neue Generation von photovoltaischen (Festkörper-) Solarzellen zu entwickeln.

Farbstoffgefüllte Zeolith-Minikristalle zum Abfangen und Einspeisen von Lichtenergie werden für die Entwicklung einer neuen, leistungsfähigeren Generation von farbstoffsensibilisierten Solarzellen eingesetzt. Dabei verfolgen wir drei Strategien: (i) Plastik Solarzellen mit Hilfe von bipolaren Antennen, (ii) Dünnschicht-Solarzelle auf Basis einer sehr dünnen Silizium Schicht als Substrat, (iii) langfristig die Entwicklung einer Dünnschicht Tandemsolarzelle und (iv) Lumineszenz Solarkonzentratoren.

Durchgeführte Arbeiten und erreichte Ergebnisse

Dünnschicht-Antennen-Solarzelle

Unsere Antennenmaterialien zum Einfangen und strahlungslosen (via Nahfeldwechselwirkung, nicht optisch) Weiterleiten von Sonnenlicht können zum Aufbau von Dünnschicht-Antennen-Solarzellen verschiedener Art dienen, die wir wie folgt einteilen: sensibilisierte Festkörper-Solarzellen, sensibilisierte Plastik-Solarzellen und sensibilisierte Farbstoff-TiO_2-Solarzellen. Der Grund für die breite Einsetzbarkeit unseres Materials hängt damit zusammen, dass in jeder Solarzelle zunächst möglichst viel Licht absorbiert werden muss, das in einem zweiten Schritt in stabile Elektron-Lochpaare umgewandelt wird. Bei den heute im Einsatz stehenden Solarzellen liegen diese beiden Schritte sowohl zeitlich als auch räumlich sehr nahe beisammen. Das ist bei den grünen Pflanzen anders. Diese sammeln im Antennensystem die Energie der absorbierten Photonen und transportieren sie strahlungslos als quantisierte Energiepakete zum Reaktionszentrum. Pro Reaktionszentrum stehen dabei wenige hundert bis einige tausend Chromophore (vorwiegend Chlorophyllmoleküle) für das Einsammeln der Photonenenergie zur Verfügung. Unsere Antennenmaterialien tun dasselbe. Im Blauen, Grünen und Roten absorbierende Farbstoffmoleküle transportieren die elektronische Anregungsenergie strahlungslos auf ein sogenanntes Stopfenmolekül. Dieses bildet die Nahtstelle zur Isolatorphasengrenze und erlaubt es u.a. einen genau kontrollierbaren Abstand einzuhalten. Vom Stopfenmolekül wird die elektronische Anregungsenergie strahlungslos durch eine dünne (ca. 3 nm) elektrisch isolierende Phasengrenze (z.B. SiO_2) auf den Halbleiter übertragen wo die Elektron-Lochpaare gebildet werden. Von diesem Moment an funktioniert alles wie in den konventionellen Solarzellen.

Für Details zum Aufbau des Materials und zum Mechanismus der strahlungslosen Energieübertragung verweisen wir auf unseren BFE Bericht 2005 und auf die in den Publikationen 1-20 beschriebenen Ergebnisse. Eine Übersicht ist in Refs. 1 und 2 zu finden.

Es ist uns im vergangenen Jahr gelungen, drei wichtige Probleme zu lösen:

(1) Wir konnten erstmals Antennensysteme aufbauen, die auf makroskopischer Ebene unidirektionalen Transport von elektronischer Anregungsenergie bewerkstelligen; Ref (6) Organizing supramolecular functional dye-zeolite crystals.

(2) Es ist uns gelungen, die farbstoffbeladenen Zeolith L nano-Kristalle so in eine Polymermatrix einzubringen, dass deren sonst sehr starke Lichtstreuung im sichtbaren Bereich vernachlässigbar wird. Wir konnten auch zeigen, dass Fluoreszenz-Konzentratoren mit Hilfe unserer Materialien so gebaut werden können, dass die bisherigen grossen Probleme solcher Anordnungen, Eigenabsorption und Stabilität, weitgehend eliminiert sind; Ref (17) Transparent Zeolite-Polymer Hybrid Materials with Tunable Properties.

(3) Organische Solarzellen auf Zn-Phthalocyanin basis sind sehr attraktiv, haben jedoch das Problem, dass sie im Bereich 400 nm-500 nm kaum Licht absorbieren, was Ihren Wirkungsgrad wesentlich beeinträchtigt. Wir konnten nachweisen, dass dieses Problem mit Hilfe unserer Antennensystem-Materialien gelöst werden kann; Ref. (20) Advanced photon harvesting concepts for low energy gap organic solar cells.

Ich möchte auch speziell auf die beiden PCT Patentanmeldungen, die in diesem Jahr realisiert werden konnten, hinweisen:

P_2: Oriented zeolite material and method for producing the same und

P_3: Transparent zeolite-polymer hybrid material with tunable properties

Nationale Zusammenarbeit

Prof. Andreas Luzzi: Institut für Solartechnik SPF, Hochschule für Technik Rapperswil HSR

Dr. Andreas Kunzmann: Optical Aditives, Staufen, Schweiz: KTI Projekt

Firma Clariant: Dr. H. Metz, Clariant Produkte AG, Muttenz, Schweiz

Dr. Dominik Brühwiler, Inst. für Anorg. Chemie, Universität Zürich

Internationale Zusammenarbeit

Wir pflegen regen Austausch mit verschiedenen Forschungsgruppen in der Schweiz und im Ausland.

Siehe EU Projekt "Nanochannel" (barolo.ipc.uni-tuebingen.de/nanochannel/) und das Nachfolgeprojekt „NANOMATCH“. Zu erwähnen sind insbesondere:

- Prof. Luisa De Cola: Westfälische Wilhelms-Universität Münster, Physikalisches Institut, Mendelstr. 7, D-48149 Münster
- Prof. Serdar Sariciftci: Linzer Institut für Organische Solarzellen (LIOS), Johannes Kepler, Universität Linz, Linz, Österreich
- Prof. R. E. I. Schropp: Debye Institute, Physics of Devices, Utrecht University, Utrecht, The Netherlands
- Prof. Gary Hodes: Department of Materials and Interfaces, Weizmann Institute of Science, Rehovot, Israel
- Prof. Ken’ichi Kuge: Department of Information and Imaging Sciences, Chiba University, Chiba, Japan
- Prof. Peter Würfel: Institut für Angewandte Physik, Universität Karlsruhe, Deutschland
- Prof. Rolf Brendel: Institut für Solarenergieforschung GmbH, Hameln/Emmerthal, Deutschland
- Dr. Robert Pansu: PPSM, Ecole Normale Supérieure de Cachan, Cachan, Fankreich

Bewertung 2006 und Ausblick 2007

Wir haben Materialien bereitgestellt, die jetzt in praktischen Anwendungen getestet werden können. Dazu ist Zusammenarbeit mit der Industrie notwendig, wobei nicht übersehen werden darf, dass jeder Anwendungsversuch neue Probleme mit sich bringt, die wiederum am Besten an einem Hochschulinstitut im Rahmen von Doktorarbeiten oder Postdocarbeiten studiert werden.

Durch meinen Rücktritt am 28.02.2007 ergibt sich ein erheblicher know-how Verlust. Zwei Bereiche dieser Forschung werden von Dr. Brühwiler im Rahmen einer Doktor-Arbeit (Le-Quyenh Dieu) und im Rahmen eines KTI Projektes (Dr. A. Deveaux und Dr. D. Zhao; Industriepartner Dr. A. Kunzmann, Leitung G. Calzaferri) weitergeführt. Hinzu kommen verschiedene Arten der internationalen Zusammenarbeit von G. Calzaferri.

Es wäre jedoch sehr wünschenswert, dieses Projekt auf eine breitere Basis zu stellen, damit die erzielten Ergebnisse in eine technische Anwendung überführt werden können.

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Module und Gebäudeintegration

PV-MODULES WITH ANTIREFLEX GLASS

Annual Report 2006

Author and Co-Authors	Christoph Schilter, Tamás Szacsvay
Institution / Company	3S Swiss Solar Systems AG
Address	Schachenweg 24, CH-3250 Lyss
Telephone, E-mail, Homepage	+ 41 (0)32 387 10 10, Tamas.Szacsvay@3-s.ch, www.3-s.ch
Project- / Contract Number	100297 / 150369
Duration of the Project (from – to)	01.08.2003 – 15.12.2006
Date	12. Januar 2007

ABSTRACT

This project intends to quantify the increase in power-output of photovoltaic-elements thanks to the use of antireflective etched solar glass. It comprises production and performance testing of modules with and without treatment. Performance measurements are made indoor with a flasher and also outdoor. Outdoor measurements comprise power analysis subject to the angle of the irradiation, as well as measurements of yield.

The increase in power output of 3% or more, which the supplier states in his marketing documents, cannot be confirmed. However, a significant increase in power has been measured. A difference of at least 2% can be measured in comparison with modules without antireflective treatment. An improvement in the behaviour at low angles of irradiation in outdoor tests could be observed. It was however not possible with this tests and the limited number of samples to reliably quantify this effect.

Zusammenfassung

Das Projekt „Photovoltaik Module mit Antireflex Glas“ überprüft die Aussage des dänischen Herstellers „Sunarc“, welche einen Leistungs- und Ertragsgewinn von mehr als 3% durch den Einsatz von antireflexgeätztem Glas propagiert.

Zu diesem Zweck wurden auf demselben Fertigungsweg Module mit Antireflexglas und normalen Glas gefertigt. Zur Quantifizierung der relativen Einflüsse wurden bei jedem Fertigungsschritt die Leistungsdaten der Test-Module gemessen. Die Zellen waren handverlesen und stammten aus einem engen Leistungsband. Erst wurden die Zellennetze vermessen, und nach der Lamination die Module.

Zusätzlich wurden einige Module nachträglich nach der Lamination im Säurebad mit der Antireflexoberfläche versehen und nochmals gemessen. Die Leistungsmessungen wurden mittels einem Flasher, sowie durch Messungen im Aussenbereich durch das TISO ausgeführt.

Eine Steigerung der Leistung um mehr als 3% kann nicht nachgewiesen werden. Jedoch wurde eine Differenz von mindestens 2% zwischen Modulen mit und ohne Antireflex-Behandlung nachgewiesen. Ferner können die Module mit Antireflexglas bei einer Einstrahlung mit einem kleinen Winkel mehr Leistung abgeben. Mit der vorliegenden Testreihe konnte dieser Effekt allerdings nicht schlüssig quantifiziert werden.

Einleitung / Projektziele

In den Unterlagen von der Firma „Sunarc“ wird ein Leistungs- und Ertragsgewinn von mehr als 3% durch den Einsatz von antireflexgeätztem Glas angegeben. Kann dies bestätigt werden, dürfte dies der vermehrten Anwendung von geätztem Antireflexglas Auftrieb geben. Eine solche Steigerung mit relativ einfachen Mitteln ist für die Photovoltaik attraktiv [1] [2].

Das vorliegende Projekt untersucht den Einfluss von antireflexgeätztem Gläsern auf die Leistung von Solarmodulen.

Der Einfluss der Antireflexoberfläche soll einmal im Quervergleich zwischen Modulen mit standardmässig geätztem und Modulen mit demselben, unbehandelten Glas untersucht werden. Weiter soll bei Modulen, welche erst nachträglich im Säurebad behandelt werden, die Veränderung der Leistung quantifiziert werden. Die Indoor-Leistungsmessungen werden doppelt ausgeführt, zum einen mit dem Halogenleuchttisch bei 3S und beim TISO mittels einer Flashmessung. Freiluft- Leistungsmessungen werden ausschliesslich durch das TISO ausgeführt.

Wird ein Leistungs- und Ertragsgewinn nachgewiesen, so kann eine marktwirtschaftliche Evaluation durchgeführt werden. Diese ist nicht Gegenstand dieses Forschungsprojektes. Es soll nur die Grundlage für diese Diskussion bereitgestellt werden.

Durchgeführte Arbeiten und erreichte Ergebnisse

Die Quantifizierung der Leistungsunterschiede wird mit Messungen nach den einzelnen Arbeitsschritten dokumentiert. Für die möglichst einheitliche Leistung der Modulen wurden handverlesene und einzeln vermessene Zellen verwendet. Nach der Herstellung der Netze wurden diese gemessen. Die Handhabung der verlöteten Netze musste sehr vorsichtig geschehen – bei der Messung beim TISO ist ein Zellenbruch entstanden, und dieses „Reservenetz“ konnte nicht weiter verarbeitet werden.

Antireflexgeätztes Glas

Optisch kann nur bei schrägem Lichteinfall ein Unterschied der Oberfläche wahrgenommen werden. Fährt man jedoch mit der Hand über die Oberfläche, spürt man einen deutlichen Unterschied (feines Schleifpapier, leicht „klebrig“). Auch sind Fingerabdrücke darauf besser sichtbar.

Leistungsmessungen

Bei den verschiedenen Leistungsmessungen liegt das Augenmerk nicht auf den absoluten Werten, sondern auf dem Quervergleich. Folgende Messungen sind durchgeführt worden:

- Netzmessung (Flash)
- Modulmessung (Flash)
- Modulmessung mit nachträglicher AR-Ätzung (Flash)

- Modulmessung nach einer Exposition von mindestens 50kWh/m^2 (Flash)
- Leistungsmessung bei verschiedenen Strahlungsintensitäten (Flash)
- Freiluftmessungen bei verschiedenen Einstrahlungswinkeln (Leistung)
- Freiluftmessung Juni bis September 2006 (Ertrag), plus Flashmessungen vorher und nachher

Ergebnisse

Differenz zwischen Netzleistung und Laminatleistung

Die handverlesenen Zellen wurden zu Netzen zusammengelötet und ihre Leistungsdaten mit einer Flashmessung im TISO quantifiziert. Anschliessend wurden sie auf verschiedene Gläser verteilt und entsprechend der vorgesehenen Versuchsanordnung laminiert:

(Netz 4865/03 ging bei der Messung im TISO kaputt = Zellenbruch)

Netze	AR-Glas	Normal	PT 100	Weisse RWF	Anthrazit RWF
4865/01		X	X	X	
4865/02		X		X	
4865/04		X	X		X
4865/05		X			X
4865/06		X	X		X
4865/07		X			X
4865/08		X	X		X
4865/09		X			X
4865/10		X	X	X	
4865/11	X		X		X
4865/12	X		X		X
4865/13	X		X		X
4865/13	X				X

Tabelle 1: Konzept (PT 100: Temperaturfühler hinter Zelle (3/3), RWF = Rückwandfolie)

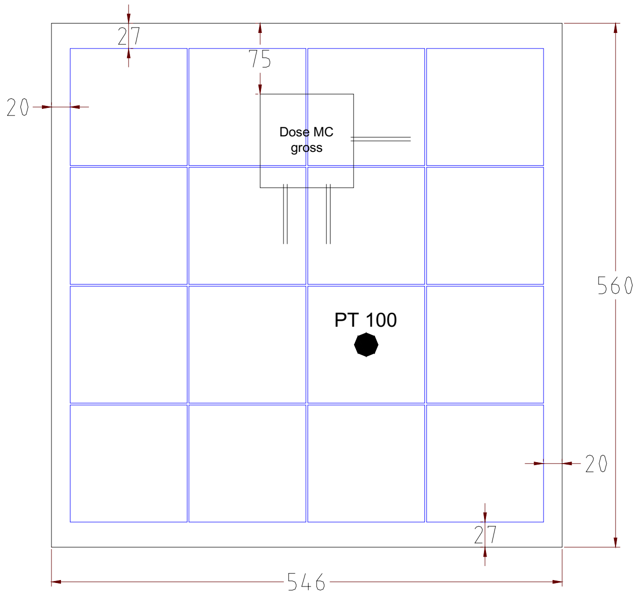

Abbildung 1: Modullayout

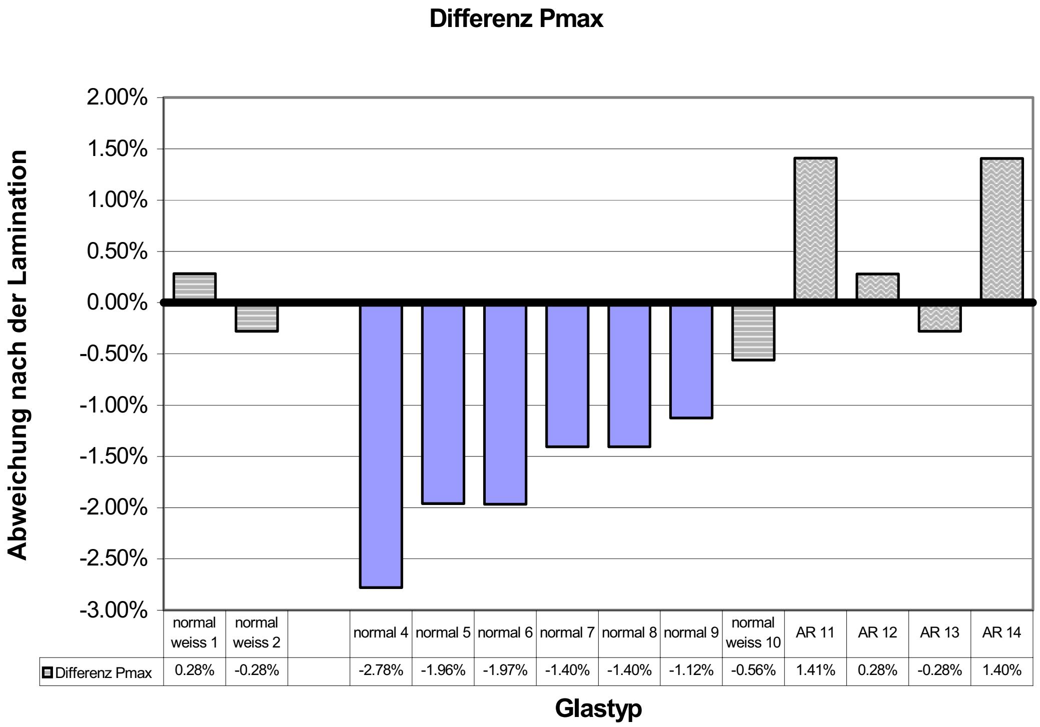

Abbildung 2: relative Differenz der Leistung zwischen dem Zellennetz und dem laminierten Testmodul

Module mit einem normalen Solarglas zeigen eine deutliche Reduktion der Leistung nach der Lamination, wobei diejenigen Module mit der anthrazitfarbigen Rückwandfolie nochmals deutlich schlechter abschneiden. Hingegen ist nach der Lamination mit dem AR-Glas die Leistung sogar eher besser.

Nachträgliches Ätzen der Oberfläche

Diese Testmodule wurden ohne Anschlussdose gefertigt, und die Leistung direkt an Anschlussverbindern gemessen, da für die nachträgliche Ätzung diese Anschlüsse nochmals abgedeckt werden müssen. Diese Module müssen eine Säurebehandlung überstehen können.

Die Module Nr. 1,2,4 und 5 wurden nochmals nach Dänemark zum Hersteller „Sunarc" geschickt, welcher die nachträgliche Oberflächenätzung durchführte. Anschliessend wurde wiederum die Leistung mittels einer Flashmessung gemessen.

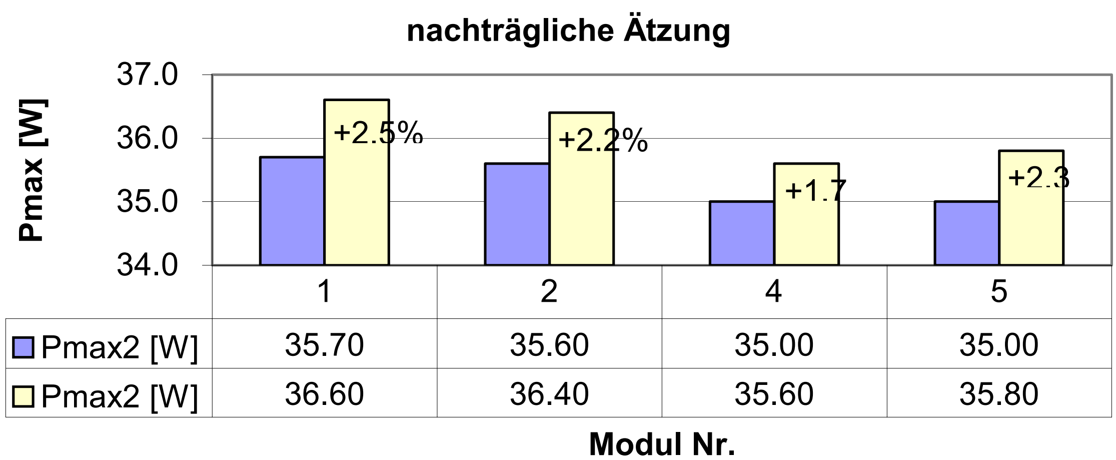

Abbildung 3: Differenz der Leistung bei nachträglicher Ätzung des Frontglases
blau = vor der Ätzung, gelb = nach der Ätzung

Die vier Testmodule mit nachträglicher Ätzung des Frontglases zeigen bei der Flashmessung eine Leistungssteigerung von durchschnittlich 2.2%.

Freiluftmessung (Leistung)

Mittels eines Freilufttests beim TISO wurde der Einfluss einer Bewitterung auf die Entwicklung der Leistung untersucht.

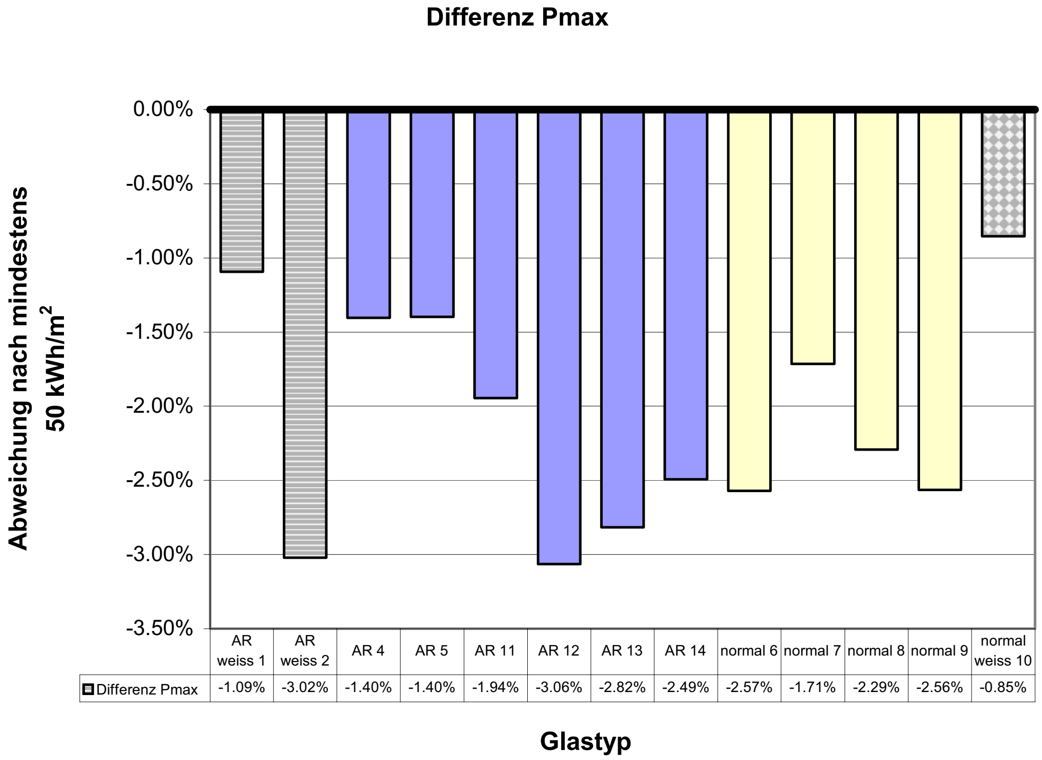

Abbildung 4: relative Leistungsabnahme nach mindestens 50kWh/m^2 Exposition im Freiland

Die Abminderung nach den ersten Betriebsstunden ist bei allen Modultypen im Bereich von 1% bis 3%. Das Glas hat keinen Einfluss auf diesen Effekt.

Zusätzlich zur absoluten Leistungsmessung wurde das Verhalten der Module mit Freiluftmessungen bei verschiedenen Einstrahlungswinkeln untersucht.

Freiluftmessungen (Ertrag)

Nach Abschluss der Freiluft-Leistungs wurden nach Bewilligung durch das BFE zur Bestätigung der Resultate auch Freiluft-Ertragsmessungen durchgeführt. Zu diesem Zweck wurden 4 Module mit schwarzer Rückwandfolie und möglichst gleicher Leistung der Netze (Nr. 07, 08, 12, 14) ausgewählt. Diese wurden vor dem Freilufttest flashvermessen, und auch nachträglich. Der Leistungsabfall des Modules 08 von 1.2% liegt ausserhalb der Wiederholgenauigkeit der Messung. Eine Ursache für diesen Leistungsabfall dafür wurde nicht gefunden.

SN	P1m	P2m		I1sc	I2sc		V1oc	V2oc	
3S-07	34.6	34.4	*-0.6%*	4.86	4.87	*0.21%*	9.85	9.89	*0.40%*
3S-08	34.8	34.4	*-1.2%*	4.85	4.84	*-0.21%*	9.9	9.86	*-0.41%*
3S-12	35.2	35.2	*0.0%*	4.92	4.97	*1.01%*	9.9	9.86	*-0.41%*
3S-14	35.4	35.6	*+0.6%*	4.97	5.02	*1.00%*	9.88	9.89	*0.10%*

Abbildung 5: Vergleich Leistung vor und nach Freiluft Ertragsmessung

Abbildung 6 zeigt die Resultate vor und nach den Freiluft-Ertragsmessungen, sowie das Verhältnis der Leistungen von Modulen mit geätzten und ungeätzten Scheiben vor und nach dem Test. Man erkennt keinen wirklich signifikanten Unterschied zwischen dem Gewinn bei Energie und bei Leistung. Tendenziell ist der Gewinn an Leistung höher. Bei der Energie ist ein Gewinn von im Schnitt 2 % auszumachen, bei der Leistung von 1.73% vor und 2.91% nach der Bewitterung. Letzteres Resultat ist bedingt durch den recht starken Leistungsverlust des Moduls 08 nach der Bewitterung.

SN	Netz	Energie	Messung 060522		Messung 061003		PRdc tot	Mehrertrag Energie		Mehrleistung
	Pmax1		Pmax3	Spez. Energie	Pmax4	Spez. Energie				vor und nach Test
	[Wp]	[Wh]	[Wp]	[Wh/Wp]	[Wp]	[Wh/Wp]	[%]	%	Klasse	%
Ohne AR										
07	35.60	18'519	34.60	535	34.4	538	90.7			
08	35.60	18'533	34.80	533	34.4	539	90.8			**vorher:**
	35.6	**18'526**	**Ø Energie**		**34.4**	**Ø Leistung**		2.01%	Ø/Ø	1.73%
Mit AR								2.23%	Best AR/Øohne AR	**nachher:**
12	35.80	18'859	35.40	533	35.6	530	89.3			2.91%
14	35.60	18'939	35.20	538	35.2	538	90.7			
	35.7	**18'899**	**Ø Energie**		**35.4**	**Ø Leistung**				

Abbildung 6

Diskussion der Resultate

Der Vergleich der Leistung von Solarmodulen mit geätzten Antireflexgläsern und mit normalem Solarglas zeigt einen Einfluss der Oberfläche.

In der ersten Testreihe, bei der die Leistung der Zellennetze mit den laminierten Modulen verglichen wird, kann ein Unterschied von 2% zugunsten der AR-Gläser gemessen werden.

Die nachträgliche Ätzung der Frontseite der Module zeigt ebenfalls eine positive Differenz von mindestens 2%, welche das erste Resultat bestätigt.

Bei der Leistungsabnahme nach einigen Betriebstagen (gemessen nach 50kWh/m^2) zeigt sich kein Unterschied zwischen Modulen mit geätztem Glas und solchen mit normalem Glas.

Bei den Freiluftmessungen bei verschiedenen Einstrahlungswinkeln zeigt sich, dass AR-Module den Grenzbereich mit flachen Einstrahlungswinkeln noch etwas besser ausnützen können. Diese Tendenz kann aufgrund der relativ kleinen Anzahl durchgeführter Messungen und der kleinen Differenz nicht schlüssig quantifiziert werden.

Die Freiluftertragsmessungen bestätigen im Wesentlichen das Resultat der Leistungsmessungen, es resultiert auch hier ein Gewinn von ca. 2% gegenüber Modulen ohne AR-Glas.

Nationale / internationale Zusammenarbeit

Lieferant für die antireflexgeätzten Gläser war die Firma Sunarc Technology A/S aus Dänemark. Zuvorkommende Behandlung sowie das Interesse an den Resultaten zeichneten diese Zusammenarbeit aus. Auch für die nachträgliche Behandlung der bereits laminierten Module ist eine Lösung entwickelt worden.

Die Messungen an den Netzen und an den Modulen wurden in Zusammenarbeit mit der SUPSI (Scuola Universitaria Professionale della Svizzera Italiana) bzw. TISO ausgeführt.

Schlussfolgerung / Perspektiven

Der Leistungs- und Ertragsgewinn von mehr als 3% durch den Einsatz von antireflexgeätztem Glas kann mit den durchgeführten Testen nicht ganz bestätigt werden. Hingegen ist eine deutliche Verbesserung von mindestens 2% erkennbar. Für präzisere Aussagen wären deutlich mehr Versuchsmuster notwendig.

Die Leistungs- und Ertragssteigerung spricht für den Einsatz dieser Gläser. So kann mit relativ wenig Zusatzaufwand ein merklicher Effekt (bzw. Mehrertrag) erreicht werden. Ob der Einsatz schlussendlich wirtschaftlich sinnvoll ist hängt aber davon ab, wie hoch die Kosten der Anbringung der Antireflexschicht sind. Bei kleinen Stückzahlen wird dies nicht wirtschaftlich sein, weil der Aufwand zu hoch ist, z.B. bei der Gebäudeintegration. Hier kann, falls wünschenswert, als Vorteil die geringere Spiegelung angeführt werden. In der Zwischenzeit gibt es aber mindestens einen Standardmodulhersteller, der diesen Typ AR-Glas bei seiner Produktion einsetzt, was einen Hinweis darauf liefert, dass es sich bei grossen Stückzahlen lohnt.

Diese Resultate haben uns anfangs 2004 dazu bewogen, AR-geätzte Gläser bei einem Projekt in Zürich (52 kWp) und in Graubünden (54 kWp) einzusetzen. Die Erfahrungswerte sprechen sehr für den positiven Effekt der antireflexgeätzten Oberfläche. Die erwähnten Anlage ist 2004 resp. 2005 in Betrieb und liefern seither sehr gute Ertragswerte, welche deutlich über dem prognostiziertem Ertrag liegen.

Referenzen

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[2] ***Increase transmittance on glass for PV-cells by using antireflective,*** sunarc Technology A/S, Danmark

BIPV-CIS- IMPROVED INTEGRATION OF PV INTO EXISTING BUILDINGS BY USING THIN FIRM MODULES FOR RETROFIT

Annual Report 2006

Author and Co-Authors	Tamás Szacsvay
Institution / Company	3S Swiss Solar Systems AG
Address	Schachenweg 24, 3250 Lyss
Telephone, E-mail, Homepage	+41 32 387 10 10 11, sz@3-s.ch, www.3-s.ch
Project- / Contract Number	503777 / BBW 03.0046
Duration of the Project (from – to)	1.1.2004 – 31.12.2007
Date	January 2007

ABSTRACT

The results of the project will improve and widen the potential for the integration of solar (PV) energy systems into existing buildings. Special attention will be paid to architectural and aesthetic questions. Building integration of PV systems in most cases leads to a “high tech” and “modern” appearance of the building. This is caused by the typical window-like surface of most conventional PV modules. Regarding however that 90% of the building stock consists of longer existing, that means “old fashioned” buildings, it is evident that an aesthetically satisfying building integration of PV needs a lot of good will and creativity from planners and architects. In many existing building integrated PV systems the modules contrast with the building and its surroundings.

A European survey on the potential and needs for building integrated PV components and systems will identify the basis for the development of modules away from the glass /window-like appearance.In the project PV roof tiles, overhead glazing and façade elements based on CIS thin film technology will be developed and investigated which have a modified optical appearance for better adaptation to the building skin. One of the ideas is optical decoupling of substrate and cover glass.

A complete roof tile system with thin film cells adapted to the visual appearance of conventional roof tiles and innovative connection and mounting will be developed. The work includes prototype fabrication and tests according to relevant standards and subsequent performance tests.

Novel overhead glazing includes semitransparent thin film modules optimised for daylight transmission. The back side appearance will be modified in order to represent the visible inner part of the building skin. For overhead and insolating glazing an invisible interconnection and for PV roof tiles a low cost connector will be developed. Project result will be PV modules and generators for improved building integration ready for industrial manufacturing.

Einleitung / Projektziele

Ziel des Projektes ist die Integration von Photovoltaik insbesondere in die bereits bestehende Gebäudehülle zu fördern. Dazu sollen geeignete Produkte wie PV-Dachelemente und PV-Isoliergläser mit den geeigneten elektrischen Anschlüssen und Verkabelungen entwickelt werden. Im Rahmen des Projektes wird auch eine Marktübersicht über gängige PV-Systeme erstellt, und eine Übersicht über für PV relevante europäische Baustands.

Kurzbeschrieb des Projekts / der Anlage

Das Projekt ist in 11 „Workpackages" aufgeteilt:

WP1 Grundlagen am Bau: Erarbeitung von Baugrundlagen betreffend Architektonischer Ansprüche betreffend erfolgreicher Gebäudeintegration und Vorschriften betreffend BIPV.

WP2 Veränderung des Modulerscheinungsbildes: Erarbeitung und Vergleich verschiedener Methoden zur Veränderung des optischen Modulerscheinungsbildes

WP3 Marktstudie: Erarbeitung der Anwendbarkeit von CIS-Modul basierter Gebäudeintegration in Europa.

WP4 PV Sandwich Elemente: Evaluation der Anwendbarkeit von Sandwichelementen in Gebäuden

WP5 Elektrische Verbindung: Erarbeitung einer guten technischen Lösung für die elektrische Verbindung von PV-Elementen in Dach, Überkopfanwendung und Fassade.

WP6 PV in Kaltfassaden: Entwicklung eines universellen CIS Elementes für die Integration in Fassaden, Überkopf und Dach, basierend auf opaken und semitransparenten CIS-Elementen und Standard Materialien.

WP7 PV in Warmfassaden: Entwicklung eines universellen CIS Elementes für die Integration in Warmfassaden mit allen dazugehörigen Komponenten.

WP8 PV Dachelement: Entwicklung eines Dachelementes basierend auf Dünnfilm mit allen benötigten Komponenten.

WP9 Testen: Testen, Messen und Qualifizieren der entwickelten BIPV-Elemente.

WP10 Publikation/Verbreitung von Resultaten

WP11 Koordination des Projektes

Am Projekt sind 14 Partnerfirmen und Organisationen beteiligt. 3S Swiss Solar Systems AG leitet WP8.

Partner:

- ZSW (DE) (Co-ordinator)
- OVE ARUP (UK)
- JCR-ISPRA (IT)
- PERMASTEELISA (IT)
- SOL. ENG. DECKER (DE)
- ST-GOBAIN RECH (FR)
- SHELL SOLAR (DE)
- T. U. DRESDEN (DE)
- TYCO ELEC (UK)
- WARSAW UNIV. (PL)
- WÜRTH SOLAR (DE)
- WROCLAW UNIV. (PL)

Durchgeführte Arbeiten und erreichte Ergebnisse

3S Swiss Solar Systems AG ist dabei, ein neues Dachelement für die Gebäudeintegration zu entwickeln. Die Konstruktion ist bereits fortgeschritten, und es sind Abklärungen zur Machbarkeit mit mehreren potentiellen Herstellern durchgeführt worden. Im Februar 2004 wurde ein europäisches Patent angemeldet. Es wurden auch Materialtests durchgeführt, sowie Abklärungen betreffend Kompatibilität mit Bau- und Brandschutzvorschriften gemacht.

Bewertung 2006 und Ausblick 2007

Zahlreiche der Projektpartner sind durch den anhaltenden Boom im Bereich Photovoltaik sehr stark ausgelastet, was sich in einer etwas schleppenden Bearbeitung des vorliegenden Projektes widerspiegelt. Hinzu kommt, dass sie aus diesem Grund auch nicht besonders empfänglich sind für neue Produkte, solange sie mit ihren Standardprodukten über Monate hinaus ausverkauft sind. Dieser Boom hat auch die 3S erfasst, insbesondere im Geschäftsbereich Sondermaschinenbau für Photovoltaikmodule. Daher wurden Personalressourcen umdisponiert, weshalb für die Bearbeitung des vorliegenden Projektes weniger Personal zur Verfügung steht. Seither hat sich der Projektfortschritt etwas verlangsamt. Die bisher erzielten Resultate werden aber nach wie vor als ermutigend betrachtet.

Für 3S Swiss Solar Systems AG steht für 2007 die Herstellung von Prototypen an, sowie einer Nullserie des neuen Dachelementes. 2006 durchgeführte Materialtests waren viel versprechend, wenngleich noch nicht ganz schlüssig beurteilt werden kann, ob die eingesetzten Materialien wirklich über lange Zeit kompatibel sind. Für die Materialtests wurde eine Klimakammer angeschafft, um die notwendigen Tests innert nützlicher Frist durchführen zu können.

Die Prototypen sollen unter anderem dazu dienen, potentielle Grosskunden vom Produkt zu überzeugen. Dies soll geschehen, bevor eine grössere Serie hergestellt wird. Wenn es gut läuft, könnte dann etwa im 3. Quartal 2007 eine Nullserie hergestellt werden. Es ist damit zu rechnen, dass die Entwicklung bis zum Projektende noch nicht abgeschlossen sein wird.

Systemtechnik

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CENTRALE LEEE-TISO

PERIODO VII: 2003-2006

Annual Report 2006

Author and Co-Authors	D. Chianese, A. Bernasconi, N. Cereghetti, A. Realini, G. Friesen, K. Nagel, D. Pittet, E. Burà, N. Ballarini
Institution / Company	Scuola Universitaria Professionale della Svizzera Italiana (SUPSI) Istituto di Sostenibilità Applicata all'Ambiente Costruito (ISAAC)
Address	Via Trevano, CH-6952 Canobbio
Telephone, E-mail, Homepage	+41 58 666 63 51; isaac@supsi.ch, www.isaac.supsi.ch
Project- / Contract Number	36508 / 151135
Duration of the Project (from – to)	October 2003 - December 2006
Date	December 2006

ABSTRACT

The sixth quality audit, for the ISO17025 accreditation maintenance of the I-V measurements at STC, supervised by the Swiss Accreditation Service, was successfully passed. Moreover, a new test was verified and accredited ISO17025: the determination of the temperature coefficients of PV modules.

During 2006 more than 4900 flashes were performed with the ISAAC-TISO sun simulator, in particular for research programmes.

The new electronic device MPPT was successfully installed outdoor and the MPPT was also tested in static and dynamic condition at BFH Burgdorf.

At present, the fourteen different module types chosen for the test cycle 10 (7 mc-Si, 3 sc-Si, 1 HIT, 2 a-Si and 1 CdTe) have been exposed outdoor for 8 months.

The temperature coefficient has been determined on the 3rd sample of each type of c-Si modules.

The accuracy of power declarations of c-Si modules improved constantly. This lead to unceasingly smaller discrepancies between modules when comparing their energy output in the basis of their nominal power (differences in Wh/Wp-nominal power: ±10.9% in 2000 and ±4.9% in 2006). The divergence between commercial to technological comparison diminished to only 1.7% (±3.2% with P3 as reference and ±4.9% with Pn as reference). All thin film technologies seem to outperform the crystalline silicon technologies.

For architects and designers visual aspects of a PV integration are important. PV modules from the outdoor test cycle 10 are characterised by shape, size and color (colour palettes NCS S and 4041 Sikkens). Impact tests were carried out with PV samples of amorphous silicon module on flexible substrate according to the standard IEC 1646 and SIA V280.

PV modules can be used as shielding elements for Non Ionising Radiation (NIR). The measurement of photovoltaic NIR attenuation show that thin-film photovoltaic modules have really good NIR attenuation properties (more than 30dB) as have low-emissivity glasses (more than 20dB).

The laboratory of Energy Ecology and Economy (LEEE) has been promoted to the rank of institute with the new name: Istituto di Sostenibilità Applicata all'Ambiente Costruito - ISAAC (Institute for applied sustainability to the built environment).

1 Aim of the project

The aim of the project is to control the quality and reliability of photovoltaic modules. The ISAAC-TISO (ex-LEEE) testing centre offers designers, installers and architect its expertise regarding module measurements (indoor and outdoor), PV systems and BiPV for a better quality of PV plants.

The goals for 2006 were:

- ISO17025 accreditation maintenance for I-V measurements with sun simulator.
- Accreditation procedure of performance measurements at different temperatures (thermal box).
- Installation and test of new MPPT electronics.
- Light soaking and stabilization on modules of test cycle 10.
- Energy Rating analysis of test cycle 10
- Collection of BiPV systems/products on the market (work in progress).
- Call for BiPV projects with Swiss Italian Municipalities.
- Synthesis of common problems for architects willing to pursue BiPV projects.
- BiPV appearance analysis (color, form, dimension).
- Thermal properties of BiPV modules (U-vales and g-values).
- NIR attenuation.
- Mechanical test (impact test).

2 Project description

The main activities of the "ISAAC-TISO Test Centre" are: indoor measurements carried out with a class A flash sun simulator, outdoor analysis of the behaviour of PV modules under environmental conditions and study of the main obstacles encountered by architects within the relatively new photovoltaic building integration (BiPV) sector.
ISAAC's pulsed Sun Simulator allows measurement of I-V characteristics under standard test conditions, in accordance to (IEC 60904-1), and dependent on module temperature. The measurements of crystalline silicon modules are accredited ISO 17025 by the Swiss Accreditation Service (SAS). Measurements of thin-film modules with different reference cells and spectral mismatch corrections are also performed.
The ISAAC-TISO centre carried out systematic outdoor tests, under real operating conditions, on the most important modules currently on the market. Up to 18 modules for each test cycle were purchased anonymously. The modules were exposed for 15 months. Initial, intermediate and final I-V measurements @STC were carried out. Each module is equipped with a Maximum Power Point Tracker (MPPT) adapted to its voltage and current range to optimise measurement accuracy. A new MPPT was developed and installed during this project in order to satisfy the increasingly higher power of new modules. An outdoor module characterisation system with sun-tracking capabilities allows a fast and flexible characterisation under real operating conditions and the measurement of thin film modules.
The building integration of PV products (BiPV) needs a new approach from both, architects and PV operators. Within this project, different alternatives on how to overcome difficulties encountered by architects willing to work with photovoltaic (BIPV) are examined.
Moreover, mechanical, thermal (U and g-values), visual (colours, forms and dimensions) properties and others like RNI attenuation of BiPV modules are investigated.

3 Work carried out and results achieved

3.1 INDOOR I-V MEASUREMENTS (I)

During 2006, more than **4900 flashes** were performed (+88% with respect to 2005) for research programmes (test centre, EU projects and other projects), I-V measurements for third-parties and maintenance measurements (accreditation maintenance, initial tests with the new thermostatic chamber, multiflash measurements).
Maintenance measurements were performed in order to verify stability and reliability of all indoor measurements. **Annual inter-comparison** measurements with two European reference laboratories (ESTI-JRC and ECN) were also performed. Results confirmed the reliability of the ISAAC sun simulator.
In order to increase the accuracy of the absolute value @ STC of a-Si and CdTe modules, a filtered crystalline silicon reference cell is now used and a IV curve spectral mismatch correction is performed (see Annual Report 2005 for details).
In November 2005 the sixth quality audit, for the **ISO 17025 accreditation maintenance**, supervised by the Swiss Accreditation Service, was successfully passed. Moreover, a new test was verified and accredited ISO 17025: **the determination of the temperature coefficients of PV modules**.
The results of the audit was positive and the official accreditation of this measurement was in June 2006.

Listed below are the parameters analysed during the test and their relatives uncertainties:

- **Current (α):** **± 187 [ppm/°C]**
- **Voltage (β):** **± 213 [ppm/°C]**
- **Power (γ):** **± 267 [ppm/°C]**

Table 1 shows the mean values of the temperature coefficients performed at ISAAC during this year for different technologies (32 modules measured). For crystalline silicon devices (c-Si), the γ value is higher than the thin-film one, which for this reason are more interesting for BIPV applications.

Table 1: mean value of the temperature coefficients for different technologies:

	α (ppm/°C)	β (ppm/°C)	γ (ppm/°C)	N° of measured modules
mc-Si	**644**	**-3414**	**-4327**	12
sc-Si	**158**	**-3549**	**-4913**	8
Thin Film	**708**	**-3255**	**-2467**	6
a-Si Triple-junction	*1383*	*-4159*	*-1923*	*2*
a-Si Double-junction	*657*	*-3887*	*-3069*	*1*
CIS	*-41*	*-2758*	*-2635*	*1*
CdTe	*543*	*-1760*	*-2016*	*1*
HIT	*323*	*-2806*	*-3233*	*1*

Service measurements:
In 2006 a total of 312 modules were tested for :

1) third-parties (259 modules),
2) "PV-Enlargement" project of the 5FP (41 modules) and
3) PV-Performance project of the 6FP (12 modules).

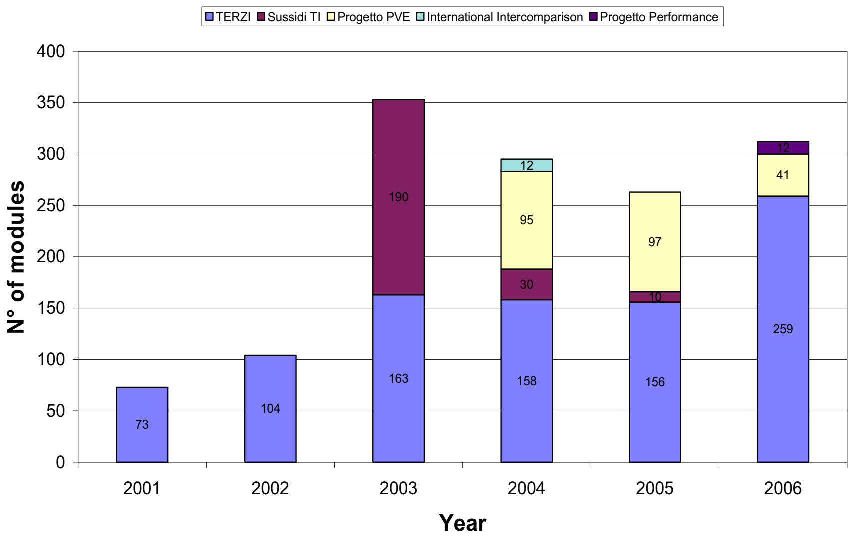


Figure 1: evolution of service measurements at ISAAC-TISO since the ISO accreditation.

3.2 MEDIUM TERM OUTDOOR MODULE CHARACTERISATION (OA, OB)

3.2.1 New MPPT

The new electronic device consists of a power unit (a DC-DC converter for normal MPPT operation and a linear MOSFET electronic load for I-V measurement), a measurement unit, a RS485 network, data loggers and a master PC unit.
In particular, the new MPPT3000 - developed by ISAAC-TISO - includes several enhanced features, like wider voltage and current ranges, a settable I-V tracer, timer functions and a built-in data acquisition system. The core of the system is a Digital Signal Processor (DSP) and the program was written in C and Assembler (VisualDSP++). Simultaneous and synchronous measurements (U and I) allow a better accuracy. Daily and total energy productions are recorded in the build-in memory.
A specific microcontroller for meteorological measurements (temperatures with PT100, pyranometer CM11, etc.) has been added (ADµC845 microconverter).
For the new test cycle, 28 new MPPT systems have been installed on the ISAAC test stand and 5 at the university of Lecce.
The MPPT was tested in static and dynamic conditions at the Berne University of Applied Science (BFH) – Division of Electrical and Communication Engineering [3]. It was possible to accurately verify the performance in a wide range of voltage and current conditions. Using manual range selection, from 100% to 10% of **all current range** the MPPT has a static efficiency ranging f**rom 99.99% to 99.75%**. Auto-range was introduced in order to increase the accuracy under 10% of current range.
The dynamic test consists in changing the working condition from 25% to 100% of maximum power and back to 25% several times using the linear PV array simulator. The change of power is done in two steps during 200 ms. After a power change, the PV simulator waits 10 seconds (P_{MPPn}). The

$\eta_{MPPTdyn}$ measured is the ratio between the energy that the MPPT absorbs from the PV simulator and the energy that the simulator can provide [4]. **The dynamic efficiency is 98.40 %**, thus very high.

3.2.2 Test cycle 10

Measurements on outdoor exposed modules (2 per type)
At present, the fourteen different module types chosen for the test cycle 10 (7 mc-Si, 3 sc-Si, 1 HIT, 2 a-Si and 1 CdTe) have been exposed outdoors for 8 months.

Crystalline silicon technologies were measured indoors before exposure and after a light soaking of about 40 kWh/m², firstly to compare the real power with the one declared by the manufacturers and then to estimate the initial degradation. After 3 months of exposure they were tested again. Results are reported in Table 2.

	MODULE	Pn [W]	Pa [W]	P0 [W]	P3 [W]	(Pa-Pn)/Pn (%)	(P0-Pa)/Pa (%)	(P3-P0)/P0 (%)	Warranty
mc-Si	Miitsubishi PV-MF130EA2LF	130	132.5	129.6	132.1	1.9%	-2.2%	1.9%	+ 10 / - 5%
	Suntech STP150-24	150	151.1	149.4	150.2	0.7%	-1.2%	0.5%	N/A
	Kyocera KC125GHT-2	125	124.3	122.3	123.0	-0.6%	-1.6%	0.5%	+ 10 / - 5%
	RWE ASE-165-GT-FT	165	163.2	158.7	158.7	-1.1%	-2.7%	0.0%	± 4%
	Solarwatt MHHplus220	210	204.8	198.8	196.5	-2.5%	-2.9%	-1.2%	± 3%
	IBC-215S Megaline	215	210.6	211.8	211.5	-2.0%	0.6%	-0.1%	± 2.5%
	Solar World SW165	165	164.8	164.6	164.1	-0.1%	-0.1%	-0.3%	± 3%
sc-Si	Sunpower STM210 F	210	204.6	205.0	202.7	-2.6%	0.2%	-1.1%	- 0 / + 3%
	Sharp NT-175E1	175	172.8	171.0	172.6	-1.3%	-1.0%	0.9%	± 5%
	BP Solar BP7180	180	175.8	173.1	173.6	-2.3%	-1.6%	0.3%	- 0 / + 2.5%

Table 2: Comparison with nominal power and initial degradation of c-Si modules in cycle 10.

As for c-Si modules, thin-film devices were initially tested to verify the acquired power.
They have not been exposed for a light soaking, but were measured after 3 and 6 months of exposure. Their performance will be checked again after 9 and 12 months and, together with c-Si modules, at the end of the cycle, which means after 15 months of exposure at real operating conditions.
Results of measurements performed on thin-film modules are shown in Table 3, where Sanyo HIP180NE1 results have been included even if HIT cells consists also of c-Si (as c-Si devices, HIP were tested for initial degradation, but no power decrease was noticed).
Due to problems with measurement settings, initial results for CdTe First Solar module are not available.

MODULE	Pn [W]	Pa [W]	P3 [W]	P6 [W]	(Pa-Pn)/Pn (%)	(P3-Pa)/Pa (%)	(P6-P3)/P3 (%)	Warranty
Sanyo HIP180NE1	180	180.5	180.0	179.3	0.2%	-0.3%	-0.4%	+ 10 / - 5%
Kaneka K60	60	84.0	61.2	58.1	39.9%	-27.2%	-5.1%	+ 10 / - 5%
UniSolar ES-62T	62	64.3	57.1	55.8	3.6%	-11.1%	-2.3%	± 5%
First Solar FS-60	60	N/A	59.3	60.8	--	--	2.5%	± 5%

Table 3: Comparison with nominal power and initial degradation of thin film modules in cycle 10.

Remarks regarding the measurement of some module types:

- Electrical characterization of Sanyo HIP180NE1 modules, with HIT solar cells is made by means of multiflash method due to the presence of capacitance effects;
- Measurements on amorphous silicon devices (Kaneka K60 and UniSolar ES62-T) are performed with filtered reference cell (nominal power Pn refers to stabilized power);
- For CdTe samples (First Solar FS-60), spectral mismatch correction has been applied.

Measurements on the 3rd module
The temperature coefficient has been determined on the 3rd sample of each type of c-Si modules. The test consists in the carrying out of I-V measurements at different temperature (from 25°C to 60°C, every 5°C). Temperature coefficients are calculated (interpolation) for current (α), voltage (β) and power (γ).
Results are reported in Table 4. Data concerning module Suntech STP150-24 are not reported due to problems occurring during the measurements (to be repeated).

	MODULE	Values @ 25°C & 800 W/m²			Temperature coefficients @ 800 W/m²		
		Isc [A]	Voc [V]	P [W]	α (ppm/°C)	β (ppm/°C)	γ (ppm/°C)
					± 187	± 213	± 267
mc-Si	Mitsubishi PV-MF130EA2LF	5.87	24.70	106.0	510	-3456	-4541
	Kyocera KC125GHT-2	6.24	22.02	100.3	502	-3256	-4438
	RWE ASE-165-GT-FT	3.87	43.93	126.8	599	-3277	-4072
	IBC 215	6.06	36.80	167.8	584	-3398	-4256
	Solarwatt MHH plus 220	6.07	36.70	161.8	574	-3358	-4550
	Solar World SW165	4.01	43.60	130.4	594	-3281	-4159
sc-Si	Sunpower STM210F	4.50	47.28	164.2	127	-2879	-4186
	Sharp NT-175E1	4.23	44.48	134.5	317	-3348	-4666
	BP Solar BP7180	4.13	43.78	139.0	497	-3401	-4366

Table 4: Temperature coefficients of c-Si modules in cycle 10.

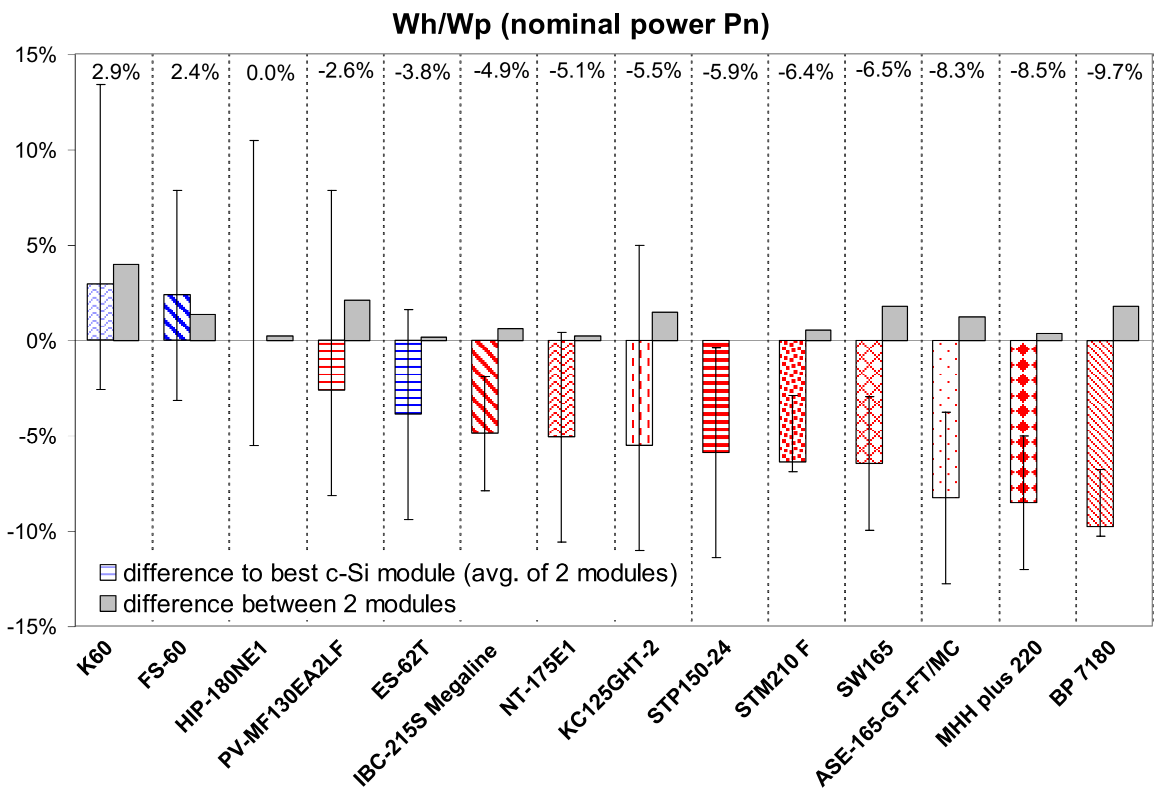
3.2.3 Wh/Wp Comparison

The energy rating measurements of the 28 modules of the new test cycle started in April 2006. In order to get a whole year of energy production at stable power, the whole exposure has been extended to 15 months ending in July 2007. So real energy rating analysis only starts at month 4 (July 2006) after 3 months degradation period. Having identical irradiation conditions for all modules, the comparison can be simply done by dividing the measured energy (in Wh) by module STC power (in Wp). As shown before, the nominal power, as declared by the manufacturer, rarely corresponds to the real stabilised power due to:1) manufacturing process related power differences, 2) declaration strategies, 3) measurement uncertainties and 4) initial degradation effects. Our laboratory generally differentiates between two points of view. The first is more consumer oriented, as it looks at the energy output in relation to the nominal power (name plate value) and the second one is a purely technological intercomparison, where the real stabilised power measured by an accredited laboratory is used as reference, in this case our own test results (see Table 2 and 3). The first approach, shown in Figure 2, gives an idea about the Wh per invested CHF and the second one about the product quality (Figure 3). For the technological comparison, the power measured after 3 months of outdoor exposure was used (P3). The preliminary results presented here are representative for Lugano and open-rack mounted modules.

Compared to previous years the following changes and observations were made:

Crystalline silicon technologies (red bars)
During the last few years the accuracy of power declarations has improved constantly. This leads to unceasingly smaller discrepancies between modules when comparing their energy output on the basis of its nominal power. In fact, some years ago, the main difference was mainly due to the high tolerance declarations (±t%), usually of ±10%, and infrequent power verifications. From 2000 the differences in Wh/Wp nominal power, of the crystalline silicon modules investigated by our laboratory, changed from ±10.9% to ±4.9%. As a result, the divergence between commercial and technological comparison also always diminished. In the first month, the new test cycle demonstrated an effective difference in module energy output of the c-Si modules in the range of only **±3.2% (with P3 as reference)**, which compared to the afore-mentioned **±4.9% (with Pn as reference)** leads to a very small difference of 1.7%. The percentages are today so little that considering the measurement uncertainties involved, it is getting increasingly difficult to tell which technology is better than another, but it is clear that the high efficiency modules available on the market today are among the best. Figures 2 and 3 show the single uncertainties in energy evaluation for each module type. In the first case (Fig. 2), the uncertainty is on the one hand due to the energy measurement itself (±0.5%) and on the other hand due to the uncertainty in power declarations (±t%). In the technological comparison, it is only due to measurement uncertainties, the STC power measurement accuracy (±2%) and the energy measurement accuracy (±0.5%).

Thin film technologies (blue bars)
All thin film technologies seem to outperform the crystalline silicon technologies, independent of which power value is used. As described in the precedent chapter, the STC power measurement at ISAAC has significantly improved within the last year, but it is still difficult to quantify the exact measurement uncertainty. For this reason, the thin film error bars are here marked by a question mark. The amorphous silicon technologies includes a further uncertainty, which is due to the natural degradation and recovery cycles the technology undergoes during 1 year. For this graph, the power measured on 20 June was used as reference.



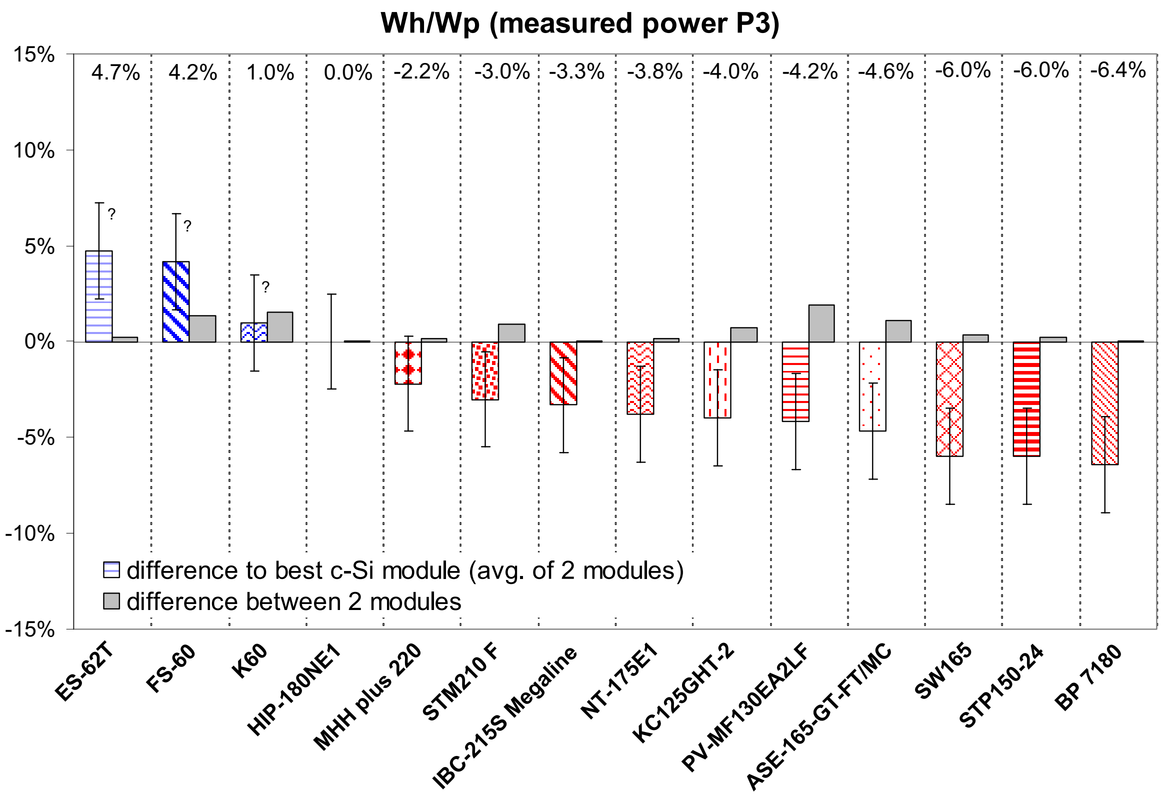


Figure 2,3: Coloured bars: Difference in energy production (average of 2 modules), expressed as percentage of Wh/Wp, of 14 different module types compared to their best crystalline silicon module with a) **nominal power Pn** as reference or b) **real power P3** as reference. (in red: crystalline silicon technologies; in blue: thin film technologies).
Grey bars : Wh/Wp Difference (in percent) between the 2 modules.

3.3 BUILDING INTEGRATED PV (BIPV)

In a building integrated PV system all considerations regarding the architectural quality of the system have to be contemplated like for any other building element; the architectural quality of the whole building will be the result of a careful study of each and every part of it, including PV modules.
Similarly, technical aspects regarding the mechanical features and the performance of the PV plant have obviously to be satisfied for a project to be considered BiPV. The main BiPV aspects dealt with in the project concern mechanical and visual functionalty of the modules and architectural obstacles and problems.
By constructive or architectural function, we consider: building envelope, sunshades, noise barrier, visual barrier, any part of the building that fulfil a proper function, part of urban structures (vehicles covers, sport structures, playground structures,…). To synthesise, our definition of BiPV is:
BiPV plants are those where PV components - modules - fulfil at least one constructive (or architectural) function in addition to electricity production.

In June 2006, ISAAC together with the Cantonal Office for Energy Saving invited all municipalities of the Italian part of Switzerland to submit architectural projects where BiPV plants could be developed. To date, six municipalities have announced projects for possible BiPV realisations (Chiasso, Cugnasco, Massagno, Paradiso, Roveredo e Stabio).
Moreover, within the sphere of subsidies granted to BiPV projects, ISAAC provides support for 5 other private-sector projects as well as two promoted by ISAAC itself.
ISAAC is supporting them to find appropriate solutions and partners.

3.3.1 Synthesis of common problems for the architects willing to realise BiPV projects

Synthesis of common problems for the architects willing to realise BiPV projects

While going through the research of solutions for BiPV projects, some difficulties have risen, most of them are linked to the fact that BiPV market is still marginal in terms of volume. In fact, it appears that almost every BiPV project is tailor made and that only few PV modules producers propose standard solutions for BiPV realisations, this situation makes the task difficult for the architects willing to work with photovoltaic, in particular for small size projects. A synthesis of the common problems has been elaborated, it includes a list of “Difficulties” put together with the relative “Consequences” and possible “Measures” for improvement:

- Difficult access to technical and cost information about BiPV products
- Problematic use of PV simulation software with special BiPV modules
- BiPV modules generally available only “tailor made”
- Lack of competency and knowledge about BiPV among PV professionals and architects
- Difficult identification and choice of PV products for BiPV solutions
- Representatives of BiPV producers not locally present and available (as advisors for architects and engineers)
- Architectural limitations for PV plants imposed by planning regulation, particularly in historical area (variable because it depends upon Municipalities)

This list of “obstacles” will be the main topic of the interactive session of an ISAAC workshop which should take place in February 2007 in Lugano. The event will get together a selected group of professionals from various horizons (architects, PV specialists and scientists, PV industrials, public institutions and real estate managers) providing a wide interdisciplinary point of view.

3.3.2 Collection of BiPV systems/products on the market

This work under progress aims at providing an overall view on what is presently available in BiPV market for helping architects, owners, engineers and planners to know who does what and where to find the product they look after. It is presented as an *Excel* table which allows to classify the list considering different criteria (producer, plant typology/application). The table is organised in 4 columns, namely: the producer’s name and complete address, the plant typology, pictures of application, notes about the technology. Since the PV market in general and BiPV market in particular are developing very fast, this list will have to be frequently updated to be really useful, this updating process should be ideally done in collaboration with the producers of BiPV solutions.

3.3.3 PV module appearance

In architecture, visual aspects of a PV integration are really important. We are used to seeing around us examples, which we can call “patchwork”, where all colours, forms and dimensions are mixed together. To help the architects and designers to choose a good combination, we characterize, amongst

others, the PV modules' colours (cells) with the standard palettes that are commonly used by architects, painters, etc.
The use of a colour and luminosity meter CS-100 of Konica Minolta and the colour-meter COLOR-CATCH of the Swiss company Colorix were not successful. The measurement of colour through glasses does not reproduce the colour impression of the human eyes.
On the other hand, colours palettes covers all the range in a logical way and allow satisfying characterisation with human eye comparison.
Initial characterizations were undertaken on PV modules from the outdoor test cycle (10). The colour palettes used were the NCS S, 4041 Color Concept Sikkens. The palette RAL K5 didn't contain enough colours.

Figure 4: colour palettes and PV module characterisation

All other appearance characterisation such as the colour background of the modules, the framed colour, the forms of the cells, the dimensions of cells, the space between the cells, the electrical grids, and PV module reflexion were indexed.

3.3.4 PV modules thermal aspects (U-value and g-value)

Some trials were made to measure thermal conductivity of glass samples with a system composed of thermal baths. We obtain some uncertainty flux measurement due to the high conductivity of glass materials. This test is more suitable for building materials such as concrete. Moreover, the PV adaptation of this test will increase inaccuracy. Hot box test facilities for U-value and outdoor test facilities for g-value, like in EMPA, require space and experience and are expensive like an EMPA service.

For this reason we tried to measure in situ the U and g-value (on real cases: i.e. newly built houses) on special glasses and in dynamic conditions [6]. The analysis method gives good results and will be extended by measurement on integrated PV modules.

Figure 5: thermal baths to measure thermal conductivity

Figure 6: U and g value measurement in situ in dynamic conditions

In collaboration with the ESCA Group of the Physics Institute of the University of Basel, indoor measurements were carried out to determine the "g" value in function of the incidence angle. Initial measurements of optical proprieties were made with simple glass Schott Solar PV modules. A database of glasses has been made by the ESCA (http://pages.unibas.ch/phys-esca/) and contains optic proprieties based on EN410 and g value measurement.

3.3.5 PV modules NIR Attenuation

Non Ionising Radiation (NIR), commonly called Electrosmog, emitted by telecommunication installations is always present nowadays. The quantity of NIR to which the population is exposed will increase as well as the intensity and diversity. In the population, fears and resistance towards NIR transmitted installation are becoming more and more common. Therefore, PV modules can be used as shielding elements. Some new building materials to shield liveable space against NIR can be already found on the market. For example: 20dB (means an attenuation of 99%) is considered as a good degree of attenuation and typical values of attenuation for building materials are generally between 6dB (75%) and 20dB (99%).

In collaboration with the TTHF (Telecom, Telematics and High Frequency) laboratory of our school, we are developing a reliable test procedure for the characterization of radio frequency attenuation, also called shielding effectiveness (SE) for various PV modules and glasses. The main technologies of mobile telephony (GSM/DCS/UMTS) are situated in the interval of frequencies from 800MHz to 2500MHz.

The measurement of photovoltaic NIR attenuation show that thin-film photovoltaic modules have really good NIR attenuation properties (more than 30dB) as have low-emissivity glasses (more than 20dB). Thin-film photovoltaics modules is really suitable for replacing building glass. Besides having the capability of being thermically isolated and a safety glass, it can also have really good properties of RNI attenuation.

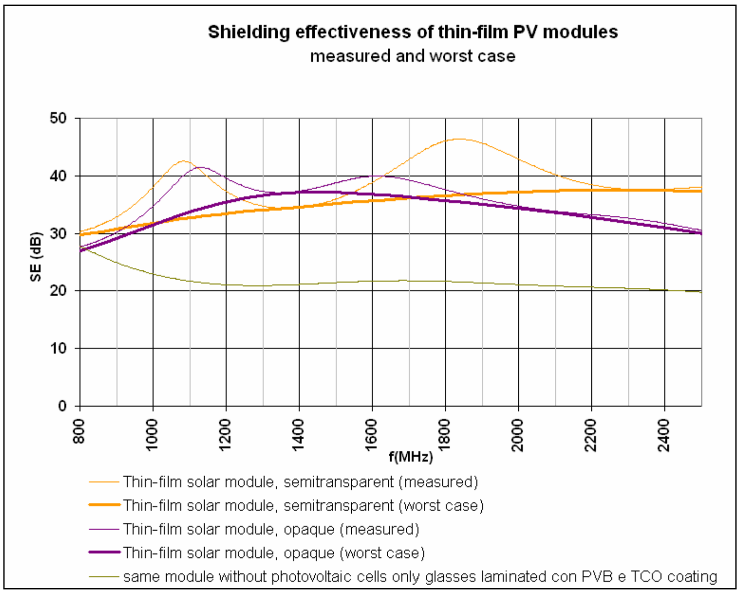


Figure 7: RNI shielding effectiveness of thin-film PV modules.

3.3.6 PV modules mechanical test

In collaboration with the EPFL of Lausanne impact tests were carried out with PV samples of two types of amorphous silicon module deposited on flexible substrate and laminate together with flexible waterproofing membrane . The test is based on the international standard IEC 1646 and SIA V280.

4 National and International collaborations

Berne University of Applied Science (BFH), Prof. H. Häberlin ; Accademia di Mendrisio ; BELVAL SA P.-R. Beljean, VHF Tech. A. Closset, P. Goulpié, D. Fischer, SOLTERRA SA Dir. S. Zappa, CUEPE A. Mermoud ; University of Basel, ESCA, Prof. Oelhafen, R. Steiner ; EPFL, Laboratoire de Technologie des Composites et Polymères, S. Lavanchy ; Cantone ticino ; Azienda Elettrica Ticinese.
Politecnico di Milano (I), Arch. Niccolò Aste ; Università di Lecce (I), Prof. L. Vasanelli, Dr. A. Cola, M. Pierro ; CREST (UK), R. Gottschlag; NREL (USA), S. Rummel; ECN (NL), M. Jansen; JRC Ispra (I) W. Zaaiman, Dr. E. Dunlop, R. Kenny.

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Umwelt, Verkehr, Energie und Kommunikation UVEK

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PV ENLARGEMENT

Annual Report 2006

Author and Co-Authors	Gabi Friesen, Antonella Realini
Institution / Company	SUPSI, DACD, ISAAC-TISO
Address	Via Trevano, 6952 Canobbio, Switzerland
Telephone, E-mail, Homepage	058 666 63 57, gabi.friesen@supsi.ch, http://www.isaac.supsi.ch
Project- / Contract Number	n° OFES: 03.0004, n° EU: NNE5/2001/736
Duration of the Project (from – to)	01.01.2003 - 31.12.2006
Date	Dezember 06

ABSTRACT

The consortium succeeded in implementing 93% (status 08/2006) of the planned PV capacity. Instead of 1.0 MWp (original contract) the consortium installed nearly 1.2 MWp (amendment 1) with the same EC support. From 27 PV systems to be realised within this project 25 are installed, 22 are in operation and two will soon be constructed.

On the scientific level the project is almost terminated. The power characteristics of nearly all module technologies were tested indoors (by ISAAC) and outdoors (by WIP). A total of 151 modules were characterised by our laboratory for their initial power and 54 of these have been tested again after 1-2 years of outdoor exposure to determine their degradation.

First system inter-comparisons shows that all CIS technologies outperforms the analysed crystalline silicon systems and that the CdTe module technology seems to compete very well with crystalline technologies (comparison by stabilised power determined by laboratory tests). The amorphous silicon systems has still to be evaluated. For the inverters the most important point was identified to be the ideal fit and the reliability and not the efficiency, which comes only next.

75% of the 23 different module types which were analysed demonstrated to have a stabilised power in the range of ±5% of the declared name plate value, the remaining 35% showed to be lower with some close or below the acceptable tolerance limits - according to the standard EN50380 “Datasheet and nameplate information for photovoltaic modules”.

Within the second measurement campaign, a detailed analysis on all thin film modules has been done to improve the overall measurement accuracy for these technologies. A new internal test procedure for the measurement of CIGS modules, consisting in the add on of a bias light within the standard indoor test procedure, was developed by ISAAC.

Presentations on the PV system and module performance were given at several international events, such as the WCPEC-4 in Hawaii and the European PVSEC in Dresden.

Introduction

One of the scopes of the laboratory tests is to allow a detailed analysis of the kWh/kWp energy output of all installations independently of PV technology, but not only by considering the nominal power as declared by the manufacturer, which is strongly influenced by the market strategies of each producer, but especially by looking at the real installed power. For this reason it has been decided to measure the STC Power of 6 to 8 randomly selected modules from each PV module technology. In this way it was possible to test the quality of power declarations from the manufacturers, to roughly estimate the real installed power of each installation and to have a more realistic inter-comparison between the different technologies.

The measurements are generally executed with a Class A pulsed Solar simulator, except for the thin film modules where the performance is additionally measured outdoors at near to STC conditions. For the outdoor performance tests the modules are stored in a room with an ambient temperature of less than 23°C. Just before the execution of the measurement the module is mounted on a Sun-tracker oriented in such way to have approximately 1000W/m² on the test area. The irradiance is measured with a crystalline silicon reference cell and a pyranometer. The module is monitored continuously during the heating phase so to have at least 1 measurement at 25°C and AM1.5.

For the crystalline silicon technologies, the indoor tests on module level are realised in two steps. In the first step two measurements are made: (a) the initial module power (purchased power) is measured at standard test conditions (STC), and (b) the module power is measured after an outdoor exposure of the module with a cumulated insolation of at least 20kWh/m². After this first step the modules are sent back to the respective European project partner and are installed outdoors in the respective PV demonstration systems. In a second step, towards the end of the project, the STC power measurements are repeated for some of the modules tested in the first step.

For the thin film technologies the main effort was put into the inter-comparison of different indoor and outdoor measurement procedures and the identification of the most reliable procedure for each single technology. The main goal was to improve the thin film test procedures for CIS, CdTe and a-Si modules currently in use at the ISAAC laboratory. The procedures identified as the best were then applied to measure the STC performance of 4 different module types taken from the Munich-Riem test field after 1 or 2 years of outdoor operation. The first test phase of the project is almost concluded The objective of this test phase was to determine the initial power of a large number of randomly selected modules. After an outdoor exposure of at least 1 to 2 years some of the initially tested modules have been measured again to determine possible degradations. The second test phase was done in 2006.

STC performance tests

So far a total of 151 modules and 23 different types were tested by the ISAAC laboratory. All modules stem from renown manufacturers in Europe. The majority are crystalline silicon technologies, but amorphous silicon, CdTe and CIGS technologies were also tested. The modules under test were selected randomly from 7 different locations, avoiding where possible modules with consecutive serial numbers. Due to budget limitations only 6 to 8 modules could be tested for each PV installation. From a statistical point of view 6-8 modules are not significant enough to predict the total installed power of a plant, but it gives an idea of the quality of power declarations and of the approximate magnitude of error introduced by these power declarations.

Some of the tested modules were tested for the third time (last test phase), in which the modules were re-measured after roughly 1 to 2 years of outdoor exposure. Table 1 shows the list of modules tested within the two measurement campaigns.

Table 1: Modules tested within the 1st and 2nd test cycle (status July 2006)

	partner name	*module technology*		*origin*	*n° 1st test*	*n° 2nd test*
1.	Università degli studi di Firenze	- Photowatt PW1250	c-Si	F	6	
2.	Gehrlicher	- Antec ATF43	CdTe	D	14	
		- RWE ASI-F 32/12	a-Si	D	6	6
		- Shell ST40	CIS	D	6	6
		- Solon M210/6	c-Si	D	6	6
		- Würth WS11007/70	CIS	D	6	6
		- Sanyo HIP-J54BE2	c-Si	J	6	6
		- Isofoton CER50	c-Si	ES	6	
		- First Solar FS55	CdTe	USA	6	6
		- RWE ASE 275	c-Si	D	6	6
		- Shell SQ 175	c-Si	D	6	6
		- Shell SE160	c-Si	D	6	6
		- Isofoton I 165	c-Si	ES	6	6
		- Solon P210	c-Si	D	6	6
3.	ATB	- RWE ASE 300	c-Si	D	6	
		- Fischer/ Power cell	c-Si	D	1	
4.	Solartec	- Solartec Radix72 dark blue	c-Si	CZ	8	
		- Solartec Radix72 marina blue	c-Si	CZ	8	
5.	Agri. University of Athens	- Shell S115C	c-Si	D	6	
		- Shell SQ150	c-Si	D	6	
		- Shell ST40	CIS	D	6	
6.	Szent Istvan University Gödöllö	- Dunasolar DS40	a-Si	HU	6	
		- RWE ASE100	c-Si	D	6	
7.	FH München	- Solarfabrik SF100	c-Si	D	6	

STC POWER OF CRYSTALLINE SILICON MODULES

The tests of the crystalline silicon modules were done in three steps: (Pm1) measurement of the purchased power, (Pm2) measurement after the first degradation, the so called stabilised power and (Pm3) measurement of the power after long-term exposure. Not all three measurements could be executed for all test modules. Some of the modules arrived to the laboratory for testing after they had been already installed and thus were tested after the first degradation . The last measurement is limited only to a smaller selection of module types.

Test 1: purchased power

For 12 of the 17 investigated module types the initial power could be determined. Fig. 1 shows the results of these measurements. Considering a measurement accuracy of ±2%, seven module types show an initial power near or even higher than the nominal power, four within 2-6% below the nominal power and two even lower. Additionally to the average power deviation the graph shows the standard deviation within each batch of 6-8 modules. The value ranges from ±0.3% to ±2.3%. In one case where only 1 module was available for testing, no standard deviation is given.

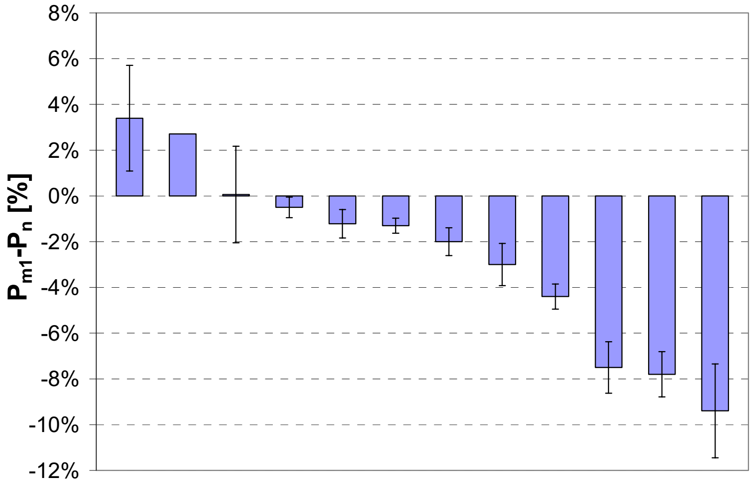

Figure 1: Average deviation of the initial power Pm1 to the nominal power Pn of 12 different module types, together with the standard deviation.

Test 2: first degradation & stabilised power

As soon as new c-Si modules are exposed for the first time to light, the modules undergo an initial non reversible degradation. The order of magnitude of this initial degradation varies from module to module. It is completed within the very first hours of exposure and it has not to be confused with the long-term degradation, which is analysed within the second test phase towards the end of the project. Generally an outdoor exposure with a cumulated insolation of at least 20kWh/m² is enough to determine this first degradation and to get the so called stabilised power of the c-Si module. Fig. 2 shows the results obtained on 11 of the 12 batches of modules investigated before. The average degradation ranged from 0 to -3.3% and the standard deviation within each batch from ±0.3% to ±1.1%.

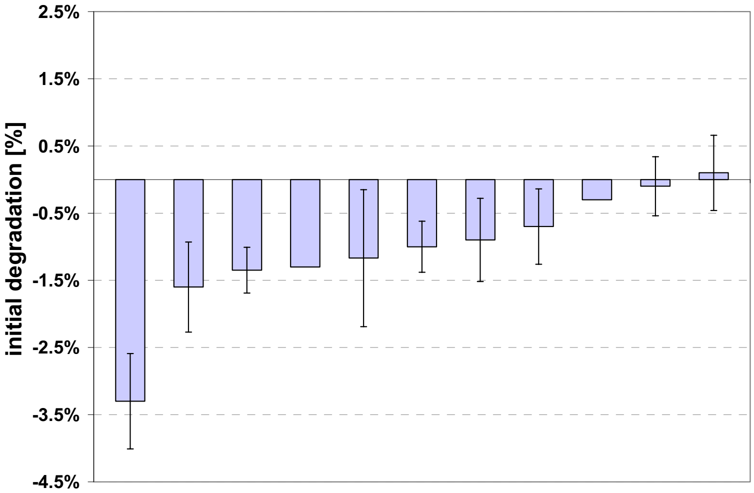

Figure 2: Average degradation after a first light soaking of at least 20kWh/m² together with the standard deviation of each batch.

With respect to the power the European standard EN50380 named “datasheet and nameplate information for photovoltaic modules” specifies two important things: (1) the declared power should correspond to the stabilised power and not to the initial value, (2) the tolerance should correspond to the real production spread and (3) the measurement accuracy should be stated. Fig. 3 shows the range of the average stabilised power for the c-Si module types tested within this project relative to the name plate value. The standard deviation bars in Fig. 1 and 2 shows instead the statistical spread within the randomly selected modules. A measurement accuracy of ±2% is considered.

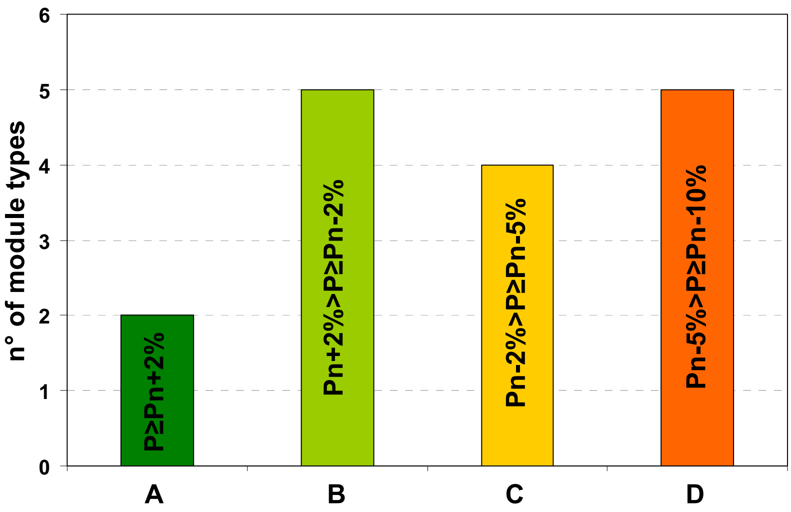

Figure 3: Power measured after light soaking: Number of module types with an average difference in the range of Pn+x%>Pmeas≥Pn-y%.

For 7 of the 17 module types the real stabilised power is very near or even higher than the declared power (see the first two green bars A and B). 4 types can be found in between Pn-2% and Pn-5% (see the yellow bar C) and 5 module batches exhibit a power ranging between Pn-5% and Pn-10% (see the red bar D). The standard deviations are all within ±0.4% to ±3.1%. These deviations are not depicted in the Figure. Even if compared to the past years an increasing number of manufacturers declare a power near to the stabilised power, there are still module types with ±10% deviations. As demonstrated by the low standard deviations, these tolerances do not correspond to the real production spread of crystalline silicon modules.

It has to be mentioned that almost no module data sheets are in conformity with the EN50380 standard introduced in 2003. Often no information about the initial degradation and the measurement accuracies is given to the end-user.

Test 3: degradation after long-term exposure

Towards the end of the project a limited number of initially tested modules are tested again to determine the annual degradation. This activity just started and results of some c-Si modules, which are in operation since 2003 are presented in Fig. 4. Three of the five module types seem to show no significant degradation, one shows a slight negative trend of -0.3%, which lies within the expected average for crystalline silicon technologies and one module type showed a major degradation of -0.9%.

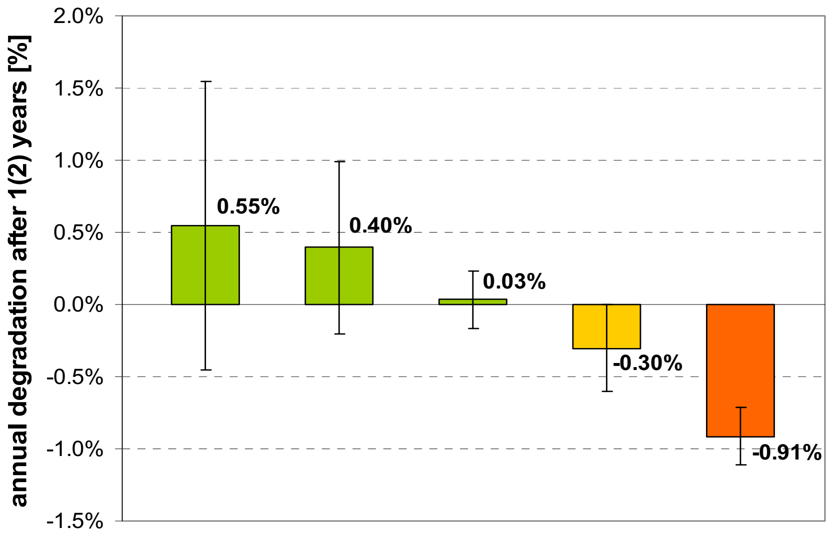

Figure 4: Average degradation after 1 year of outdoor exposure (2 years for the first module type), together with the standard deviation of the 5 different c-Si type module batches.

STC POWER OF THIN FILM MODULES

The thin film module results are sorted by technology (CIS, CdTe and a-Si). For each technology modules from two different manufacturers were available. In Fig. 5 the final measurement results of the first 4 module types (TF1 to TF4) are presented. 2 CIS, 1 CdTe and 1 a-Si were measured with different indoor and outdoor test procedures and the final stabilised power was determined for each type.

CIS modules

Both here investigated CIS technologies showed a strong dependency on the light exposure immediately before the measurement. Outdoor light soaking resulted to be not sufficient for a correct indoor measurement, as the relaxation time is so short that it's not possible to measure a reproducible IV-curve. For this reason different indoor light soaking approaches were tested. A bias light of approx. 25W/m² (halogen spot light) added to our standard flash simulator light resulted to be enough to get reproducible IV-curves . The low bias light intensity allowed to maintain a constant module temperature of 25 ± 0.5°C without any cooling. The steady state IV-curves were confirmed by outdoor measurements at near to STC conditions. Table I shows the differences between the test procedures for six tested modules.

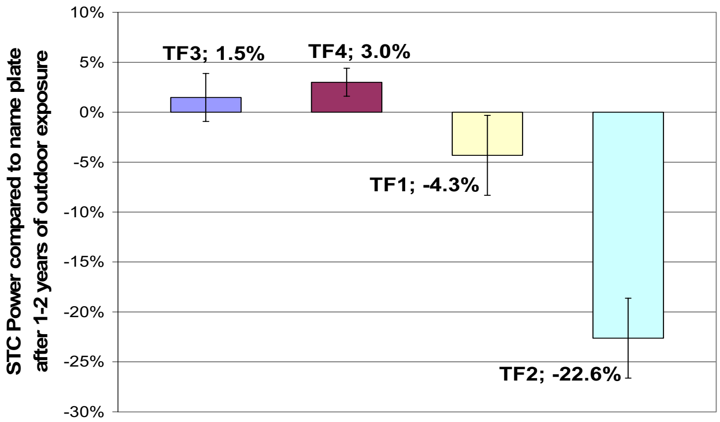

Figure 5: Average deviation of the power after 1 or more years of outdoor exposure to the nominal power Pn of 4 different thin film module types, together with the standard deviation.

Table I: Difference of CIS indoor measurement with bias light vs. outdoor measured at near to STC.

n°	*Pm*	*Voc*	*Isc*
1.	*-0.7%*	*0.9%*	*-0.9%*
2.	*-4.5%*	*0.0%*	*-1.9%*
3.	*0.5%*	*0.1%*	*-0.7%*
4.	*-0.9%*	*0.8%*	*-0.2%*
5.	*-1.4%*	*0.8%*	*-1.8%*
6.	*-0.9%*	*1.4%*	*-0.8%*
Avg.	***-1.3%***	***0.7%***	***-1.0%***
St.Dev	*1.7%*	*0.5%*	*0.7%*

Depending on the CIS module type different bias light pre-conditioning times were needed to reach the steady state IV-curve. For one only 1 minute resulted to be sufficient for the other 10 minutes were needed independently of the before executed outdoor light soaking time.

Table II: Difference of indoor measurement with and without bias light for two CIS types (CIS1/CIS2).

n°	*Pm*	*Voc*	*Isc*
1.	*5.3%/12.2%*	*1.4%/1.6%*	*-0.5%/2.0%*
2.	*4.3%/7.2%*	*1.0%/0.7%*	*0.0%/0.8%*
3.	*5.4%/10.4%*	*2.1%/1.0%*	*-0.5%/2.0%*
4.	*8.4%/12.1%*	*2.5%/2.5%*	*-0.9%/2.4%*
5.	*4.9%/8.9%*	*1.4%/1.1%*	*-0.5%/1.6%*
6.	*5.0%/9.6%*	*1.4%/1.9%*	*-0.5%/1.6%*
Avg.	***5.6%/10.0%***	***1.6%/1.5%***	***-0.5%/1.7%***
St.Dev	*1.5%/1.9%*	*0.5%/0.7%*	*0.3%/0.5%*

Table II shows the differences in power, Voc and Isc between measurements with and without bias for the two investigated CIS module types (6 modules of each type). Without bias light an average error of 10% is made for one of the two module types and 5.6% for the other.

CdTe modules

For CdTe modules no pre-conditioning or other measurement artefacts, like capacitive effects, were detected. The modules were measured indoors with a standard c-Si reference cell and corrected for mismatch (M=0.907). Even though the spectral response data of the measured CdTe module were not available, and SR data had to be taken from literature, the IV curves match very well, as shown by Table III, the outdoor measured IV data.

a-Si modules

Multi-junction modules can not be measured with standard single source flash solar simulators. For this reason the amorphous modules were tested outdoors at near to STC conditions (AM 1.5, 1000W/m², 25°C). The modules investigated were measured after 2 years of outdoor operation at the end of the winter season. For this reason the power was at its lowest value. This is due to the typical seasonal variations caused by the Staebler-Wronsky effect. Further measurements are needed to acquire information about the power evolution.

Table III: Difference between outdoor and indoor mismatch corrected measurement (M=0.907) for 6 CdTe modules.

n°	*Pm*	*Voc*	*Isc*
1.	*-1.56%*	*-1.89%*	*0.99%*
2.	*-0.67%*	*-1.56%*	*1.02%*
3.	*-0.03%*	*-0.99%*	*0.51%*
4.	*1.42%*	*-0.71%*	*0.90%*
5.	*0.61%*	*-1.31%*	*0.69%*
6.	*-1.97%*	*-1.76%*	*1.30%*
Avg.	***-0.37%***	***-1.37%***	***0.90%***
St.Dev	*1.29%*	*0.46%*	*0.28%*

kWh/kWp PERFORMANCE TESTS

To permit the comparison of different simultaneously measured modules the energy output is usually divided by its STC power. But which value should be used: the nominal power (name plate value), the power as measured by the manufacturer on a single module level (manufacturer protocol value) or the power measured by a certified laboratory? The last has the disadvantage to be expensive and time consuming, but it allows to do a real technological comparison. The second one has the advantage that the single module data are almost always available and are given by the manufacturer under request, but unfortunately, as shown in Fig. 7 and discussed in chapter 3 the data corresponds only more or less to the real power. The first most common and simple approach is influenced by many external factors like the declaration accuracy which depends on the applied marketing strategies of each single manufacturer and which can change in time. A real technological inter-comparison is thus almost impossible.

To demonstrate the influence of the different approaches a single clear sky day measurement has been used. The data stem from test field of Munich Riem and correspond to the DC Energy output of different PV sub-systems. A more detailed analysis of the DC and AC performance ratio for a large number of technologies and for different climatic conditions is presented in a separated paper [1].

As shown in the lower graph of Figure 6, in the case of the name plate value as reference, the difference within the nine here investigated module types are in the range of ±15%. It reduces to ±10% by considering the manufacturer protocols and reduces to only ±3.5%, including the thin-film technologies, if values from a certified laboratory are used as reference.

The upper graph in Figure 6 shows how large the corresponding discrepancies in power are. A clear difference between thin-film and crystalline silicon type modules is visible. It can be seen that the largest discrepancies can be found for the thin film modules. Here the differences between name plate (Pn) and factory module power (single module protocols) are quite high (around 5%), negative and positive. The lower measurement accuracy for thin film technologies at laboratory and manufacturer level, as well as the material related changes during life time leads to higher discrepancies between manufacturer and laboratory data. This complicates the energy production inter-comparison of these technologies.

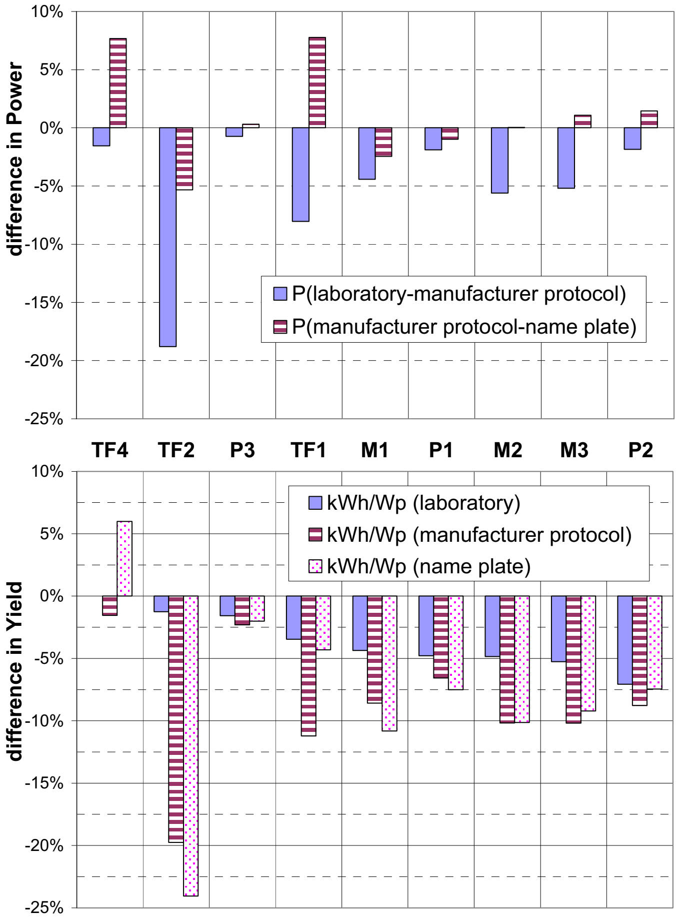

Figure 6: DC energy yield comparison for a clear sky day (08 Apr 2006) taken from 9 different PV-systems all mounted on the roof of the Munich fair. The top graph shows the calculated differences between declared and measured STC power.

Conclusions

- The scientific accompanying measures of the PV-Enlargement project leaded to the development of a large data base which allows a real scientific and standardised performance inter-comparison of the main technologies and module types on the market.
- During the project the indoor and outdoor measurement results of all thin-film technologies was improved significantly and first inter-comparisons with crystalline silicon was made. For a clear sky day in April, the real energy yield [kWh/kWp] of all investigated technologies resulted to be within ±3.5%.
- The laboratory tests demonstrated that there is still the need to (1) improve the STC power declarations, by applying existing standards like the EN50380, and (2) to further reduce the discrepancies between laboratory and manufacturer performance measurements.

Acknowledgements

This work is co-financed by the EC via the EESD programme of the Directorate General for Energy and Transport (EC DG-TREN) and by the State Secretariat for Education and Research (SER, Bern).

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PERFORMANCE

ISAAC ACTIVITIES

Annual Report 2006

Author and Co-Authors	Gabi Friesen
Institution / Company	SUPSI, DACD, ISAAC-TISO
Address	Via Trevano, 6952 Canobbio, Switzerland
Telephone, E-mail, Homepage	058 666 63 57, gabi.friesen@supsi.ch, http://www.isaac.supsi.ch
Project- / Contract Number	n° 019718 EU: (SES6) – Integrated project
Duration of the Project (from – to)	01.01.2006 - 31.12.2009
Date	Dezember 2006

ABSTRACT

The PERFORMANCE project covers all pre-normative aspects from module to system level and from instantaneous device characterisation and system measurement to their life-time performance prediction and assessment. The limitations of current indoor and outdoor calibration measurement technology will be investigated and precision will be improved, covering current technologies as well as new and advanced cell and module concepts. Methods will be developed to connect from measurements of module power to module energy production. In a third pillar, methodologies for the assessment of the life-time performance of PV modules will be developed. Based on all these work packages, a modelling and analysis programme will provide the analytical understanding of PV performance in the broad and systematic manner mentioned above. Following this work programme, the project will produce a consistent set of measurement and modelling methodologies to create the transparency needed for the European market and industry. Next to this significant scientific effort, intense involvement of all European companies along the value chain will be organised systematically through feedback loops. Project results will be fed directly into standardisation processes on CENELEC and IEC level.

The project is divided into 8 sub-projects:

SP1 Traceable performance measurement of PV devices

SP2 Energy delivery of photovoltaic devices

SP3 PV system performance evaluation

SP4 Modelling and analysis

SP5 Service life assessment of PV modules

SP6 PV as a building product

SP7 Industry interaction and dissemination

SP8 Standardisation processes

The ISAAC institute is involved in SP1, SP2 and SP4 and is work-package leader of SP4.4 entitled "Annual Energy Rating Production and Device Comparator". The scope of this report is to present the institute activities of year 2006.

General information about the project can be found under **http://www.pv-performance.org**

1. Traceable performance measurement of PV devices (SP1)

Within this sub-project, led by TÜV Rheinland, the ISAAC is mainly involved in WP1.1 "Round Robin tests" and WP1.2 "Solar simulator performance assessment" and in a more indirect way in WP1.3 "Thin Film, multi-junction and novel technologies" and WP1.4 "Measurement accuracy and traceability chain".

1.1 Approach and Objectives (SP1)

The scope of WP1.1 is to document the current measurement differences for commercial PV module technologies (crystalline silicon, thin-film, multi-junction) within 8 of the major European test laboratories. In addition to STC performance measurements also the characterisation at different test conditions (module temperature and irradiance) is under investigation. The laboratories with spectral response facilities (ISE, JRC) will measure the spectral response of some modules. This information will be used to quantify the spectral mismatch errors between solar simulator spectrum, reference cell and test sample. Further to these PV module performance measurements, specific measurement programmes will be conducted aiming to identify technology specific measurement effects (cell capacitance, pre-conditioning effects etc.). On the basis of these round robin tests, an analysis of the single measurement systems and test procedures will be made, and the test laboratories will be enabled to identify the potential for improvement. The results of the scientific work will also serve as input to WP1.3 which deals with the development of measurement methods for new PV technologies. A second round robin with similar PV modules will be performed at the end of the project after having improved or expanded the measuring technology of the involved solar simulation systems. The change of discrepancies compared to the initial round-robin will be an indicator for the success of the scientific work.

The result of indoor performance measurements of PV devices depends strongly on the solar simulator properties and the used measuring technique. This information is required to interpret results and to explain measurement differences between the different parties. Within the work package WP1.2, the existing indoor measurement and evaluation techniques for PV devices are documented and discussed. This will be done through questionnaires and from measurement results of WP1.1. Based on these analyses minimum requirements for solar simulators will be defined for achieving an overall measurement uncertainty below ±3% for maximum power. Harmonised measurement procedures will be introduced in the test labs and solar simulator or measurement systems will be modified aiming to deliver comparable results and to consider the particular requirements of new and emerging technologies. The work will involve close contact with solar simulator manufacturers, to increase their awareness of the needs of test labs and the PV industry.

1.2 ISAAC 2006 Activities (SP1)

1.2.1 Round Robin tests (WP1.1)

Two different round robins are currently executed, one with crystalline silicon PV modules and a second one with thin film technologies only. The crystalline silicon measurements at ISAAC have been completed beginning of September while the thin film measurements are currently undertaken. The thin film test results will be available early next year.

Table 1 shows the list of measured c-Si modules. Two modules of each type were delivered (#2 and #3). #1 went to ISE and JRC for spectral response measurements. Except for the modules B and the E spectrally matched reference devices were included for the irradiance calibration. An additional standard crystalline silicon reference cell was delivered by JRC. For all test devices (modules and reference devices) the spectral response curves were given.

ID code	Cell type	Cell Size	Cell technolgy
A	mono-Si	5-inch	back contact: Sunpower
B	mono-Si	5-inch	heterojunction with intrinsic thin layer (HIT), Sanyo
C	mono-Si	6-inch	Motech Technologies
D	poly-Si	5-inch	edge-defined film-fed growth technique (EFG), Schott
E	poly-Si	8-inch	Qcells

Table 1: c-Si test samples

The following measurements have been done within the c-Si RR:

- The STC performance was measured for both modules by using 1) the standard ISAAC reference cell (calibrated every year at PTB), 2) the JRC reference cell and 3) the corresponding matched reference mini-module (when available).
- For 1) and 2) mismatch correction has been done. These mismatch corrections have to be probably recalculated once the real spectral distribution of the ISAAC solar simulator is measured. Currently only the spectral irradiance curve given by the manufacturer is available for mismatch correction. The measurement of the solar simulator characteristics (part of WP1.2) is planned for the first months of 2007. The measurement will be done by TÜV.
- For three of the investigated module types, more precisely all high capacitive modules (A, B and C), multiflash measurements had to be executed instead of forward swept measurements (Isc to Voc). The high cell capacitance of these modules leads to pronounced distortions of the IV-curve when sweeped at speeds of around 2 ms, time prescribed by the irradiance shape of the ISAAC simulator. In the multiflash mode, the IV curve is measured point by point, by applying a fixed bias voltage at the module. Around 20 flashes are executed to obtain the whole IV-curve. The respective IV pairs are extracted from the raw data by verifying that the current reached its steady state. So far only the swept IV measurement of c-Si modules is accredited according to ISO17025 at ISAAC. The multiflash procedure is still under investigation.
- The capacitive effects were investigated in more detail for module #3 where the forward (Isc to Voc) swept measurements were compared to the multiflash measurements. A difference of 4.5% up to 12.6% in STC power could be observed within the two methods. A major difficulty has been identified for 2 of the modules at voltages in-between Vmax and Voc where the 2ms are too short to allow the module current to reach its steady state. Only for voltages near or larger Voc , where the cell capacitance is getting smaller, steady state is again reached.
- For the largest module (199 x 89 cm) some uniformity tests have been done to define the best position for the reference cell respect to the module positioning. The reference cell has been mounted in order to get the equivalent irradiance as measured in average over the whole module area. The non uniformity, defined as 100 x $(Isc_{max}-Isc_{min})/(Isc_{max}+Isc_{min})$, was equal ±1.6%.
- The temperature coefficients of the modules #3 were measured at 800W/m². Only the module E couldn't be measured as it did not fitted into the thermostatic chamber needed to bring the module at the desired temperature. The test procedure consists in the IV measurement at 5°C intervals from 25°C up to 60°C (8 measurements). The module is heated in a thermostatic chamber and the measurement (swept or multiflash in dependence of the module type) is executed when the target temperature is stable for at least 5 minutes. The measurement is done during its heating phase and never during its cooling. The chamber has no active cooling system. The temperature coefficient measurement at ISAAC is accredited to ISO17025 by the Swiss Accreditation Service (STS309).
- IV-measurements at different irradiances, from 200 to 1000W/m² (at intervals of 200W/m²) were done for all modules #3. The irradiance on module level is changed by modifying the flash generator power. This way of doing could have an influence on the spectral distribution of the irradiance and consequentially on the measurement accuracy, especially for the low irradiance measurement at 200W/m². However all the measurements show a linear trend in Isc, which lets assume that no spectral related errors are introduced. A final verification of the spectrum at different irradiance levels will be done within the simulator performance test executed by TÜV for WP1.2 in 2007.

1.2.2 Solar simulator performance assessment (WP1.2)

- The questionnaire "Indoor measuring equipment and measurement practices" has been filled in by ISAAC and delivered to the SP1 project leader. The questionnaires will be later used to evaluate the state of the art of all indoor test facilities for STC performance measurements available within the project. All major European test laboratories are involved here.

1.2.3 Thin Film, multi-junction and novel technologies (WP1.3)

- The ISAAC contributed to the "Workshop on thin film measurements" organised by ISE at Chambery the 17 Nov 2006. Within the presentation entitled "experience with thin-film module calibration at ISAAC" the laboratory presented a new test procedure for CIGS modules developed within the European project PV-Enlargement and the by ISAAC applied mismatch correction procedure. The presentation will be published on the official web page.

1.2.4 Measurement accuracy and traceability chain (WP1.4)

- All documents concerning the measurement uncertainty, valid for c-Si module measurements at ISAAC, were delivered to JRC (WP1.4 leader) for further analysis. A comparison of the existing practices in measurement accuracy determination within all laboratories will be used to identify deficiencies in the PV calibration traceability chain and to minimise the overall measurement uncertainty.

2. Energy Delivery of Photovoltaic Devices (SP2)

Within this sub-project, led by ZSW, the ISAAC is involved in WP2.1 "Assessment of actual outdoor evaluation procedures", WP2.2 "Influence of performance relevant parameters", WP2.4 "Translation between indoor and outdoor performance measurements", WP2.5 "Preparation and implementation of harmonised procedures" and WP2.6 "Performance evaluation at system level". The other work-package is WP2.3 "Minimum set of characterising module parameters" and. The work-packages WP2.3 and WP2.4 starts only in 2007. In 2006 ISAAC was only involved in WP2.1.

2.1 Approach and Objectives (SP2)

This SP aims to resolve issues related to the measurement of the energy yield of PV modules and systems at specific site and the correlation to PV module power parameters declared on data sheets, where values usually measured indoors at STC. One of the final goals is to strengthen the European R&D infrastructure for PV by empowering ten institutions and labs to deliver outdoor performance results with an improved replication error level through the application of optimised and harmonised procedures, independently of technology and geographical location. Especially for thin-film PV technologies the outdoor performance figures determined by different institutions vary still by about 10%. A special measurement campaign employing a large number of PV technologies will be carried out at three sites in different regions of Europe with identical measurement equipment. This data will be analysed in detail and used to solve the main issues of SP2.

Another important scope of this sub-project is to find a minimum set of measured parameters, which is sufficient to determine the annual module energy yield of c-Si and thin-film technologies. Strong links exist here to sub-project SP4, which concentrates on the modelling aspects. Within the measurement campaign and outdoor data analysis the following relations, which are essential for SP4, will be investigated in detail:

- PV module characteristics measured indoors with simulators versus
  outdoor PV module power measurements,
- outdoor PV module energy yield recorded at one place during a specific weather pattern versus
  outdoor energy yield at another place during another period of time,
- outdoor optimal energy yield of a PV module versus
  the field energy yield of a PV array.

2.2 ISAAC 2006 ACTIVITIES (SP2)

2.2.1 Assessment of actual outdoor evaluation procedures (WP2.1)

- In this first phase the ISAAC institute participated in the review of present measurement procedures used at different test sites in Europe. A questionnaire has been filled in and input has been given to the report "Review of present measurement procedures - PV modules power and energy rating". The two main outdoor measurement facilities of ISAAC have been documented for this purpose. First the large energy rating test stand, for up to 36 modules, dedicated to annual energy yield measurements of single modules and secondly the small sun-tracker system for short-term multi-purpose measurements, with a capability of 1 module at a time. Detailed information was given about the climatic conditions present in Lugano, the applied measurement and electronic characterisation equipment and the meteorological sensors and measurement procedures used on both systems.
- Two irradiance sensors (1 pyranometer and 1 crystalline silicon reference cell) have been defined and prepared for an inter-comparison at the INES institute at Cadarache. The calibration will be carried out in spring when good test conditions persist. One or more sensors from each test laboratory involved in this WP will be measured simultaneously under clear sky conditions as well as

cloudy ones and different angles of incidence to determine the absolute calibration values and their dependencies. These values will be compared to the values usually applied in-house.

- A data-handling workshop was organised by CREST in October 2006 with the objective to compare existing data collection and evaluation approaches and to define a common procedure to be used for the measurement campaign executed within SP2. ISAAC's operation procedure has been presented and then summarised for the final report "Assessment of data validation procedures".

3. Modelling and analysis (SP4)

Within this sub-project, led by CREST, the ISAAC is coordinating work-package WP4.4 entitled "Annual Energy Rating Production and Device Comparator". The laboratory is only indirectly involved into the other work-packages, which are: WP4.1" Interfacing and Data Assimilation", WP4.2 "Environmental Modelling", WP4.3 "I-V Characteristic Based Modelling" and WP4.5 "Life Time Energy Rating".

3.1 Approach and Objectives (SP4)

It is currently not possible to provide an accurate prediction of energy yield from a given PV system at a given site, and thus there is a lack of guarantee of results for the system purchaser. This applies to all PV technologies. Above this there are particular effects to consider for thin film PV modules. Especially the impact of environmental effects such as spectral variations on wide band gap materials and multi-junction devices are not well understood. While a good understanding exists for crystalline devices, the short and long term behaviour of thin film devices is still limited. Reliable tools for yield estimation and system diagnostics must be based on validated models which take these factors into account.

WP4.4 brings together the knowledge gleaned from the other SP4 work packages, and compares this to more empirical methods. A comparison will be carried out of several energy rating methodologies, their accuracy will be evaluated and key weaknesses identified and where possible remedied. While the detailed modelling as carried out in WP4.3 is required for a more knowledge-based energy prediction, it is expected that more empirical methods would be more suitable for standardised energy prediction. There are several modelling methods currently available which merit further development; each has advantages for certain applications. A consensus will be established reflecting both the researchers and the industry, as to the most appropriate approach to calculation of the annual energy prediction, based on ease of use, availability of input data and accuracy of the methodology. This agreed method will then be used to generate a performance comparator for different devices in different climates (as defined in WP4.2), which allows a non-expert to compare between the different technologies and products. It is crucial that a device comparator is found which is consumer-friendly and fair to all technologies. The general approach of WP4.4 is to proceed step by step, starting on module level and ending with system simulations. Each step should allow to identify and quantify the main error sources of existing energy prediction approaches. The work-package is divided into 3 phases with 1 round robin for each. Currently the project is within its first phase. Each phase is split into five consecutive steps: 1) identification of appropriate RR data and to be involved energy rating methods, 2) execution of a modelling inter-comparison round robin, 3) presentation of the results and discussion of the next steps, 4) improvement of single methods and 5) dissemination of results. The first 3 steps are almost completed and step 4 is currently under way.

3.2 ISAAC 2006 ACTIVITIES (SP4)

3.2.1 First Modelling Round Robin (WP4.4)

3.2.1.1 Identification of appropriate RR data and to be involved energy rating methods

The first RR was restricted to energy predictions of single PV modules and the evaluation of different simulation models, by limiting the meteorological parameter to an absolute minimum. Two different data sets and 8 different energy rating methods was identified for this RR.

All module data was originating from concluded European or national projects. The first data set comes from an outdoor measurement campaign, carried out within the European project "PV-Catapult", and the other from long-term monitoring tests executed by INES and ISAAC within national projects and by ZSW within the European project "Pythagoras". The general approach consisted in the use of some base module data, measured in one site, to predict the energy of the same or a similar module, the so called predict module, installed at the same site or a different site. A blind simulation was done, with no electrical data for the predict module. Figure 1 shows the type of information distributed by ISAAC to the single round robin participants.

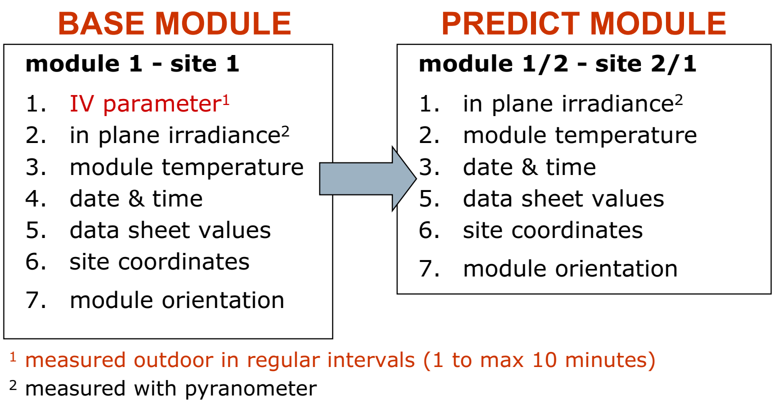

Figure1: Input data given to the participants of the first round robin.

In the first case (PV-Catapult data), the base module and the predict module is the same (same serial number). Data of 4 different modules (sc-Si, mc-Si, CIS, 3j a-Si) measured at 4 different sites (FR, PL, NL, UK) was available. The data consisted in 1 to 4 weeks data measured consecutively. In this case the output was not only influenced by the different geographical locations but as well by the different times of the year during which the measurements were executed. The French data set acted as base module data.

For the second dataset the annual and monthly energy for a module of the same type, but with different serial number, had to be predicted for different sites. 3 different technologies has been investigated (mc-Si, CdTe and CIS) and 4 different locations (FR, CH, DE, FL).

In both cases it has been started with a minimum of input data, consisting only in back of module temperature and in-plane irradiance measured with a pyranometer. No information about spectral distribution, wind speed or diffuse fraction was given at this stage. The aim of this first approach was to validate each method by excluding the environmental aspects which are treated separately in work-package SP4.2. In this first phase the errors related to the translation from a) horizontal irradiance to in plane irradiance, b) ambient temperature to module temperature and c) monthly data to minute data can be considered to be zero and errors due to environmental conditions and the simulation models them self can be more easily quantified.

The 8 different analysed energy prediction methods calculate either the real operating efficiency or the power of a module at different irradiances and temperatures. These two parameters can be easily translated into each other. The main difference within the methods are the way of parameter extraction and the input requirements. The models evaluated in this RR are listed in Table 2, together with the groups operating them.

method	developed by	ER module input data
RRC	ISE	$\eta ssc = r_T \bullet r_G \bullet r_x \bullet \eta_{stc}$
SSE	CREST	$\eta ssc = r_T \bullet r_G \bullet r_x \bullet \eta_{stc}$
On-Line Yield Simulator	ECN	η(G,25°C), γ
PV-SAT	H2M	η(G,25°C), γ
Somes	UU	η(G,25°C), γ
MotherPV	INES	η(G,25°C), γ
Performance Surface	JRC	P(G,T)
Matrix method	SUPSI	P(G,T)

Table 2: List of the performance models reviewed in this RR with the groups operating them.

3.2.1.2 Execution of modelling round robin

Each partner had to predict the energy of the different modules for given environmental conditions. To start with this minimum set of input parameter, as described in 3.2.1.1, most partners had to simplify their methods for this round robin. Within the next round robins the features of the single methods excluded before will be re-introduced progressively. In this way single effects can be distinguished and quantified and where possible corrected. The modelling data were collected and analysed by ISAAC.

3.2.1.3 Presentation of results

First results and further steps have been presented to all partners and discussed at the last SP4 project meeting in Loughborough. The presented results are summarised here. The general approach consisted in the comparison of real measured energy to calculated energy obtained by the different prediction methods. It has been observed that the use of only two input parameters, the module temperature and in-plane irradiance measured by a pyranometer, even if astonishingly good for some technologies and very close for all energy rating methods, it is not sufficient to reach the final goal of ±5% prediction accuracy on system level for crystalline silicon technologies and ±10% for thin film technologies.

The results obtained up to now can be summarised as follows:

1. For the easy case, where the energy of the base module itself had to be predicted (same module and same meteo data) the error of all methods was around 0.1% for the 1 to 4 weeks data (no winter months were included!) and around 1% for the annual averages. Only a closer look to the monthly energy predictions within the annual data showed that a clear seasonal variation exist in energy prediction accuracy. Figure 2 shows that for the winter months an under-prediction of up to 8% is made with all methods and this even if no site to site or module to module translation is done at this stage. This result demonstrates a strong potential for further improvements which will be faced within the next round robins in which the angle of incidence effects will be considered as first.

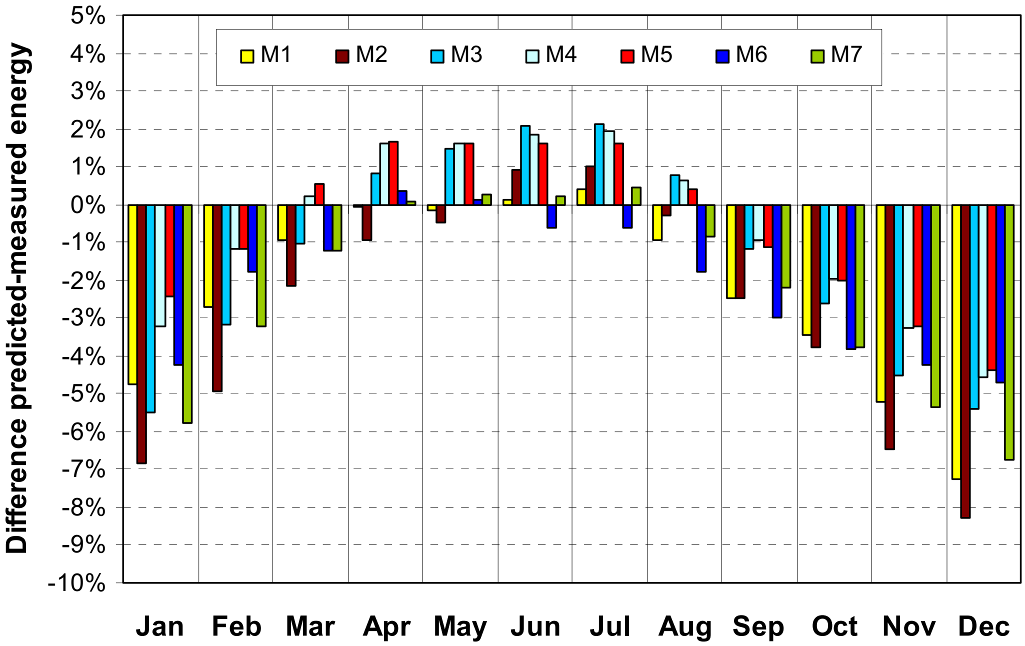

Figure 2: Monthly energy prediction accuracy of a base module (mc-Si) for 7 different prediction methods.

2. The energy predictions of similar modules but of different STC power leaded as expected to the highest errors, due to the differences in performance it self. The knowledge or estimation of these differences is therefore crucial for an accurate energy prediction.
3. If corrected for differences in performance, the 3 technologies (c-Si, CIS and CdTe) leaded all to an under-prediction of the energy output, independently of the applied energy rating method or the site for which the energy had to be predicted. The average error was in the order of 3% for all

c-Si modules and of 5% for all CIS and CdTe modules. This is in line with what has been observed for the 1 to 4 week predictions of identical modules.

4. The amorphous silicon technology is the most difficult to predict due to their seasonal changes in STC performance. The correction for these variations introduces a higher uncertainty into the final prediction due to the difficulty to model the seasonal variations over time and for different sites. Even though the energy predictions leaded to astonishing good results of ±4% for almost all approaches.
5. The analysis of the error as function of irradiance confirms that a part of the error is probably due to reflection losses as well as spectral effects in case of thin-film technologies. Another part is instead due to unpredictable events such as moving clouds, but which more or less averages out over longer time periods. A more detailed analysis to quantify the error due to air mass, angle of incidence and diffuse light fraction dependencies is currently under progress.

3.2.1.4 Improvement of single methods

A major effort has to be done by each single partner to systematically improve their prediction accuracy. For this purpose each partner will receive by ISAAC the complete data sets of some of the modules, so that each one can test how effective the introduction of new features is. Within the second round robin, which will be again a blind test, the actual validity of introduced changes will be identified.

3.2.1.5 Dissemination of results

The results of this RR will be presented at the next PV conference in Staffelstein.

EFFICIENCY AND ANNUAL ELECTRICITY PRODUCTION OF PV-MODULES

Annual Report 2006

Author and Co-Authors	[1]Wilhelm Durisch, Jan-Claude Mayor, [2]King Hang Lam
Institution / Company	[1]Paul Scherrer Institut, PSI; [2]University of Hong Kong
Address	[1]CH-5232 Villigen PSI
Telephone, E-mail, Homepage	+41 56 310 26 25, wilhelm.durisch@psi.ch, http://www.psi.ch/
Project- / Contract Number	101431 / 151715
Duration of the Project (from – to)	November 2005 – April 2007
Date	January 2007

ABSTRACT

Efficiency data of PV-modules under actual operating conditions are of vital importance for reliable prediction of their annual electricity production. For measuring these data, an outdoor test facility was erected at PSI. It consists of a sun-tracker and a PC-based measurement system. The sun-tracker is used to orient test modules continuously towards the sun. The measurement system is designed for automated acquisition of current/voltage (I/V) characteristics, from which the efficiency is determined. I/V tests performed under constant irradiation, but different module temperatures, allow the temperature coefficient of the efficiency to be determined. Measurements under varying irradiation and varying air mass allow the efficiency in these conditions to be determined. Some hundreds up to a few thousand I/V characteristics per module are required to develop semi-empirical efficiency models, which allow an accurate calculation of the efficiency under all possible operating conditions. From the efficiency models and local meteorological data, the annual electricity production of the modules at the site selected for the PV plant can be calculated. These data allow the expected cost of electricity generation for different modules to be calculated, and thus the type of modules with the highest yield-to-cost ratio for a specific installation site can be identified.

Testing and development of efficiency models were carried out for two commercial modules (SunPower SPR-90 with mono-crystalline cells, and Kyocera LA361K51S with poly-crystalline cells).

Cell efficiencies under Standard Test Conditions, STC of 19.5% and 12.7% were found for the SunPower and Kyocera modules, respectively. Efficiency maxima of 19.7% and 13.3% were observed at 519 W/m^2 and 419 W/m^2, respectively. The efficiency of both modules linearly decreases with temperature. The temperature coefficients were found to be -0.0637 and -0.0493 percentage points/°C, respectively. The SunPower module has an efficiency practically independent over the whole irradiance and air mass range. The Kyocera module also performs very well under varying irradiation, but its red light sensitivity in the late afternoon is somewhat reduced, as compared to the SunPower module. However, the Kyocera module tested is fairly old (acquired in 1994). Recent measurements on Kyocera's latest modules show a much better red sensitivity and a remarkably higher efficiency (cf. http://grid-pv.web.psi.ch).

Using measured meteorological data from a sunny site in Jordan, the electricity production for the SunPower and Kyocera modules were calculated. The yearly output of South-oriented, 30°-inclined modules was found to be 459 and 299 kWh/(m^{2}cell area). For sun-tracked modules, the annual output amounts to 636 and 405 kWh/ (m^{2}cell area). Due to the high efficiency of SunPower's SPR-90 module, the module area required for 1 kW$_{STC}$ is only 5.9 m^2, whereas it turns out to be 9.7 m^2 for the 12.7 % efficient Kyocera module.

Einleitung / Projektziele

Herstellerangaben zu kommerziell erhältlichen PV-Modulen reichen nicht aus für die optimale Modulwahl, weil sich die Angaben auf Testbedingungen (Standard Test Conditions, STC) beziehen, welche beim praktischen Betrieb der Module nie auftreten [1, 2]. Ziel des Projekts ist deshalb, Grundlagen für die optimale Wahl von PV-Modulen zu erarbeiten und bereit zu stellen, welche es ermöglichen, die verschiedenen Modul-Typen wirtschaftlich optimal in PV-Anlagen einzusetzen. Dazu sollen ausgewählte Module unter realen Betriebsbedingungen experimentell untersucht und die Messergebnisse in Form semi-empirischer Modelle dargestellt werden. Mit standortspezifischen Meteodaten führen die Modelle zur genauen Ermittlung der Jahreserträge und damit zur wirtschaftlich optimalen Modulwahl für vorgegebene Standorte. Die wissenschaftliche Zielsetzung besteht im Verständnis der klimatischen Einflüsse auf die Leistungsfähigkeit von Modulen.

Versuchsanlage / Messmethode

Die Versuchsanlage besteht aus einer Sonnennachführvorrichtung (parallaktische Montierung), Abbildung 1 und einer computergestützten Messeinrichtung, beides am PSI entwickelt [3]. Mit der Nachführvorrichtung (Sun tracker) werden Testmodule kontinuierlich zur Sonne ausgerichtet. Die Messeinrichtung dient der genauen Erfassung von Strom/Spannungs(I/U)-Kennlinien, woraus der Wirkungsgrad η der Module bestimmt wird. Erfahrungsgemäss hängt der Wirkungsgrad von verschiedenen Einflussgrössen ab, wie von der Einstrahlungsintensität G, der Zellentemperatur ϑ, der relative atmosphärische Luftmasse AM usw. Deshalb soll er über weite Bereiche der Intensität, Temperatur und Luftmasse ausgemessen und in Abhängigkeit dieser Einflussgrössen modellmässig dargestellt werden.

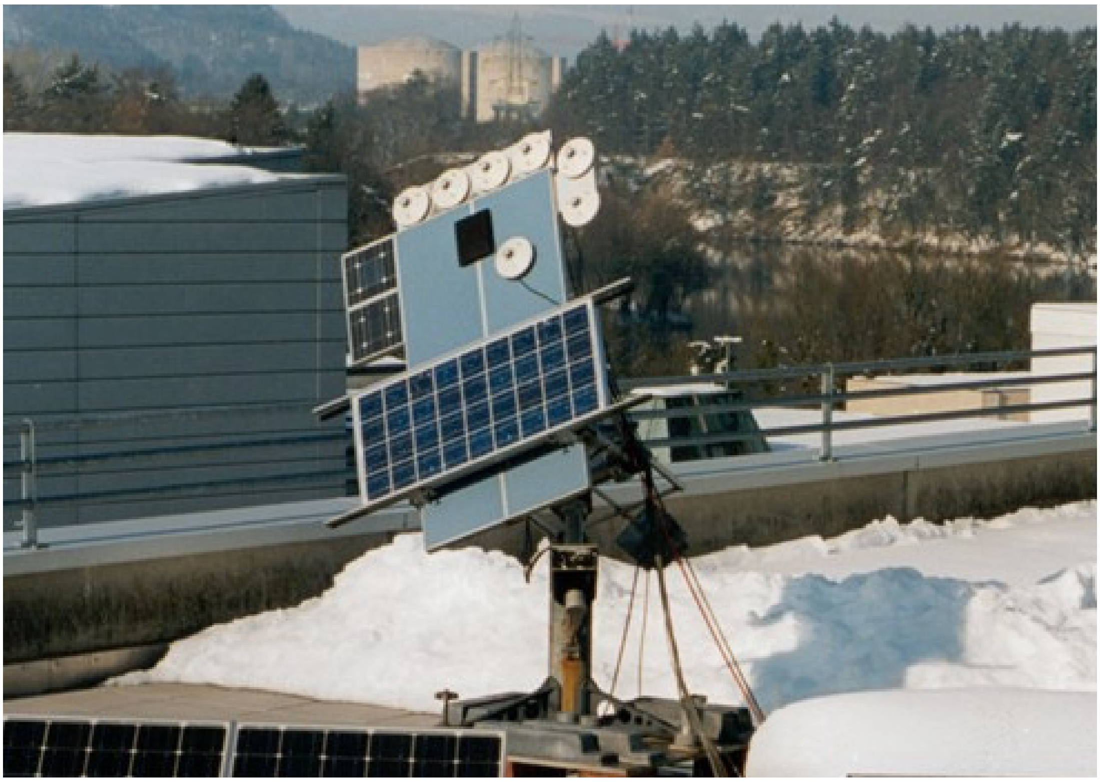

Abb. 1: Freiland-Testanlage des PSI zur Messung des Wirkungsgrades von Modulen. Die zu testenden Module werden auf einem Sun tracker befestigt. Während einer Wirkungsgrad-Messreihe richtet der Tracker die Testmodule kontinuierlich zur Sonne aus. Zur genauen Messung der Einstrahlung auf die Module dienen Pyranometer und Referenzzellen (oben am Sun tracker montiert). Die Signale werden ins nahe gelegene Labor geleitet, wo sie gemessen, verarbeitet und gespeichert werden.

Neben dem Modulstrom I, der Modulspannung U, globalen Einstrahlung G und der Zellen-Temperatur ϑ werden auch die Umgebungstemperatur ϑ_u, die Windgeschwindigkeit v und die direkt-normale Einstrahlung I_n gemessen. Zu jeder I/U-Kennlinienmessung wird die relative Luftmasse AM aus der Sonnenelevation nach den bekannten astronomischen Gesetzen berechnet. Jeder I/U-Test führt zu einem Datensatz bestehend aus η, G, ϑ und AM. Zur Entwicklung geeigneter, benutzerfreundlicher Wirkungsgrad-Modelle der Form $\eta = f(G, \vartheta, AM)$ sind einige Hundert bis einige Tausend I/U-Tests unter verschiedensten Klimabedingungen erforderlich. Eine neu entwickelte, programmierbare Steuerung führt bei ausgewählten Wettersituationen im Minutentakt automatisch Kennlinien-Messungen durch. Das Messsystem ist in Abb. 2 dargestellt.

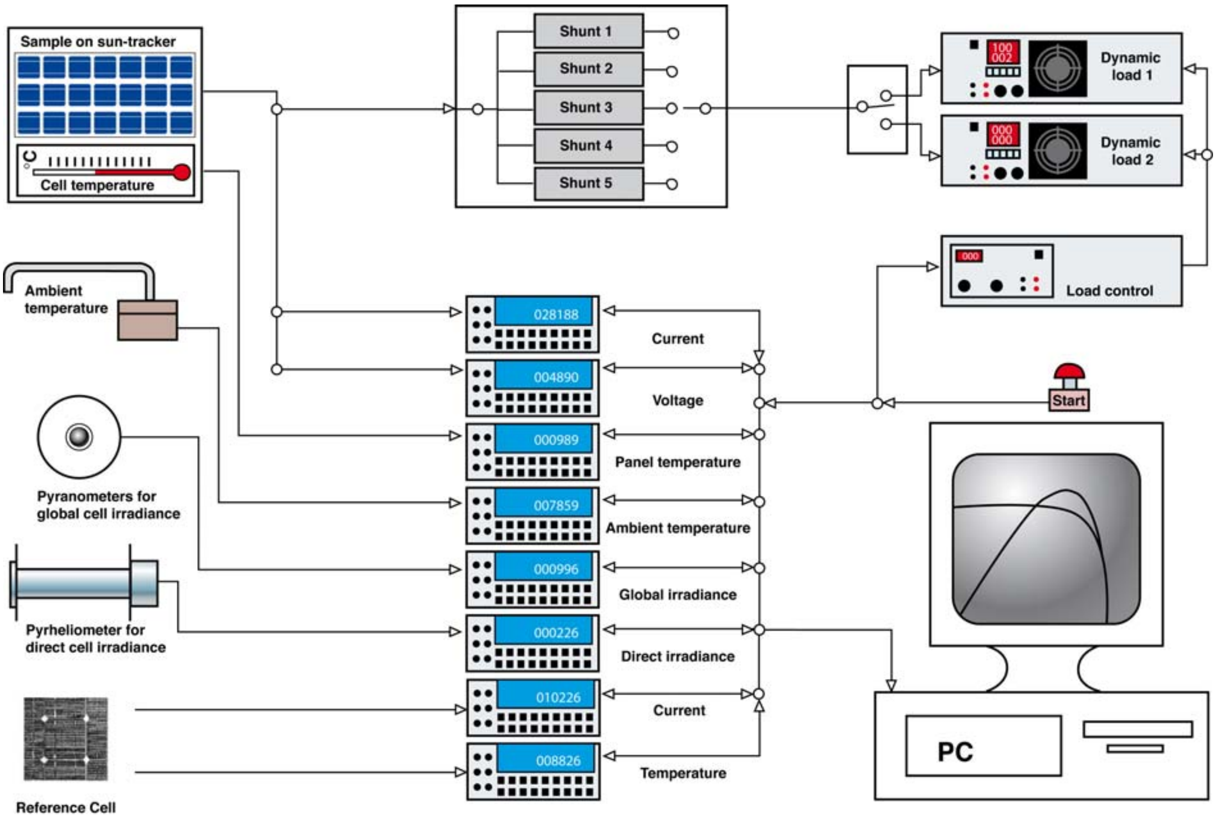

Abb. 2: Mess- und Datenerfassungssystem zur Aufnahme von Strom/Spannungs-Kennlinien von Solarzellen und Modulen. Die Prüflinge werden an elektronisch gesteuerte dynamische Lasten angeschlossen und nach einem vorgegebenen Programm belastet. Während der sich ändernden Belastung werden Strom und Spannung mit hoher Genauigkeit und zeitlicher Auflösung gemessen und an den PC übertragen. Zur Messung der auf die Solarzellen und Module auftreffenden Solarstrahlung werden Pyranometer, Pyrheliometer und Referenzzellen verwendet.

Das Messsystem besteht aus dynamischen Lasten (Höcherl&Hackl), elektronischer Lastansteuerung (PSI-Entwicklung), hochgenauen Multimetern (Fluke und Prema) und einem PC, welcher über eine IEEE-Schnittstelle mit den Multimetern verbunden ist. Zur Messung des Zellen- bzw. Modulstroms werden Präzisionswiderstände (Burster) mit sehr niedrigen Temperaturkoeffizienten verwendet. Auf der Rückseite der Zellen bzw. Module werden spezielle Pt-100-Oberflächenfühler (Rosemount) angebracht, um die Zellen- bzw. die Modultemperatur zu messen. Die solare Einstrahlung auf die Zellen und Module wird mittels geeichter Pyranometer (Kipp & Zonen), Pyrheliometer (Eppley) und Referenzzellen (Siemens) gemessen. Die Aufnahme einer Kennlinie dauert 5 bis 25 Sekunden, je nach Wahl der Parameter an der Lastansteuerung. Während dieser Zeit werden rund 100 bis 500 Strom/Spannugs-Wertepaare gemessen und auf den PC übertragen. Dort wird mit dem Programm SolCell eine Teilauswertung durchgeführt, und die wichtigsten Ergebnisse werden unmittelbar nach jedem I/U-Test auf dem Bildschirm angezeigt, Abbildungen 3 und 4.

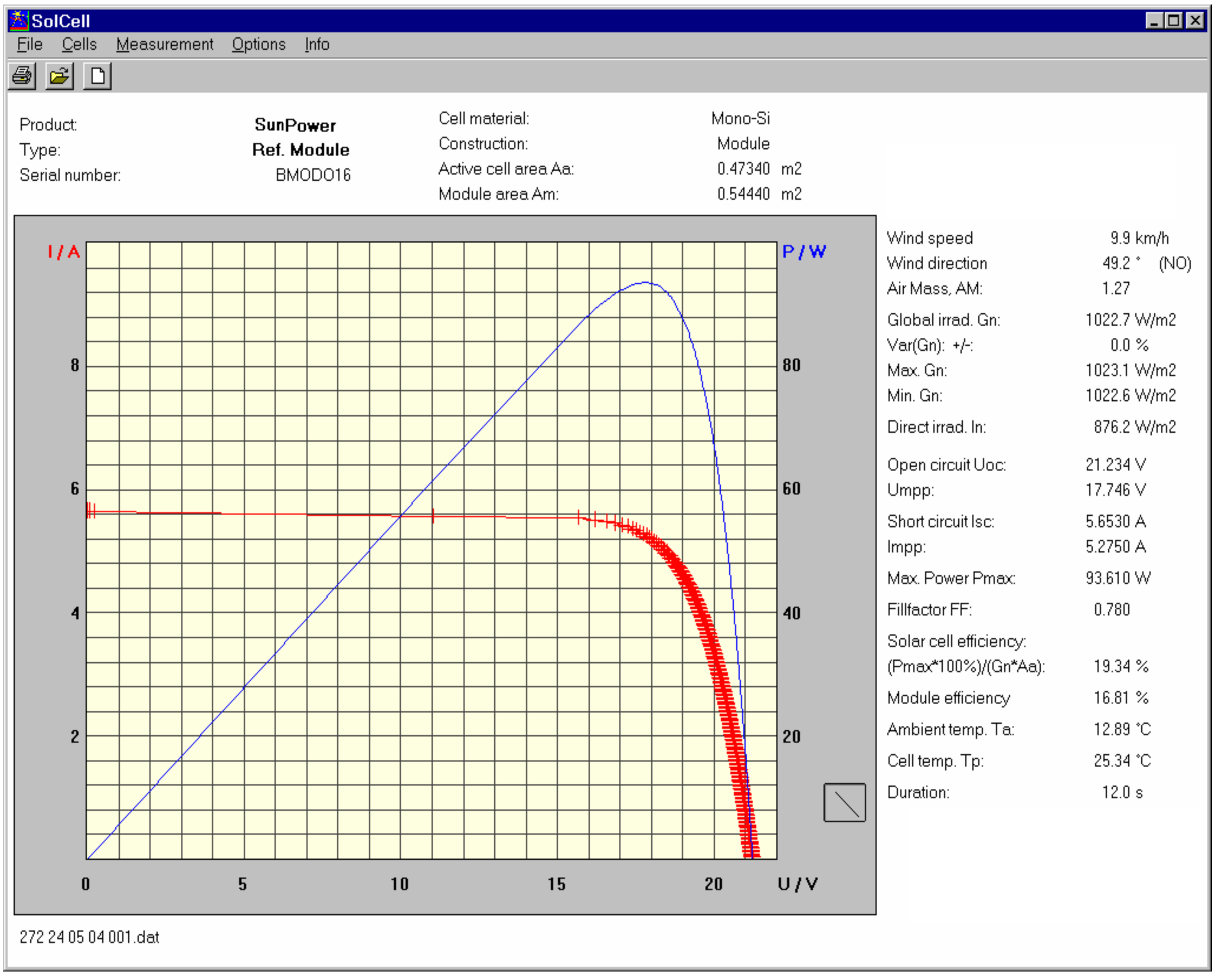

Abb. 3: Wichtigste Ergebnisse eines online ausgewerteten I/U-Tests an einem SunPower-Modul.

In Abb. 3 sind die gemessenen Strom/Spannungs-Wertepaare als Kreuzchen dargestellt. Daraus wird die Leistungs/Spannungs-Kurve berechnet, gemäss P = IU. Das Programm SolCell ermittelt daraus das Leistungsmaximum P_{max}, welches zur Bestimmung des Wirkungsgrades benötigt wird. Der Test wurde bei einer Einstrahlung von 1023 W/m^2, einer Zellentemperatur von rund 25°C und einer relativen Luftmasse von 1.3 durchgeführt, also bei nahezu Standard-Testbedingungen, STC. Unter diesen Bedingungen beträgt der Zellenwirkungsgrad 19.3%. Im Vergleich zu andern heutigen Modulen ist dies ein hervorragender Wert. Weitere Kenngrössen, wie Windgeschwindigkeit, Windrichtung, Direktnormale Einstrahlung, Leerlaufspannung, Kurzschlussstrom, Füllfaktor, Modul-Wirkungsgrad und Umgebungstemperatur werden ebenfalls gemessen bzw. bestimmt und rechts vom Kennliniendiagramm angezeigt. Die Kennlinie in Abb. 3 wurde zu Beginn einer Messreihe zur Bestimmung des Temperaturkoeffizienten des Wirkungsgrades aufgenommen. Dabei werden Wirkungsgrade bei konstanter Einstrahlung und Luftmasse, jedoch variierender Zellentemperatur gemessen. Variierende Zellentemperatur erhält man während des Aufwärmvorganges an der prallen Sonne nach Abdecken des auf dem Sun tracker befestigten Moduls.

In Abb.4 sind die wichtigsten Ergebnisse einer Kennlinienmessung an einem älteren Kyocera-Modul dargestellt. Der Test wurde bei einer Einstrahlung von 999 W/m^2, einer Zellentemperatur von 36.4°C und einer relativen Luftmasse von 2.8 durchgeführt Der dabei erhaltene Zellenwirkungsgrad von 12.6% ist im Vergleich zu andern heutigen Modulen relativ bescheiden.

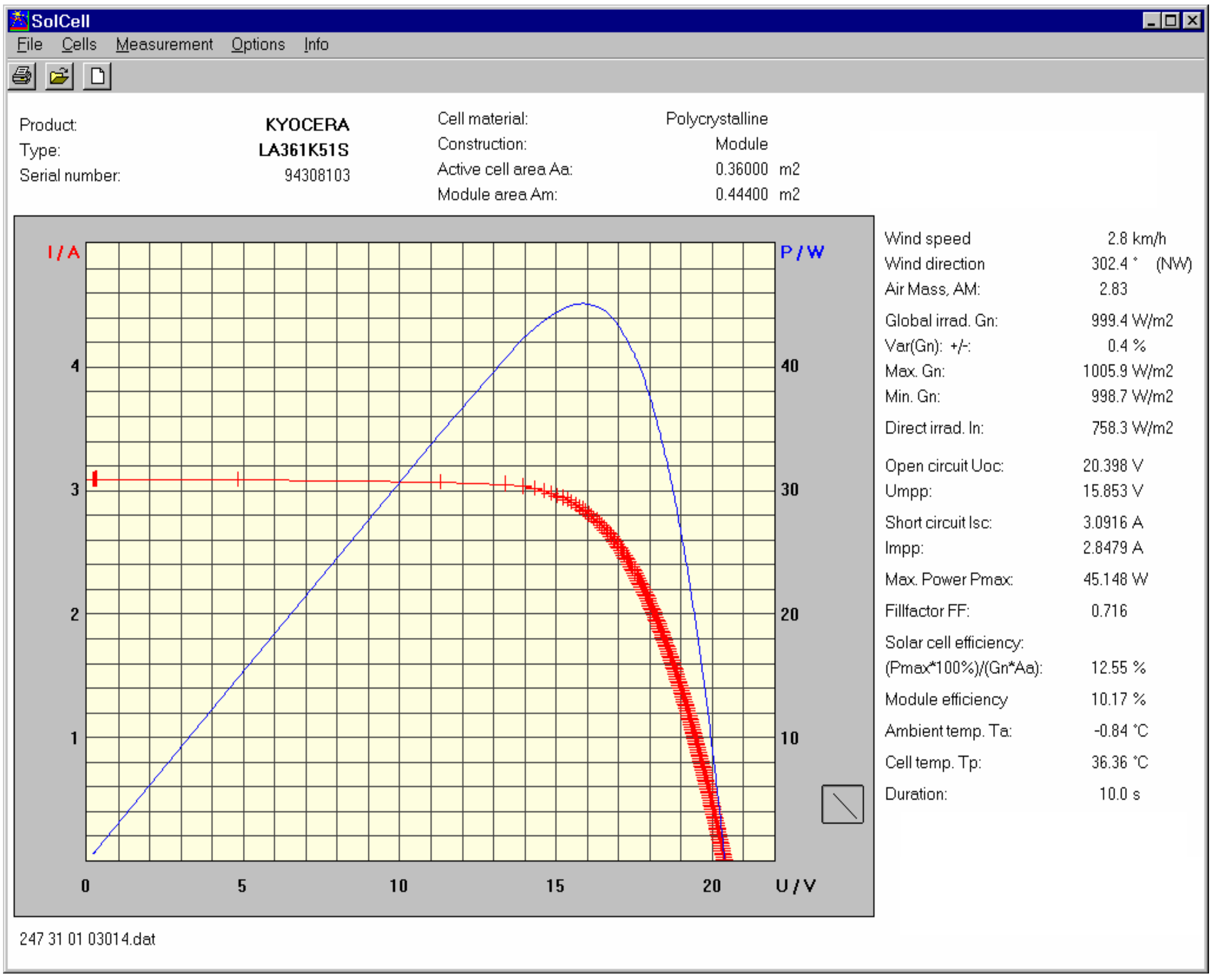

Abb. 4: Wichtigste Ergebnisse eines online ausgewerteten I/U-Tests an einem älteren Kyocera Modul.

Sämtliche Daten eines I/U-Tests Tests werden auf der Harddisk gespeichert bzw. in eine Datenbank (Access) abgelegt für spätere Auswertungen.

In den Abb. 3 und 4 ist die globale Einstrahlung in die sonnennachgeführte Modulebene mit G_n bezeichnet. Im Folgenden wird der Einfachheit halber G an Stelle von G_n verwendet.

Wirkungsgradmodell / Ergebnisse

Gestützt auf umfangreiche Wirkungsgradmessungen bei variierender Einstrahlung G, Temperatur ϑ und relativer Luftmasse AM an den beiden oben erwähnten Modulen wurden mehrere Wirkungsgrad-Modelle entwickelt und auf ihre Tauglichkeit hin untersucht. Als bestgeeignetes Modell hat sich folgende semi-empirische Beziehung ergeben:

$$\eta = p[qG/G_o + (G/G_o)^m][1 + r\vartheta/\vartheta_o + sAM/AM_o + (AM/AM_o)^u] \qquad (1)$$

$$\text{mit} \quad G_o = 1000 \text{ Wm}^{-2} \qquad \vartheta_o = 25\ °\text{C} \qquad AM_o = 1.5$$

Das Modell berücksichtigt, dass der Wirkungsgrad bei verschwindender Einstrahlung gleich Null wird, ebenso, dass der Wirkungsgrad mit abnehmender Temperatur in guter Näherung linear abnimmt, bei konstanter Einstrahlung und konstanter Luftmasse. Zudem berücksichtigt es die ebenfalls empirisch gefundene nichtlineare Abhängigkeit des Wirkungsgrades von der Luftmasse. Die Parameter p, q, m, r, s und u in der Beziehung (1) werden aus einer Vielzahl gemessener Datensätze (η, G, ϑ und AM) via nichtlinearer Ausgleichsrechnung nach der Methode der kleinsten Fehlerquadratsumme bestimmt. Für die in dieser Arbeit ausgemessenen Module sind die Parameter in Tabelle 1 aufgelistet [5, 6].

Modul	Hersteller	p	q	m	r	s	u
SPR-90, mc-Si	SunPower	22.07	-0.1065	0.06510	-0.08078	-0.9300	0.9698
LA361K51S, p-Si	Kyocera	15.39	-0.1770	0.07942	-0.09736	-0.8998	0.9324

Tabelle 1: Modellparameter eines SunPower- bzw. Kyocera-Moduls.

Aus Gleichung (1) ergeben sich der Wirkungsgrad, sein Temperaturkoeffizient und die Modul-Leistung bei STC, d.h. $G = G_o$, $\vartheta = \vartheta_o$ und $AM = AM_o$ wie folgt:

$$\eta_{STC} = p(q + 1)(2 + r + s) \qquad (2)$$

$$\alpha_{STC} = (\partial\eta/\partial\vartheta)_{STC} = p(q + 1)r/\vartheta_o \qquad (3)$$

$$P_{STC} = \eta_{STC} G_{no} A_a \qquad (4)$$

Die so ermittelten Grössen sowie die relativen Abweichungen der gemäss Gleichung (4) berechneten Modulleistungen von den von den Herstellern angegebenen Leistungen sind in der folgenden Tabelle wiedergegeben.

Modul		**SPR-90**	**LA361K51S**
Hersteller		**SunPower**	**Kyocera**
Zellenwirkungsgrad η_{STC}, diese Arbeit	%	19.5	12.7
Zellenwirkungsgrad $\eta_{STC,p}$, Hersteller	%	19.0	14.2
Temperaturkoeffizient α_{STC}, diese Arbeit	%/°C	-0.064	-0.049
Modulleistung P_{STC}, diese Arbeit	W	92.3	45.7
Modulleistung $P_{STC,p}$, Hersteller	W	90	51
Relative Abweichung der Modulleistung	%	+2.6	-10.4
Ross- Koeffizient h	°C/(Wm^{-2})	0.029	0.026
Aktive Zellenfläche A_a	m^2	0.4734	0.3600
Modulfläche A_m	m^2	0.5444	0.4440

Tabelle 2: STC-Wirkungsgrad, Temperaturkoeffizient und effektiv gemessene Modulleistung im Vergleich mit den Herstellerangaben. Mitaufgeführt sind auch die aktive Zellenfläche, die Modulfläche und der Ross-Koeffizient, der später benötigt wird. Der Temperaturkoeffizient ist in absoluten Prozentpunkten pro Grad Celsius Temperaturerhöhung angegeben.

Aus Tabelle 2 geht hervor, dass das 2004 eingeführte SPR-90-Modul von SunPower einen hervorragenden STC-Wirkungsgrad aufweist. Dieser wird unter anderem ermöglicht durch eine einzigartige Rückseiten-Kontaktierung, welche die aktive Zellenfläche maximiert. Die gemessene STC-Modulleistung übertrifft die Herstellerangaben um 2.6 %. Beim Kyocera-Modul handelt es sich um ein Modul, welches 1993 auf den Markt kam. Sein Wirkungsgrad ist relativ bescheiden. Für die damalige Zeit war dies für polykristalline Module jedoch ein sehr guter Wert. Wie damals ebenfalls üblich, lag die gemessene Modulleistung 5 bis 10% unter den Herstellerangaben. Ein weiterer Grund für den tiefen Wirkungsgrad könnte eine leichte Degradation während der vergangenen 13 Jahre sein.
Wirkungsgradmessungen an neuesten polykristallinen Modulen von Kyocera mit neuer fortschrittlicher Texturierung der Frontfläche (bessere Lichtabsorption) führen zu Werten um 14%, vgl.: http://grid-pv.web.psi.ch/. Für p-Si-Module ist das ebenfalls ein hervorragender Wert.

Vergleich Modell / Messungen

Durch die Anwendung mathematischer Transformationen [7] können die gemessenen Wirkungsgrade mit dem Wirkungsgradmodell (1) in zweidimensionalen Darstellungen visualisiert, verglichen und die klimatischen Einflüsse auf den Wirkungsgrad dargestellt werden, Abb. 5, 6 und 7.

Aus dem Modell (1) ergibt sich der Wirkungsgrad bei konstanter Zellentemperatur $\vartheta = \vartheta_o = 25°C$ und konstanter Luftmasse $AM = AM_o = 1.5$ zu

$$\eta_{25,1.5} = p[qG_n/G_{no} + (G_n/G_{no})^m](2 + r + s) \quad (5)$$

Bei konstanter Einstrahlung $G = G_o = 1000 W/m^2$ und konstanter Luftmasse $AM = AM_o = 1.5$ gilt

$$\eta_{1000,1.5} = p(q + 1)(2 + s + r\vartheta/\vartheta_o) \quad (6)$$

Analog findet man für konstante Einstrahlung $G = G_o = 1000 W/m^2$ und konstante Zellentemperatur $\vartheta = \vartheta_o = 25°C$

$$\eta_{1000,25} = p(q + 1)[1 + r + sAM/AM_o + (AM/AM_o)^u] \quad (7)$$

Die Gleichungen (5) bis (7) werden benutzt, um in den folgenden Abbildungen die Wirkungsgrad-verläufe gemäss Modell (1) zu berechnen.

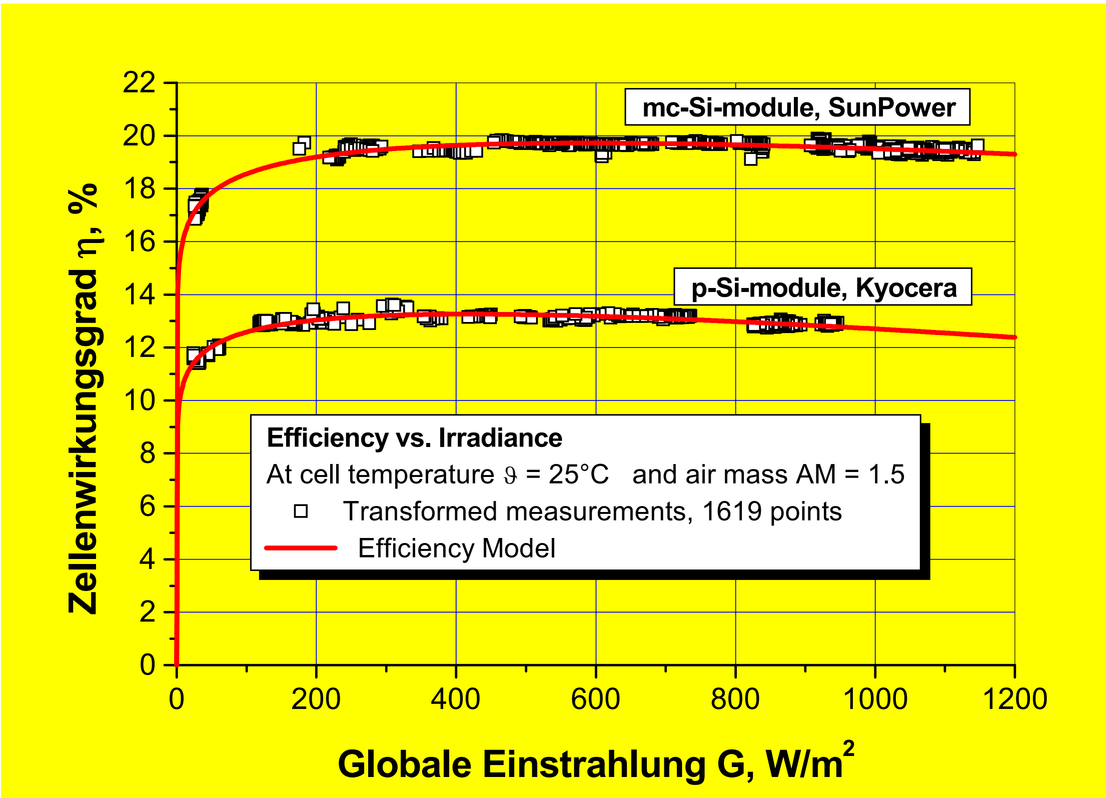

Abb. 5: Abhängigkeit des Wirkungsgrades von der Einstrahlungsintensität, bei konstanter Zellentemperatur und konstanter Luftmasse, für zwei verschiedene Modultechnologien.

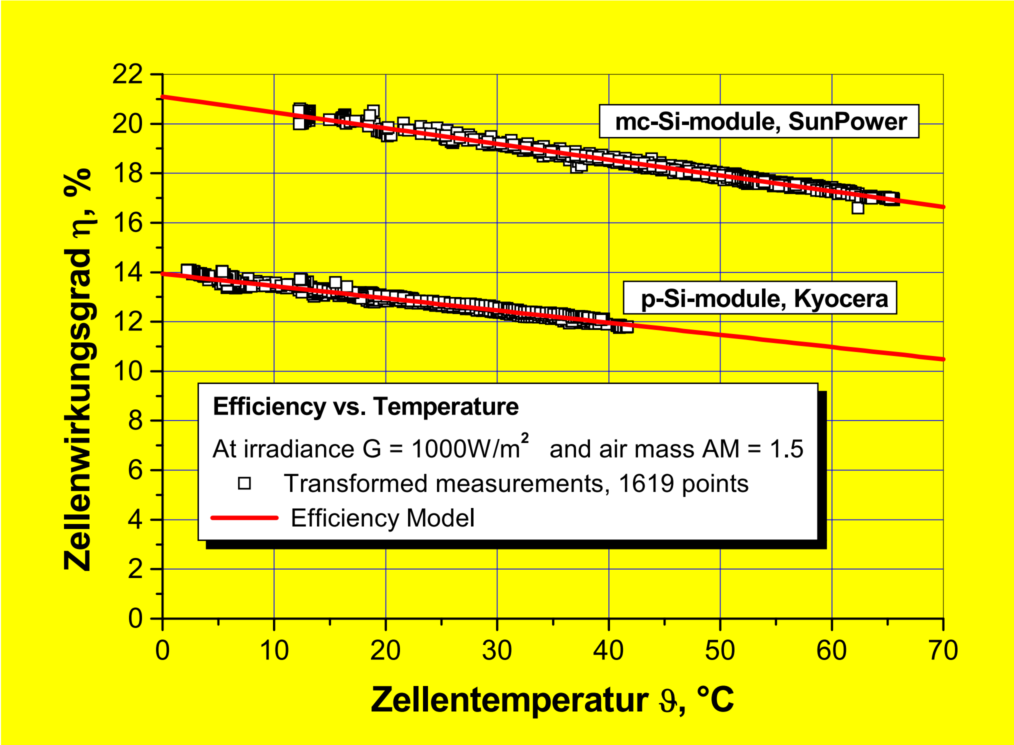

Abb. 6: Abhängigkeit des Wirkungsgrades von der Zellentemperatur, bei konstanter Einstrahlung und konstanter Luftmasse, für zwei verschiedene Modultechnologien.

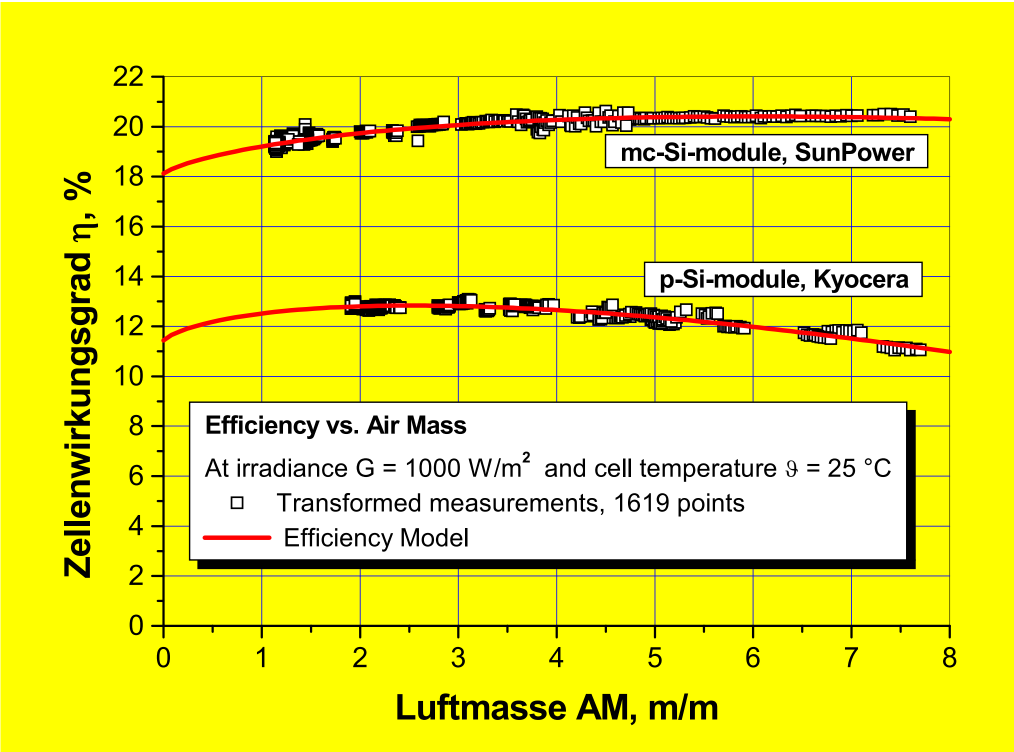

Abb. 7: Abhängigkeit des Wirkungsgrades von der Luftmasse, bei konstanter Einstrahlung und konstanter Temperatur für zwei verschiedene Modultechnologien.

Das mc-Si-Modul von SunPower zeigt einen hervorragenden Wirkungsgradverlauf über nahezu den gesamten Einstrahlungsbereich, Abb. 5. Bei einer Einstrahlung von 591 W/m^2 weist der Wirkungsgrad ein Maximum von 19.7% auf. Selbst bei der relativ tiefen Einstrahlung von 100 W/m^2 beträgt der Wirkungsgrad noch 18.6 %. Wie bei Modulen mit monokristallinen Zellen üblich, sinkt der Wirkungsgrad mit zunehmender Zellentemperatur vergleichsweise stark, Abb. 6. Sie eignen sich deshalb vor allem für alpine Anwendungen und weniger für heisse Wüstengebiete. Abb. 7 zeigt, dass der Wirkungsgrad auch bezüglich Luftmasse einen hervorragenden Verlauf aufweist. Im Gegensatz zu anderen Modultypen, bei welchen der Wirkungsgrad mit zunehmender Luftmasse abnimmt, Abb. 8, steigt er beim SunPower-Modul sogar leicht an, was auf eine gute Anpassung seiner Empfindlichkeit auf das rotverschobene Sonnenspektrum am früheren Vormittag und späteren Nachmittag hindeutet.

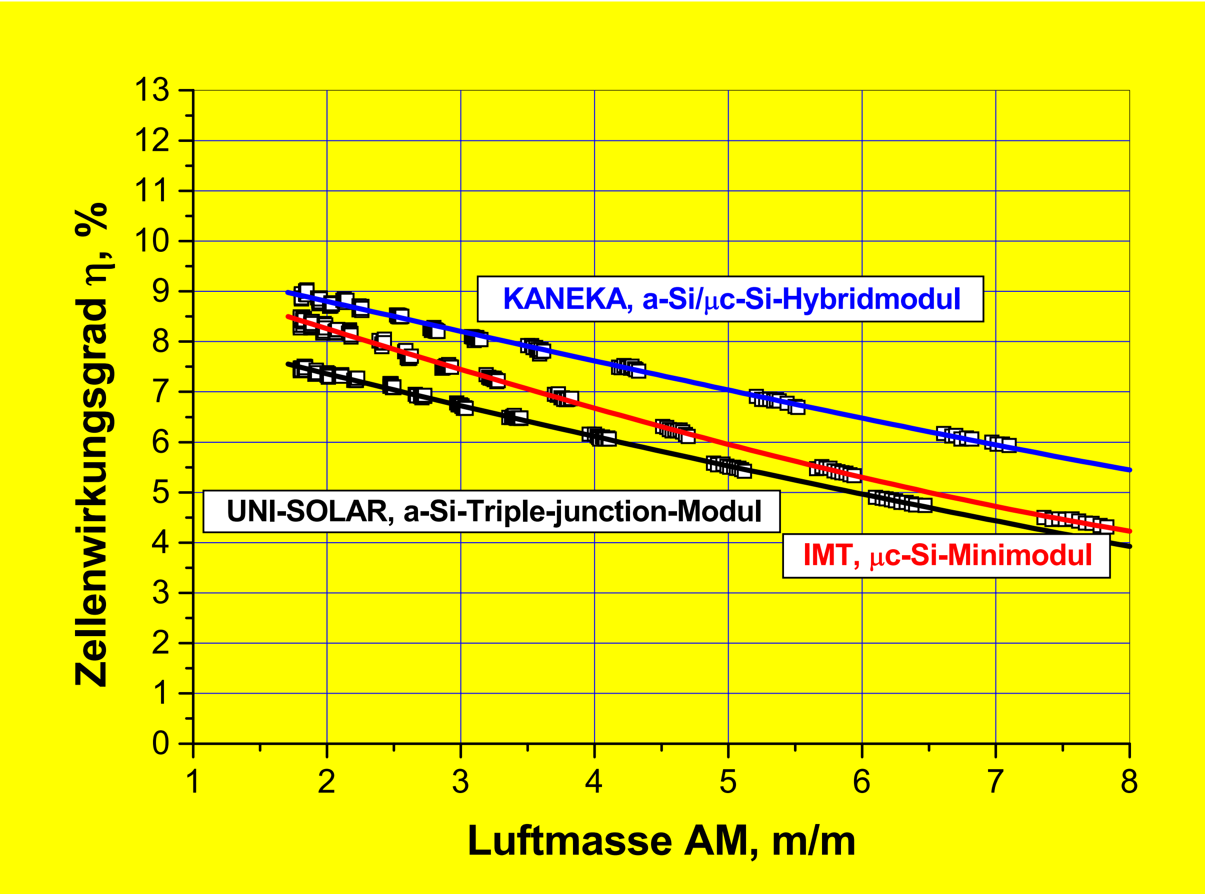

Abb. 8: Abhängigkeit des Wirkungsgrades von der Luftmasse für drei verschiedene Modultechnologien [8]. Die Messreihen wurden um die Mittagszeit gestartet und bei Sonnenuntergang beendet. Während dieser Zeit hat die Luftmasse zu-, die Einstrahlungsintensität und die Zellentemperatur abgenommen.

Auch das Kyocera-Modul weist einen sehr schönen Verlauf des Wirkungsgrades über der Einstrahlung auf, Abb. 5. Der maximale Wirkungsgrad von 13.3 % wird bei einer Einstrahlung von 419 W/m^2 erreicht. Bei der relativ tiefen Einstrahlung von 100 W/m^2 beträgt der Wirkungsgrad immer noch 12.6 %. Auch beim p-Si-Modul von Kyocera nimmt der Wirkungsgrad mit zunehmender Zellentemperatur ab, Abb. 6. Allerdings etwas weniger stark als beim SunPower-Modul. Der Wirkungsgrad des Kyocera-Moduls weist ebenfalls ein recht gutes Verhalten bezüglich variierender Luftmasse auf, Abb. 7. Im Gegensatz zum SunPower-Modul, bei dem der Wirkungsgrad mit der Luftmasse leicht zunimmt, weist das Kyocera-Modul einen maximalen Wirkungsgrad von 12.8 % bei einer relativen Luftmasse von 2.55 auf und sinkt danach leicht ab.

All diese Fakten sind jedoch lediglich einzelne Indikatoren. Worauf es letztlich ankommt, sind die Jahreserträge der verschiedenen Module an ausgewählten Standorten, bzw. die mit ihnen erzielten spezifischen Stromgestehungskosten. Für die zwei oben modellierten Module wurden die Jahreserträge für einen sonnigen Standort in Jordanien berechnet. Dies als Voraussetzung zur Durchführung von Wirtschaftlichkeitsbetrachtungen.

Jahresertrag

Aus der solaren Einstrahlung auf die Module und ihrem Wirkungsgrad gemäss Modell (1) lässt sich die Modulleistung zu jedem Zeitpunkt berechnen, falls zeitlich gut aufgelöste Einstrahlungsdaten vorhanden sind. Daraus lassen sich die inkrementalen Erträge bestimmen, welche aufsummiert zu den Monatserträgen und schliesslich zum Jahresertrag führen. Letzterer ist erforderlich zur Berechnung der spezifischen Stromgestehungskosten. In vereinfachter Form ist die Anwendung dieser Methode in der folgenden Abb. 9 dargestellt.

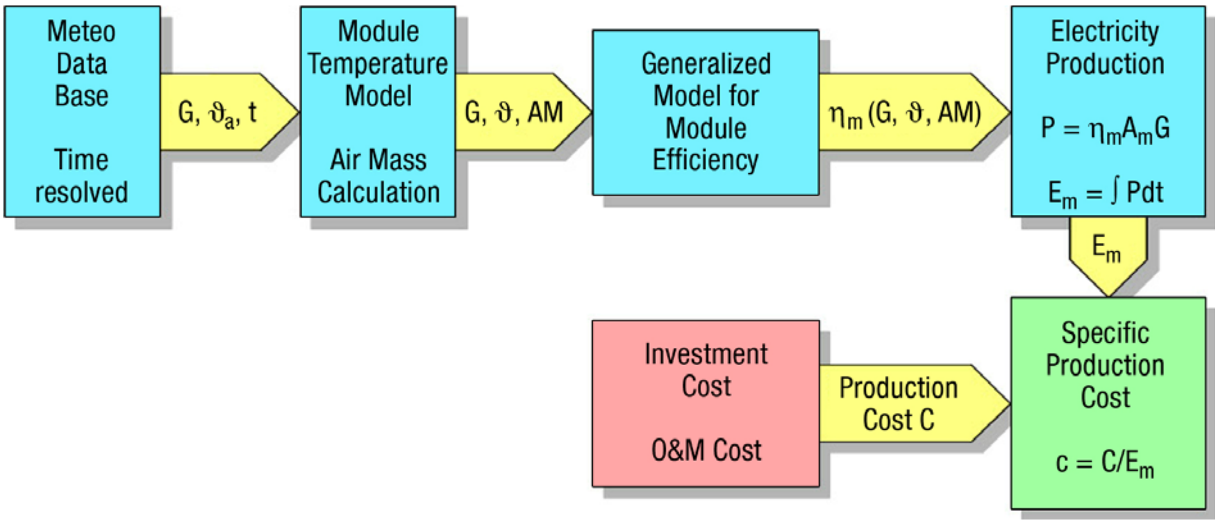

Abb. 9: Methode zur Berechnung des Jahresertrags von Modulen und der spezifischen Stromgestehungskosten. Es bedeuten:

G	Globale Einstrahlung in die Modulebene, W/m^2
ϑ_a	Umgebungstemperatur, °C
t	Zeit, s.
ϑ	Zellentemperatur, °C
AM	Relative Luftmasse, m/m
η_m	Modulwirkungsgrad, W/W
A_m	Modulfläche, m^2
P	Modul-Leistung, W
E_m	Jährliche Stromproduktion, kWh
C	Jährliche Produktionskosten, Fr
c	Spezifische Stromgestehungskosten, Fr/kWh

Der Rechengang zu Abb.9 läuft wie folgt ab: Zunächst wird aus der Umgebungstemperatur ϑ_a, der Einstrahlung G und dem experimentell bestimmten Ross-Koeffizient h, vgl. Tabelle 2 und [10], die Zellentemperatur zur Zeit t berechnet

$$\vartheta = \vartheta_a + hG \qquad (8)$$

Aus der bei der Zeit t erreichten Sonnenhöhe γ wird nun die relative atmosphärische Luftmasse AM bestimmt gemäss

$$AM = 1/\cos(90° - \gamma) \qquad (9)$$

Die Sonnenhöhe γ zur Zeit t wird aus bekannten astronomischen Beziehungen ermittelt.

Nun sind die unabhängigen Variablen G, ϑ und AM bekannt, und es kann aus dem Modell (1) und den dazugehörigen modulspezifischen Parameter p, q, m, r, s und u (vgl. Tab. 1) der Zellenwirkungsgrad berechnet werden

$$\eta = p[qG/G_o + (G/G_o)^m][1+ r\vartheta/\vartheta_o + sAM/AM_o + (AM/AM_o)^u] \qquad (10)$$

$$\text{mit } G_o = 1000 \text{ Wm}^{-2} \quad \vartheta_o = 25 \text{ °C} \quad AM_o = 1.5$$

Für den Modulwirkungsgrad η_m gilt

$$\eta_m = \eta A_a/A_m \qquad (11)$$

Der inkrementale Modulertrag während der Zeit Δt_k zur Zeit t_k ergibt sich nun zu

$$\Delta E_{mk} = \eta_{m,k} \cdot A_m \cdot G_k \cdot \Delta t_k \qquad (12)$$

Die Summation dieser Erträge führt schliesslich zum Jahresertrag E_m des betrachteten Moduls

$$E_m = \sum \eta_m(G_k, \vartheta_k, AM_k) \cdot A_m \cdot G_k \cdot \Delta t_k \qquad (13)$$

Nach dieser Methode sind für die beiden oben erwähnten Module von SunPower und Kyocera die Jahreserträge an einem sonnigen Standort im Süden Jordaniens (Al Quawairah) ermittelt worden. Dort sind seinerzeit vom PSI Einstrahlungsdaten mit guter zeitlicher Auflösung (5-Min.-Mittelwerte) erhoben worden [9]. Die Berechnungen wurden für fix-installierte (Orientierung nach Süden, Anstellwinkel 30°) und sonnennachgeführte Module durchgeführt. Die Ergebnisse sind in den folgenden Tabellen 3 und 4 wiedergegeben.

		SPR-90	LA361K51S
Einstrahlung $G_{Süden,30°}$	$kWh/(m^2a)$	2523	2523
E_m, jährlicher Modulertrag	kWh/a	217.3	107.5
$E_{m,p} = \eta_{STC,p}\ G_{Süden,30°} A_a$	kWh_p /a	226.9	129.0
$(E_{m,p} - E_m)/E_m$	%	4.4	20
E_m/A_a	$kWh/(m^2a)$	459	299
E_m/A_m	$kWh/(m^2a)$	399	242
E_m/P_{STC}	$kWh/(kW_{STC}a)$	2354	2352
Jahresmittelwert Zellenwirkungsgrad	%	18.2	11.8
Jahresmittelwert Modulwirkungsgrad	%	15.8	9.6
Erforderliche Modulfläche für $1kW_{STC}$	m^2	5.9	9.7

Tabelle 3: Einstrahlung, Modulertrag und Wirkungsgrad zweier Module von SunPower (SPR-90) und Kyocera (LA361K51S) bei Südausrichtung und Anstellwinkel von 30°. Der Index p kennzeichnet die Produzentenangaben. A_a und A_m sind die aktive Zellen- bzw. Modulfläche. In der letzten Zeile ist die Modulfläche angegeben, die zur Produktion einer elektrischen Leistung von einem kW erforderlich ist, bei einer Einstrahlung von $1kW/m^2$, einer Zellentemperatur von 25°C und einer relativen Luftmasse von 1.5.

		SPR-90	LA361K51S
Einstrahlung G_n	$kWh/(m^2a)$	3547	3547
E_m, jährlicher Modulertrag	kWh/a	301.1	145.8
$E_{m,p}=\eta_{STC,p}\ G_n A_a$	kWh_p /yr	319.0	181.3
$(E_{m,p}-E_m)/E_m$	%	5.9	24.4
E_m/A_a	$kWh/(m^2a)$	636	405
E_m/A_m	$kWh/(m^2a)$	553	328
E_m/P_{STC}	$kWh/(kW_{STC}a)$	3262	3190
Jahresmittelwert Zellenwirkungsgrad	%	17.9	11.4
Jahresmittelwert Modulwirkungsgrad	%	15.6	9.24
Mehrertrag geführte Zellen $(E_{m,s}-E_{m,i})/E_{m,i}$	%	39	36

Tabelle 4: Einstrahlung, Modulertrag und Wirkungsgrad zweier Module von SunPower (SPR-90) und Kyocera (LA361K51S) bei kontinuierlicher Sonnennachführung. Der Index p kennzeichnet die Produzentenangaben. A_a und A_m sind die aktive Zellen- bzw. Modulfläche. In der letzten Zeile ist der relative Mehrertrag der sonnennachgeführten gegenüber den fix-montierten (Süden, 30°) Modulen angegeben.

Gemäss Tabellen 3 und 4 führen die Herstellerangaben zur Überschätzung der Modulerträge im Bereich von 4 bis 24 %. Gründe dafür können zu hoch angegebene Wirkungsgrade sein sowie fehlende Angaben der Hersteller zum Klimaverhalten ihrer Module. Denn die üblicherweise angegebenen STC-Daten reichen nicht aus, um die klimatischen Einflüsse auf den Ertrag zu berücksichtigen. Zusätzliche Angaben, wie z.B. Parameter gemäss Tabbelle 1 und der Ross-Koeffizient wären hier dienlich und sollten von den Modulherstellern bei anerkannten neutralen Testlabors bestimmt werden lassen. Noch besser wären Ertragsgarantien für die jeweils gewählten Anlage-Standorte.

Aus den Tabellen 3 und 4 geht hervor, dass der Jahreswirkungsgrad sonnennachgeführter Zellen etwas niedriger ist als jener fix-montierter. Dies rührt daher, dass die geführten Zellen höherer Einstrahlungsintensität ausgesetzt sind und deshalb dauernd etwas wärmer als die fix-montierten sind, was zu einem leicht reduzierten Wirkungsgrad führt.

Wie für einen guten Standort in einem Sonnenland erwartet, liegen die leistungsbezogenen Jahreserträge in die geneigte südorientierte Fläche gut 2.5 mal höher als im Schweizer Mittelland. Nachführen der Module bringt einen Mehrertrag von 36 bis 39 %.

Nationale / internationale Zusammenarbeit

Die nationale Zusammenarbeit beschränkt sich auf Kontakte und Erfahrungsaustausch mit Hersteller und Vertreiber von Modulen und Wechselrichter sowie die Beratung bei den im ETH-Bereich realisierten PV-Anlagen (EAWAG, WSL und ETH Hönggerberg).

International erfolgte eine Zusammenarbeit mit dem Dept. of Architecture der University of Hong Kong, wo zu Vergleichszwecken analoge Messungen und Auswertungen durchgeführt werden wie am PSI.

Zudem pflegen wir innerhalb des EU-Projekts FULLSPECTRUM regen Austausch mit dem IOFFE-Institut, St. Petersburg, Russland (Charakterisierung von GaSb-Zellen), sowie mit dem IES-UPM, Madrid, Spanien (Kühltechnik für Konzentratorzellen).

Bewertung 2006 und Ausblick 2007

Aufgrund unserer Kompetenz in Photovoltaik und Thermophotovoltaik ist der Schreibende zum Mitglied des International Scientific Committee der 7th World TPV Conference (Thermo-photovoltaic Generation of Electricity), TPV7, Madrid, Spain, September 2006 ernannt worden (cf. http://www.ies.upm.es/tpv7/index.html).

Im Rahmen des vorliegenden Projekts sind noch ausstehende Messungen an einem mc-Si-Modul chinesischer Provenienz, nämlich dem JM-050W-S4C von Jumao Photonics durchzuführen und auszuwerten. Danach bleibt der Schlussbericht zu diesem Projekt zu erstellen.

Weiterführende Arbeiten wie oben beschrieben könnten interessant sein im CCEM-CH-Projekt „Cost Efficient Thin Film Photovoltaics for Future Electricity Generation“. Dies, sobald erste Prototyp-Zellen bzw. -Module verfügbar sind, deren Sensitivitäten auf Klimaeinflüsse untersucht werden können. Die daraus gewonnenen Erkenntnisse sollen helfen, neuartige Module zu entwickeln mit signifikant höheren spezifischen Jahreserträgen (kWh/m^2) und/oder massiv tieferen spezifischen Kosten (Fr/m^2) als herkömmliche Technologien.

Schliesslich sollen die hier dargestellten Mess- und Auswertemethoden einschlägigen Institutionen zur Verfügung gestellt werden.

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Auszeichnung

Die Veröffentlichung [4] und frühere Arbeiten des Schreibenden wurden am World Renewable Energy Congress VIII, September 2004, Denver, Colorado mit dem **Pioneer Award of the World Renewable Energy Network** ausgezeichnet.

PHOTOVOLTAIK SYSTEMTECHNIK 2005-2006

(PVSYSTE 05-06)

Annual Report 2006

Author and Co-Authors	H. Häberlin, L. Borgna, Ch. Geissbühler, M. Kämpfer, U. Zwahlen
Institution / Company	Berner Fachhochschule, Technik und Informatik, Burgdorf
Address	Jlcoweg 1, CH - 3400 Burgdorf
Telephone, E-mail, Homepage	+41 (0)34 426 68 11, heinrich.haeberlin@bfh.ch, www.pvtest.ch
Project- / Contract Number	100451 / 151395
Duration of the Project (from – to)	01.01.2005 – 31.12.2006 (full project period 01.01.03 - 31.12.06)
Date	6. December 2006

ABSTRACT

Purpose and Goals of the project during 2006

- Continuation of long-term monitoring of PV plants.
- Extended semi-automated tests of grid-connected PV inverters from different manufacturers
- Realisation of a second DC power supply of 800V / 40A – 80 A
- Ongoing participation in national network of competence BRENET (building & renewable energy network).

Most important results in 2006

- Inclusion of fault-current measurement procedures for single phase inverters without transformers according to new German standard VDE126-1-1 (2.2006).
- Realisation of a new interface for MPPT measurements, allowing measurement of I-V-curve of the PV-array simulator and MPPT-behaviour of the inverter with the very same equipment.
- A new DC generator 815 V / 88 A could be purchased with enough power for a new large PV array simulator of 60 kW to be built in 2007.
- Confidential (paid) tests of different inverters for major PV trading companies.
- Confidential tests of different MPP-Trackers for project Solarimpulse.
- Extended semi-automated tests performed at new inverters with new PV array simulator. In the same measurement run, DC-AC conversion efficiency, harmonic currents, power factor, static and dynamic maximum-power-point-tracking (MPPT) efficiency and total efficiency $\eta_{tot} = \eta \bullet \eta_{MPPT}$ vs. power can be determined.
- Inspection of DC-side of several older PV plants revealed different present and possible future problems in modules and wiring which might lead to electrical arcs.
- Arcs in connection boxes of PV modules of BP Solar reported in Photon 8/2006 showed again the potential (underestimated) danger of arcs on the DC side of PV plants. The arc detector developed already in the years 1993-1998 in common projects with Alpha Real AG was reactivated and improved by some new ideas. A patent for these new ideas was filed.
- Extension of pvtest.ch with normalized monthly statistics and various on-line representations.
- Extended test reports (in German) about inverters tested now available under www.pvtest.ch.
- 2 conference contributions at the 21st EU PV conf. in Dresden, 3 conference contributions at the 21st PV symposium at Staffelstein/D and 3 publications in professional journals.

Projektziele für 2006

- Fortführung des Langzeit-Monitorings an allen Anlagen des Projektes (mit kristallinen und Dünnschichtzellen-Modulen).
- Qualitätskontrolle der DC-Seite von verschiedenen älteren PV-Anlagen
- Erweiterung der Messdatendarstellung auf www.pvtest.ch durch Darstellung der in Burgdorf gemessenen Strahlungsdaten als Dienstleistung für PV-Anlagenbesitzer im Mittelland.
- Tests neuer auf dem CH-Markt vorhandener Netzverbund-Wechselrichter mit hohem Innovationsgehalt.
- Integration eines 2005 mit Schulmitteln beschafften, präziseren Leistungsmessgerätes, sowie des neuentwickelten MPP-Tracking Interfaces ins halbautomatische PV-Wechselrichter-Messsystem.
- Beschaffung einer zweiten vollwertigen DC-Speisung (800 V, 40 A - 80 A) für zweiten Messplatz.
- Mitarbeit im Nationalen Kompetenznetzwerk BRENET (Gebäudetechnik/ erneuerbare Energien).

Kurzbeschreibung der 2006 durchgeführten Arbeiten

Die 2005 entwickelte FI-Überwachungs-Prüfschaltung wurde an die neue Norm DIN VDE 0126-1-1 (Ausgabe 2.2006) angepasst. Damit konnte zu Jahresbeginn erstmals die FI-Überwachungseinheit eines trafolosen Wechselrichters (SolarMax 6000C) erfolgreich nach dieser Norm geprüft werden.

Zu Beginn des zweiten Quartals konnte das neuentwickelte MPPT-Interface mit integrierter Kennlinienmessung in den Wechselrichter-Messplatz eingebunden werden. Zusammen mit der Inbetriebnahme des hochpräzisen Leistungsmessgerätes WT3000 steht nun eine äusserst effiziente WR-Test-Infrastruktur zur Verfügung, mit der sich in einem Arbeitsgang Solargenerator-Kennlinie, DC-AC-Umwandlungswirkungsgrad, MPP-Trackingwirkungsgrad, Totaler Wirkungsgrad und Stromoberwellen bestimmen lassen.

Im Frühjahr 2006 wurde festgestellt, dass die bis zu diesem Zeitpunkt durchgeführten Tests des dynamischen MPP-Trackings von Wechselrichtern etwas zu streng waren (zu starke MPP-Spannungsvariation bei Einstrahlungs- bzw. Leistungsänderung). Durch eine Modifikation des Solargenerator-Simulators wurden die Tests deshalb etwas entschärft, so dass die auftretende Spannungsvariation nun für kristalline Module typisch ist. Damit die publizierten Testergebnisse möglichst fair und korrekt sind, mussten deshalb die noch zugänglichen Geräte nachgemessen werden und die bereits auf dem Internet publizierten WR-Testbereichte entsprechend überarbeitet werden.

Wie bereits im Vorjahr führte das PV-Labor etliche vertrauliche Tests an Netzwechselrichtern und anderen PV-Komponenten verschiedenster Hersteller durch. Da diese Tests voll bezahlt wurden, können ohne Erlaubnis der Auftraggeber keine Resultate publiziert werden. Dadurch konnten aber gewisse zusätzliche Einkünfte zur Erstreckung der Projektmittel und zur Verbesserung der Infrastruktur generiert werden. Aus solchen Mitteln konnte eine neue Motor-Generatorgruppe von 800 V / 88 A beschafft werden, die den 2007 zu bauenden Solargenerator-Simulator von 60 kW speisen wird.

Das Langzeit-Monitoring wurde auch in diesem Jahr erfolgreich weitergeführt. Die Messeinrichtungen wurden entsprechend gewartet und lieferten die gewünschten Messdaten. Bei der Meteomessung in Burgdorf wurde eine totale Erneuerung der Datenerfassung vorgenommen.

Die auch zum Langzeit-Monitoring gehörende Dünnschichtzellen-Anlage „Newtech“ wurde in diesem Jahr erneut zweimal (im Frühling und im Herbst) vor Ort mit dem Kennlinienmessgerät ausgemessen. Somit konnte das Degradations-Verhalten der Anlagen weiter beobachtet werden.

Die weitergeführte Ausfallstatistik der Wechselrichter zeigt im vergangenen Jahr wieder einen erfreulichen Tiefstand der registrierten Ausfälle.

Bei den Qualitätskontrollen der DC-Seite bei einigen Anlagen (mit der Thermografie-Kamera) wurden diverse Mängel festgestellt und an die Besitzer der Anlagen gemeldet. Verschiedene dieser Mängel könnten langfristig (besonders bei Versagen der Bypassdioden) auch zu Lichtbögen führen.

Im Laufe des Jahres wurde unsere Labor-Webseite (www.pvtest.ch) weiter ausgebaut. So sind nun von sämtlichen Feinmessanlagen neben den normierten Jahresstatistiken auch die normierten Monatsstatistiken verfügbar. Auch die Online-Darstellung aktueller Messwerte wurde noch ausgebaut.

Nach den in BP-Modulen aufgetretenen Lichtbögen (Photon 8/06) ist sich die PV-Branche der Gefahr durch DC-seitige Lichtbögen wieder vermehrt bewusst geworden. Deshalb wurden die 1993 – 1998 im Rahmen mehrerer Projekte (mit Alpha Real AG) entwickelten Lichtbogendetektoren wieder reaktiviert und einige neue Ideen entwickelt. Für diese neuen Ideen wurde ein Patentantrag eingereicht.

Das PV-Labor war auch 2006 weiterhin Mitglied im Nationalen Kompetenznetzwerk BRENET.

Durchgeführte Arbeiten und erreichte Ergebnisse

Wechselrichtertests

ÜBERBLICK ÜBER DIE IM RAHMEN DIESES PROJEKTES BISHER DURCHGEFÜHRTEN TESTS

Die unten stehende Tabelle enthält eine Zusammenstellung der wichtigsten Eigenschaften der getesteten Geräte. Die ausführlichen Wechselrichter-Testberichte sind auf dem Internet unter www.pvtest.ch > Wechselrichter-Testberichte allgemein verfügbar. Aus Platzgründen wird in diesem Beitrag auf die Darstellung detaillierter Testergebnisse bewusst verzichtet.

WR-Typ	Testjahr	S_N [kVA]	Transformator	MPP-Spannung [V]	η_{EU} [%]	η_{MPPT_EU} [%]	η_{tot_EU} [%]	Dyn. MPPT-Verhalten	Strom-Harm. (0.1–2kHz)	EMV AC	EMV DC	RSS-Empf.	Frequenz-Überwachung	Spannungs-Überwachung	Inselbetrieb
Sunways NT4000	04	3.3	TL	400 *480* 560	95.4 *94.9* 94.6	99.5 *99.0* 98.0	94.9 *94.0* 92.6	+	+	0	+	++	--	++	++
Fronius IG30	04	2.5	HF	170 *280* 350	91.0 *92.1* 91.6	99.8 *99.7* 99.5	90.8 *91.8* 91.2	0	++	+	+ [4]	+	++	+	+
Fronius IG40	04	3.5	HF	170 *280* 350	91.1 *92.5* 91.8	99.9 *99.6* 99.5	91.1 *92.2* 91.3	-	++	++	+ [4]	+	++	+	+
Sputnik SM2000E	05	1.8	TL	180 *300* 420	92.4 *93.4* 94.0	99.9 *99.7* 99.2	92.3 *93.1* 93.2	*0***	++	0 [1]	+ [4]	++	++	++	+
Sputnik SM3000E	05	2.5	TL	250 *330* 420	93.5 *94.0* 94.7	99.5 *99.4* 99.7	93.0 *93.4* 94.4	*0***	+	0 [1]	++	++	++	++	+
Sputnik SM6000E	05	5.1	TL	250 *330* 420	94.3 *94.8* 95.2	99.8 *99.9* 99.6	94.1 *94.6* 94.9	*0***	-	0 [1]	++	+ [3]	++	++	++
Sputnik SM6000C *	05	4.6	TL	250 *330* 420	94.3 *94.8* 95.3	99.9 *99.9* 99.5	94.2 *94.7* 94.8	+	+	0 [1]	++	+	++	+	+
Sputnik SM25C	05	25	NF	490 *560* 630	93.1 *93.1* 92.9	99.6 *99.5* 99.7	92.7 *92.6* 92.6	+	++	0 [1]	+ [6]	++	+ [7]	++	+ [8]
ASP TC Spark	05	1.4	NF	160 *190*	90.0 *90.4*	99.7 *99.8*	89.8 *90.3*	++	++	0 [1]	++	0	+	+	0 [5]
SMA SB3800 *	06	3.8	NF	200 *280* 350	94.8 *94.2* 93.6	99.8 *99.9* 99.9	94.6 *94.1* 93.4	+	++	++	++	++	++	++	+
SMA SMC6000	05	5.5	NF	280 *350* 420	94.7 *94.1* 93.7	99.6 *99.6* 99.7	94.3 *93.8* 93.4	*0***	++	++	++	+	++	++	+ [2]
Convert 6T *	06	5	TL	630	94.7	99.8	94.5	+	++	++	+	++	+ [7]	++	0

++	sehr gut	1)	Grenzwertüberschreitung für Frequenzen < 300 kHz
+	gut	2)	Nur mit aktivierter ENS betreiben
0	genügend	3)	Relativ frühe Abschaltung bei RSS mit f = 200 Hz
-	mangelhaft	4)	Grenzwertüberschreitung für Frequenzen < 200 kHz
--	schlecht	5)	Älteres Modell; erfüllt nur frühere ENS-Norm, heutige nicht mehr
*	*η mit neuem Power-Analyzer gemessen*	6)	Grenzwertüberschreitung für Frequenzen < 400 kHz
		7)	Nach neuer VDE 0126-1-1 kleine Normverletztung bei Überfrequenz
		8)	Testleistung etwas zu klein, da Simulator am Leistungslimit
**	*Messungen etwas zu streng*		

DYNAMISCHES TRACKINGVERHALTEN

Im April 2006 wurde festgestellt, dass bei den dynamischen MPP-Tracking-Tests [2] etwas zu strenge Testbedingungen (zu grosse Variation der MPP-Spannung bei Leistungsvariation) angewendet werden. Nach einer Hardware-Modifikation an den Solargenerator-Simulatoren des PV-Labors liess sich dieser Mangel beheben, so dass die MPP-Spannungsvariation nun mit derjenigen von echten kristallinen Modulen praktisch übereinstimmt. Abbildung 1 zeigt, wie nach der Hardware-Modifikation die Änderung der MPP-Spannung deutlich kleiner ist. Wechselrichter (hier ein SolarMax 6000C), die im ersten Moment nach einer schnellen Leistungsänderung auf ihrer DC-Arbeitsspannung verharren, schneiden dadurch bei den dynamischen Tests um ein paar Prozentpunkte besser ab.

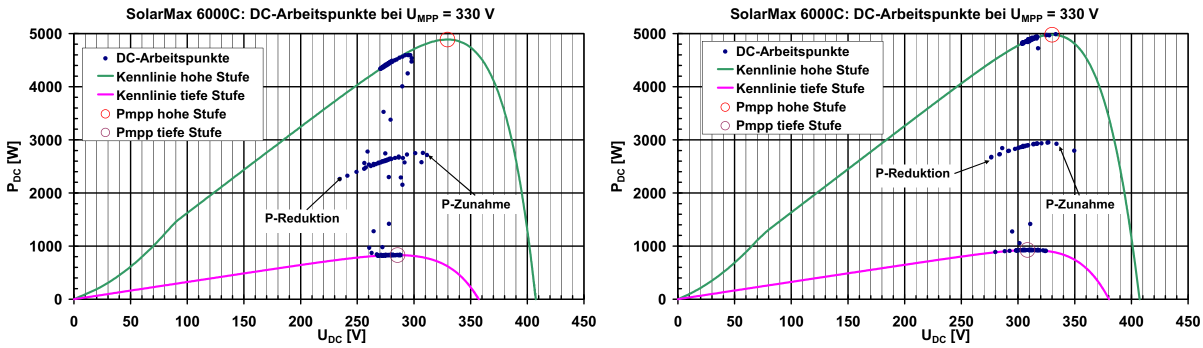

Abbildung 1: Links: Diagramm dynamische MPPT-Messung mit MPP-Spannungsvariation ca. 15%; Rechts: Diagramm mit neuer, realistischerer MPP-Spannungsvariation (ca. 3-7%)

AUSBAU TEST-INFRASTRUKTUR

Damit die in der neuen deutschen Norm DIN VDE 0126-1-1 (2.2006) vorgeschriebenen Testverfahren realisiert werden können, muss die PV-Labor-Infrastruktur kontinuierlich ausgebaut und angepasst werden. So konnte im Frühjahr 2006 ein Messaufbau zur Fehlerstrom- (FI-)Überwachung von Wechselrichtern ohne galvanische Trennung in Betrieb genommen und erfolgreich getestet werden. Dank dieser Erweiterung ist es nun möglich, die aufwändigen FI-Tests möglichst effizient durchzuführen.

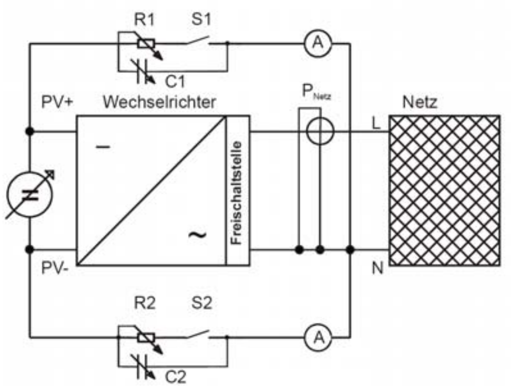

Abbildung 2:
Prüfschaltung der FI-Überwachungstests (Ausführung für einphasig einspeisende Wechselrichter)

Ein schaltbarer einstellbarer Widerstand wird zwischen jeweils einem Gleichspannungs- und dem Neutralleiter (N) angeschlossen. Bei einem Wechselrichter mit den Gleichspannungsanschlüssen PV+ und PV- sind es zwei Konfigurationen: N mit PV+ (R1), N mit PV- (R2). Dem schaltbaren Widerstand wird in der Prüfung ein einstellbarer Kondensator parallel geschaltet (C1 und C2).

Zu Beginn des zweiten Quartals dieses Jahres konnte auch das neue MPP-Tracking-Interface mit integrierter Kennlinienmessung erfolgreich in Betrieb genommen und in den bestehenden Messplatz eingegliedert werden. Mit Hilfe dieses neuen Interfaces können die zu testenden Geräte (sowohl Wechselrichter als auch DC-DC MPP-Tracker) vollautomatisch und somit äusserst effizient in Bezug auf Wirkungsgrade, Trackingverhalten und Stromoberwellen untersucht werden. Messtechnisch besteht eine wesentliche Verbesserung gegenüber dem Vorgängermodell darin, dass neu die als Referenz dienende Generatorkennlinie und das Wolkendiagramm mit demselben Strom- und Spannungssensor gemessen werden. Dadurch entfallen die Messfehler, die wegen der unterschiedlichen absoluten Genauigkeit bei Verwendung verschiedener Sensoren zwangsläufig vorhanden sind und es wird eine noch präzisere Bestimmung des MPPT-Wirkungsgrades möglich.

Systemtechnik

LICHTBOGENDETEKTOR

Mit Hilfe eines Lichtbogendetektors (LBD) können gefährliche Lichtbögen auf der DC-Seite einer PV-Anlage frühzeitig erkannt, die Anlage sicher abgeschaltet und der Lichtbogen somit gelöscht werden. Im laufenden Jahr wurde dieses Thema wieder aktuell, da sowohl in Deutschland als auch in der Schweiz an einzelnen Solarmodulen (siehe Photon 8/2006) Schwelbrände auftraten. Das PV-Labor hat sich schon 1993 -1998 mit dieser Problematik auseinandergesetzt und entsprechende Geräte zur sicheren Abschaltung solcher Lichtbögen entwickelt. Im laufenden Jahr wurde das immer noch vorhandene Know-How aufgefrischt sowie ein neuer Patentantrag für eine verbesserte Version des LBD eingereicht. Das Gerät wurde bereits mehreren interessierten Wechselrichter-Herstellern präsentiert.

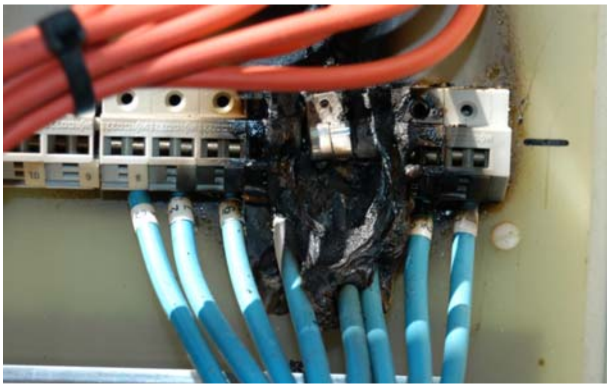

Abbildung 3: Detailaufnahme eines Schwelbrandes in einem GeneratorAnschlusskasten

Vermutlich hat sich eine Lötstelle erwärmt und ist dann unter Lichtbogenbildung durchgeschmolzen. Hier hätte ein Lichtbogendetektor (LBD) die Anlage sicher freigeschaltet.

UNTERSUCHUNGEN DER DC-SEITE / IR-MESSUNGEN

In den vergangenen zwei Jahren wurde an verschiedenen PV-Anlagen die DC-Seite untersucht. Dabei kamen immer wieder Mängel zum Vorschein. Besonders hilfreich bei den Kontrollen war die Thermografie-Kamera, mit welcher schlechte Kontakte aufgrund ihrer Erwärmung sofort lokalisiert werden konnten (siehe Abbildung 4 und Abbildung 5). Die Anlagenbesitzer wurden jeweils über den Zustand ihrer Anlage informiert, damit sie allfällige Reparaturen in Auftrag geben konnten.

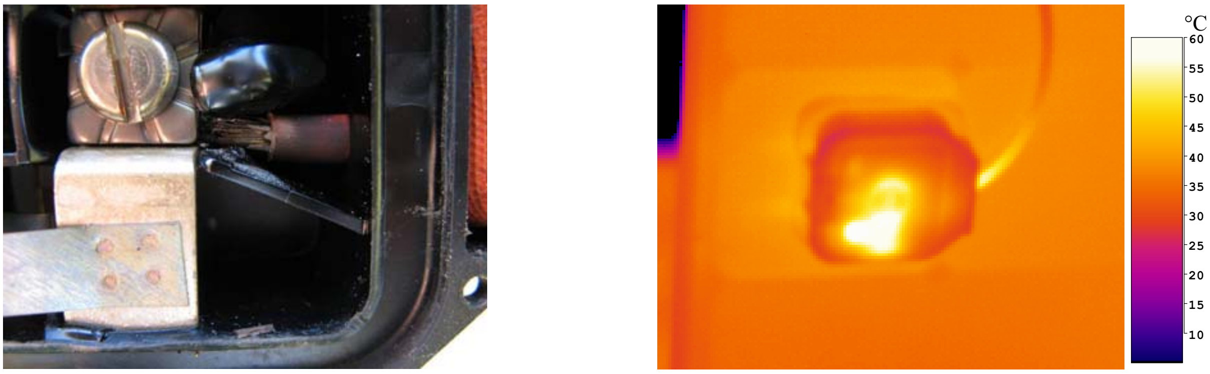

Abbildung 4: Verschmorter, heisser Kontakt in Modulanschlussdose wegen schlechter Verbindung

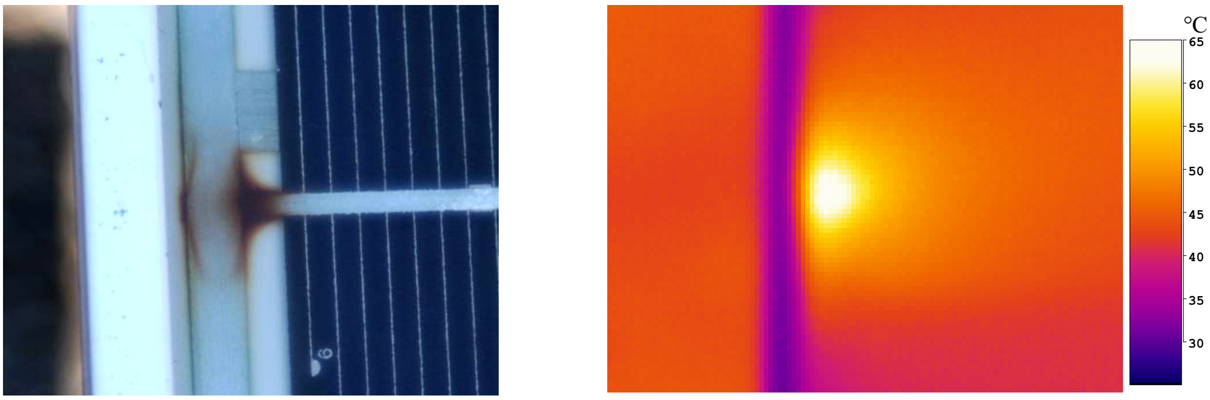

Abbildung 5: Heisser Kontaktierungsstreifen in einem Modul wegen schlechter Lötstelle (kann langfristig zu Unterbrüchen und bei einem Versagen der Bypassdiode sogar zu Lichtbögen führen).

Langzeitmessungen

METEOMESSUNG GSTEIG

Die Meteomessung auf einem Gebäude der BFH in Burgdorf (Gsteig) ist seit 1992 in Betrieb. Nun wurde die Messdatenerfassung überarbeitet. Neu werden die Messwerte nebst den 5-Minuten-Mittelwerten auch als Sekundenwerte gespeichert. Dies wird neue Möglichkeiten für die Analyse von Strahlungsspitzen geben (aktuell läuft eine Semesterarbeit zu diesem Thema). Die Erkenntnisse sollen in das Prüfverfahren von Wechselrichtern einfliessen.

Zusätzlich werden die aktuellen Meteo-Messdaten (Einstrahlungswerte, Temperaturen) online (Aktualisierung alle 5 Minuten) auf www.pvtest.ch grafisch und numerisch dargestellt (siehe Abbildung 6).

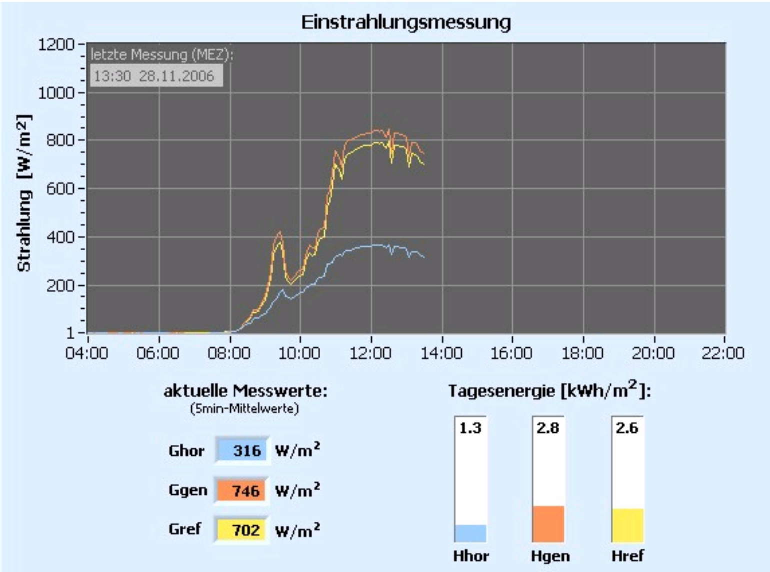

Abbildung 6:

Beispiel der Online-Darstellung der Einstrahlungsmessung von Meteo-Gsteig. Nebst den aktuellen Messwerten, werden auch die laufend integrierten Tagesenergien angezeigt

Die Einstrahlung wird mit verschiedenen Sensoren (Pyranometer und Referenzzelle) und in verschiedenen Ausrichtungen (horizontal und 45° geneigt) gemessen.

ONLINE DARSTELLUNG PV-ANLAGE TIERGARTEN

Seit diesem Jahr sind nun auch die aktuellen Messwerte der PV-Anlage Tiergarten auf dem Internet verfügbar. Die Darstellung wurde analog zur Online-Darstellung der Meteomessung Gsteig realisiert.

PV-ANLAGE „STADE DE SUISSE", WANKDORF

Die PV-Anlage „Stade de Suisse" (Wankdorf) ist seit dem März 2005 in Betrieb. Seit anfangs April 2005 werden die Messdaten vom PV-Labor der *BFH-TI* erfasst und ausgewertet. Neben einer kurzen Anlagebeschreibung sind auch eine Online-Messdatendarstellung und normierte Statistiken (siehe Abbildung 7 und Abbildung 8) von dieser Anlage auf www.pvtest.ch zu finden.

Durch tägliche Kontrolle der Ertragsdaten konnte bei der schnellen Intervention bei Fehlern in der PV-Anlage mitgeholfen werden. Jede Woche wurde ein Rapport über die Ertragsdaten der vergangenen Woche an Dr. R. Minder übermittelt, der das Projekt im Auftrag der GMS wissenschaftlich begleitet.

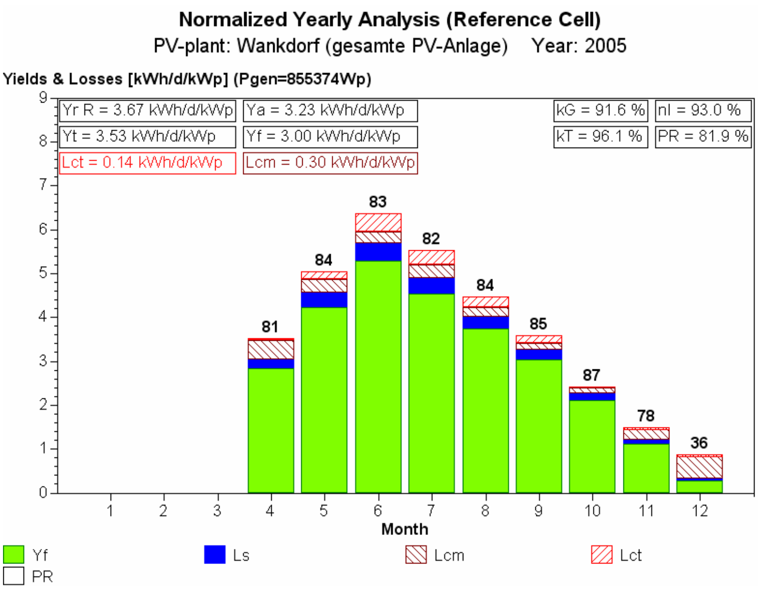

Abbildung 7:

Normierte Jahresstatistik 2005 der Anlage „Stade de Suisse" (Wankdorf).

Da die Anlage erst Ende März ans Netz ging, fehlen in der Statistik die ersten drei Monate.

Da die Anlage nur einen Anstellwinkel von ca. 7° hat, bleibt der Schnee im Winter relativ lange auf dem Generator liegen. Dies war Ende November und besonders im Dezember 2005 der Fall und ist in der Statistik durch höhere L_{cm}-Werte und tiefere PR-Werte klar erkennbar.

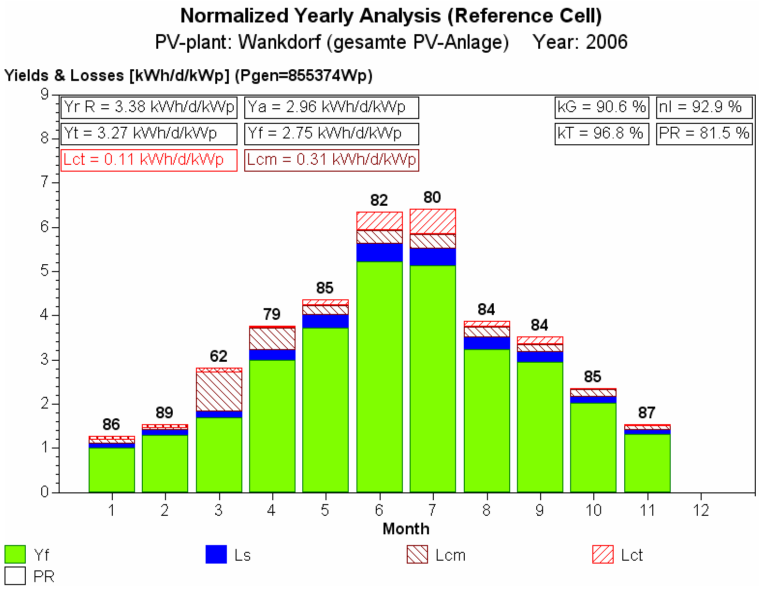

Abbildung 8:

Normierte Jahresstatistik 2006 der Anlage „Stade de Suisse“ (Wankdorf), Stand Ende Nov. 2006.

Es ist zu erkennen, dass die Energieproduktion der Anlage wegen des flachen Anstellwinkels auch im März und Anfang April 2006 durch Schneebedeckung beeinträchtigt war.

Der Winterenergieanteil beträgt ca. 24%.

DÜNNSCHICHTZELLEN-ANLAGEN NEWTECH 1 –3

Die Anlage „Newtech“ besteht aus 3 netzgekoppelten 1kWp-PV-Anlagen mit 3 verschiedenen, neuartigen Dünnschichtzellen-Technologien (CIS, a-Si-Tandemzellen, a-Si Tripelzellen). Jede der 3 Teilanlagen speist die Energie über einen ASP Top Class Spark Wechselrichter (mit Trafo) ins Netz.

In Abbildung 9 werden die Generator-Korrekturfaktoren $k_G = Y_a/Y_T$ der drei Newtech-Anlagen und von einer Anlage mit kristallinen Siliziumzellen miteinander verglichen.

Anhand der Messungen in den vergangenen Jahren wurde festgestellt, dass der Temperaturkoeffizient der Newtech 1 Anlage etwas nach oben korrigiert werden muss (von -0.33 auf -0.4%/K).

Bei der CIS-Anlage Newtech 1 ist eine weiterschreitende allmähliche Degradation feststellbar. Newtech 2 und 3 scheinen sich hingegen fast stabilisiert zu haben.

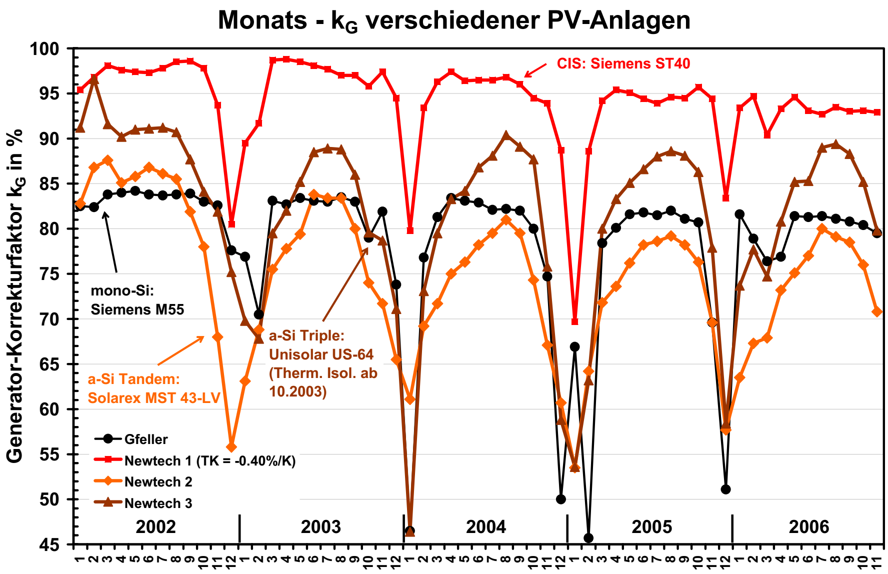

Abbildung 9:

Monats-Generator-Korrekturfaktor k_G der drei Newtech-Anlagen im Vergleich zu einer Anlage mit mono-c-Si.

Seit der thermischen Isolation von Newtech 3 ist der weitere Abfall deutlich gebremst. Wegen der geriffelten Oberfläche der Module US-64 ist Newtech 3 im Winter empfindlicher auf Schneebedeckung.

WECHSELRICHTER-AUSFALL-STATISTIK

Die seit 1992 geführte Ausfallstatistik wurde auch 2006 weitergeführt. Im Jahr 2006 sank die Ausfallrate auf den erfreulich tiefen Wert von 0,07 WR-Defekten pro WR-Betriebsjahr (Stand November 06, hochgerechnet auf Ende Jahr) und lag damit etwas tiefer als in den Vorjahren.

Neben der Gesamtstatistik (Abbildung 10) wurde auch die 2004 eingeführte zusätzliche Statistik mit Unterteilung der Ausfälle nach Wechselrichtern mit und ohne galvanische Trennung (Abbildung 11) weitergeführt.

Von den Ausfällen betroffen waren ein trafoloser SolarmaxS und ein trafoloser Convert4000. Bei einem Solarmax125 (Stade de Suisse, Wankdorf) musste ein defekter QDC-Schalter ersetzt werden. Der Gross-Wechselrichter von *ABB* bei der Anlage „Mont Soleil“ musste 2006 auch repariert werden.

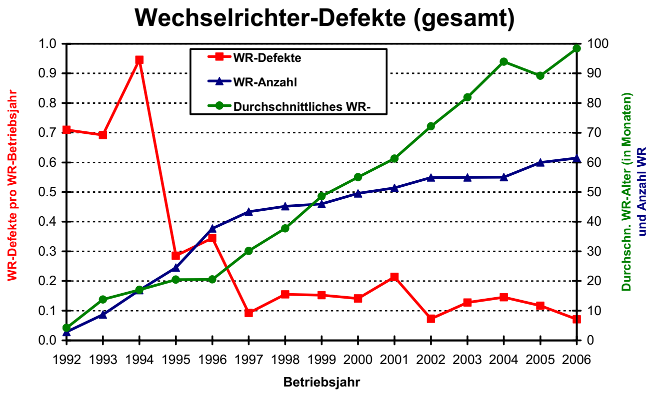

Abbildung 10:

Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr und durchschnittliche Anzahl von der BFH-TI Burgdorf überwachter Wechselrichter (Hochrechnung vom Stand Ende November 2006).

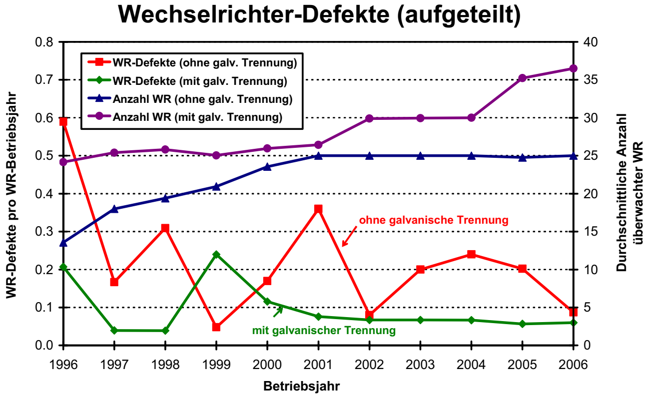

Abbildung 11:

Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr aufgeteilt nach Wechselrichtern mit und ohne galvanische Kopplung (Hochrechnung vom Stand Ende November 2006). Die bisher beobachtete Tendenz, dass die Wechselrichter ohne galvanische Trennung anfälliger sind, setzt sich nicht weiter fort.

INTERNETAUFTRITT (WWW.PVTEST.CH)

Der Internetauftritt vom PV-Labor der BFH-TI wird laufend ausgebaut und aktualisiert. Neu stehen von jeder Anlage, welche mit einem Feinmesssystem ausgerüstet ist, nebst den normierten Jahresstatistiken auch die **normierten Monatsstatistiken auf der Homepage** dem breiten Publikum zur Verfügung. Die normierten Monatsstatistiken werden monatlich aufdatiert.

Nationale / internationale Zusammenarbeit

- MPP-Tracker-Tests (vertraulich) für Projekt *„Solarimpulse“*
- MPP-Tracker-Test, *SUPSI - DACD - ISAAC*
- Vergütete Wechselrichter Tests für diverse in- und ausländische Hersteller und Vertriebsfirmen
- Austausch über Wechselrichter-Testverfahren mit *Arsenal Research*
- VDE-Normenkommission, Tagung am 29.9.06 bei uns mit Vorführung des Lichtbogendetektors
- Messdaten aus Langzeitmessungen an *ETHZ (EEH-Power Systems Group), University of New Mexico (USA), IEA PVPS Task 2 (Aktivität 52) und Meteotest* Bern (für Weiterentwicklung von Meteonorm)
- Wöchentliche Rapporte an die GMS (Diagramme von PV-Anlage Wankdorf und Mont Soleil)

Referenzen / Publikationen (als PDFs auf www.pvtest.ch)

[1] H. Häberlin, L. Borgna, M. Kämpfer, U. Zwahlen, ***"Dynamisches MPP-Tracking - Neue Tests an PV-Wechselrichtern"***, Elektrotechnik 9/2006.

[2] H. Häberlin, L. Borgna, M. Kämpfer, U. Zwahlen, ***"Measurement of Dynamic MPP-Tracking Efficiency at Grid-Connected PV Inverters"***, 21th EU PV Conf., Dresden, Germany, September 2006.

[3] H. Häberlin, L. Borgna, M. Kämpfer, U. Zwahlen, ***"New Tests at Grid-Connected PV Inverters: Overview over Test Results and Measured Values of Total Efficiency"***, 21th EU PV Conf., Dresden, Germany, September 2006.

[4] H. Häberlin, ***"Le photovoltaïque en Suisse - la Suisse risque d'être à la traîne de l'Europe"***, Le monteur électricien No 3, Mars 2006.

[5] H. Häberlin, ***"Rekordernte auf dem Jungfraujoch"***, Elektrotechnik 3/2006.

[6] H. Häberlin, M. Kämpfer und U. Zwahlen, ***"Messung der dynamischen Maximum-Power-Point-Trackings bei Netzverbund-Wechselrichtern"***, 21. Symposium Photovoltaische Solarenergie, Staffelstein / D, 2006.

[7] H. Häberlin und Ch. Geissbühler, ***"Photovoltaik-Anlage Newtech - drei Dünnschichtzellentechnologien im mehrjährigen Langzeitvergleich (2002-2005)"***, 21. Symposium Photovoltaische Solarenergie, Staffelstein / D, 2006.

[8] H. Häberlin, M. Kämpfer und U. Zwahlen, ***"Neue Tests an PV-Wechselrichtern: Gesamtübersicht über Testergebnisse und gemessene totale Wirkungsgrade"***, 21. Symposium Photovoltaische Solarenergie, Staffelstein / D, 2006.

Ausblick 2007

Eingabe eines Fortsetzungsprojektes PV-SYTE07-09 (vorgesehene Arbeiten in separatem Antrag)

Diverse Projekte und Studien

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

UPDATE PHOTOVOLTAIC IN VIEW OF ECOINVENT DATA V2.0

Annual Report 2006

Author and Co-Authors	Niels Jungbluth
Institution / Company	ESU-services GmbH
Address	Kanzleistr. 4, CH-8610 Uster,
Telephone, E-mail, Homepage	044 940 61 32, www.esu-services.ch, jungbluth@esu-services.ch
Project- / Contract Number	101805
Duration of the Project (from – to)	1.11.2006 - 30.6.2007
Date	14.11.2006

ABSTRACT

Life cycle assessment (LCA) is an environmental management tool for analysing, comparing and improving products or technologies. A basic requirement for LCA are life cycle inventory (LCI) data describing the inputs and outputs of each stage of the life cycle. The ecoinvent database provides such data for currently more than 2700 unit processes. The data are used within all major LCA software products.

The last data update of mono- and polycrystalline PV plants in the Swiss ecoinvent database was made in 2003. The ecoinvent data v1.2 describe the situation of the European PV industry and the use of PV plants in Switzerland for the reference year 2000.

At the moment several projects are ongoing for the release of ecoinvent data v2.0. Existing datasets will be updated as necessary and new economic sectors such as bioenergy are additionally investigated in view of this new release.

In the past years the PV sector developed rapidly. Ongoing projects such as Crystal Clear have investigated the up-to-date life cycle inventory data of the poly- and monocrystalline technologies. However, these data are not yet implemented in the ecoinvent database and the ecoinvent data on PV does, therefore, not correctly reflect the environmental performance of the PV sector of today. An update of the existing data in the ecoinvent database has become necessary. Since there were significant improvements in performance of PV systems in recent years, it is in the interest of companies in the photovoltaics sector that these changes also appear in life cycle inventories. This project aims to update the LCI data for crystalline photovoltaics and to investigate also data for thin film technologies for the first time.

Einleitung / Projektziele

Im Rahmen des Projektes ecoinvent 2000 wurden die Sachbilanzdaten für mono- und polykristalline Photovoltaikanlagen grundlegend überarbeitet. Dabei wurde der Produktionsstatus für das Jahr 2000 betrachtet ([1-3]). Diese Daten sind bereits fünf Jahre später veraltet, da die Produktionstechnologien verbessert wurden und sich das Wissen um die Umweltbelastungen aus der Herstellung erweitert hat.

Eine Aufdatierung und Erweiterung der bestehenden Datensätze zum jetzigen Zeitpunkt ist deshalb sinnvoll. Die neu erhobenen Sachbilanzdaten sollen so erhoben und dokumentiert werden, dass eine Integration in den Datenbestand v2.0 der ecoinvent Datenbank ohne Probleme möglich ist und die Daten somit einer breiten Öffentlichkeit zur Verfügung stehen.

Neben der Aufdatierung werden auch erstmals Daten für die Herstellung und den Betrieb von Dünnschichtmodulen erhoben (CIS und CdTe). Ausserdem werden die Stromerträge für eine Reihe von Europäischen Ländern bestimmt.

Der bisherige Schlussbericht zum Thema Photovoltaik wird vom Deutschen ins Englische übersetzt. Damit wird die Art der Dokumentation an die Anforderungen des ecoinvent Zentrums gerecht und der weltweite Kundenstamm für diese Datenbank besser bedient.

Durchgeführte Arbeiten und erreichte Ergebnisse

Die Zusage zum Projekt erfolgte vor einigen Tagen. Bisher liegen keine Ergebnisse vor.

Nationale / internationale Zusammenarbeit

Der Projektteil zur Aufdatierung der bestehenden Daten wird durch die European Photovoltaic Industry Association (EPIA) gefördert. Von einem europäischen Forschungsprojekt Crystal Clear werden alle notwendigen Sachbilanzdaten zur Verfügung gestellt. Hierzu besteht enge Zusammenarbeit mit zwei Forschungsinstituten aus den Niederlanden.

Die Aktivitäten wurden parallel zum IEA PVPS Task 12 entwickelt. Mit diesem Task soll die internationale Zusammenarbeit zum Thema Recycling und Umwelt gestärkt werden. Die hier finanzierten Arbeiten werden ein Bestandteil des Schweizer Beitrags zu diesem Task sein.

Teile dieses Projektes werden in Unteraufträgen durch die EMPA Dübendorf und die ETH Zürich bearbeitet.

Bewertung 2006 und Ausblick 2007

Die Datenerhebung wird im Jahr 2006 begonnen. Der Bericht und die elektronischen Daten sollen bis Ende Februar 2007 zum Review vorliegen. Dann wird in einem internen Verfahren des ecoinvent Zentrums der Qualitätsstandard durch das PSI Villigen überprüft. Hiernach werden die Berichte und Daten überarbeitet. Die Daten werden Bestandteil des ecoinvent Datenbestandes Version 2.0. Die Veröffentlichung ist für Mitte 2007 vorgesehen.

Referenzen

[1] N, Jungbluth, ***Photovoltaik*, in *Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz*,** Dones R, (Editor). 2003, Final report ecoinvent 2000 No. 6-XII, Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories: Dübendorf, CH. www.ecoinvent.org.

[2] N. Jungbluth, ***Life Cycle Assessment for Crystalline Photovoltaics in the Swiss ecoinvent Database,*** Prog. Photovolt. Res. Appl., 2005. **2005**(13): p. 429-446. http://www3.interscience.wiley.com/cgi-bin/jissue/82003028 or www.esu-services.ch.

[3] N. Jungbluth, C. Bauer, R. Dones, & R. Frischknecht, ***Life Cycle Assessment for Emerging Technologies: Case Studies for Photovoltaic and Wind Power,*** Int J LCA, 2004. **10**(1): p. 24-34. http://dx.doi.org/10.1065/lca2004.11.181.3 or www.esu-services.ch

Schweizerische Eidgenossenschaft
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Bundesamt für Energie BFE

ENVISOLAR - ENVIRONMENTAL INFORMATION SERVICES FOR SOLAR ENERGY INDUSTRIES

Annual Report 2006

Author and Co-Authors	Sandra Stettler, Peter Toggweiler
Institution / Company	Enecolo AG
Address	Lindhofstrasse 52, 8617 Mönchaltorf
Telephone, E-mail, Homepage	044 994 90 01, info@enecolo.ch, www.solarstrom.ch
Project- / Contract Number	ESA Earth Observation Envelope Program Market Development Element, Contract number 17734/03/I-IW
Duration of the Project (from – to)	December 2004 - May 2007
Date	December 2006

ABSTRACT

The new generation of Meteorological satellites - Meteosat Second Generation (MSG) - opens a whole new era in the monitoring of irradiance from space by improving the spatial, temporal and spectral resolution of satellite data, which are thereby becoming even more accurate and synoptic than traditional ground measurements.

Integrating this information within business practices of solar energy companies is the objective of the Envisolar project (Environmental Information Services for Solar Energy Industries), funded by ESA within the framework of the Earth Observation Market Development Programme (EOMD) and managed by the German Aerospace Center (DLR).

ENVISOLAR aims at the increased use of satellite based solar radiation information in solar energy industries. The project services will help end-users in planning, construction and operation of solar energy power plants and while operating conventional power plants.

The following services providing solar radiation information will be improved through the ENVISOLAR project:

- Services for Investment Decision: Site analysis and optimisation which allows finding the best site for a planned power plant.
- Services for plant management: online monitoring service for PV system with automated failure detection (www.spyce.ch)
- Solar energy forecasting for utilities
- Time-Series Services for Science and Consulting

In Switzerland ENVISOLAR supports the development of the online PV monitoring SPYCE. SPYCE is offered as a joint venture of Enecolo AG and Meteotest. It uses irradiance data generated by the French research center Ecole des Mines de Paris with the aid of satellite data from the ESA MSG satellite. SPYCE monitors the production of solar power plants, which increases their energy yield as well as their capacity to compete with other (non renewable) energy sources.

Introduction / Project goals

ENVISOLAR aims at the increased use of satellite based solar radiation information in solar energy industries. The project services will help end-users in planning, construction and operations of solar energy power plants and while operating conventional power plants.

The photovoltaic market has got a volume of about 1000 Mio €/year in Germany and 100 Mio €/year in the rest of EU. This will lead to market volumes of 2500 Mio €/year and 3000 Mio €/year in 2010 (based on prices given by the Sarasin Bank).That means, the solar energy sector is turning from an idealistic driven to a financial driven market. Therefore investment assurance is necessary. Services, which can provide and support this, are needed in two phases:

1. Investment decisions
2. Plant Management

Because of the spatial distribution Earth Observation-data will give advances over ground measurement in both phases.

Another emerging market that promises good benefits is the load and production forecasting for utilities. For the time schedule of large power plants good knowledge of the load is necessary. Beside temperature, irradiance is the major environmental influence on the electricity demand. The demand has to be calculated for every single town and therefore the above described advantage of Earth Observation-data is also applied here. Because of liberalised markets and higher penetration with renewable energies a professional load forecast is necessary to achieve good prices at the energy spot markets.

The goals of ENVISOLAR are to support market entry of products and services using Earth Observation data for the renewable energy sector. Thus, within ENVISOLAR the operational service chains from Earth Observation data to meta data to end user services shall be improved and market entry of end user services shall be supported.

Short description of the project

The components to be developed and improved are:

- **Near real time service chain:** The operational service chain for near real time delivery of irradiance data shall be improved and automated.
- **Long term service chain**: Data base with long term satellite derived irradiance data shall be extended, gaps in time series filled and geographical coverage extended. Data delivery to end users shall be automated.
- **Investment decision:** Exchange of long term irradiance data between data providers and the market players shall be automated.
- **Plant management**: The online services for plant management (SPYCE and SaferSun) shall be validated and evaluated. In the already existing service SaferSun new simulation methods shall be implemented, while the new service SPYCE shall be set up and market entry shall be supported.
- **Utilities:** Data quality and other needs of the utilities for Earth Observation data shall be investigated and business plans for services for utilities set up. First tests with forecast data for utilities shall start in autumn 2006
- **Science and Consulting**: A commercial website with access to long term Earth Observation data shall be set up. Several services shall be available on this website as e.g. irradiance data, temperature data, relative humidity and maps.

Executed work and achievements in 2006

Plant Management

The SPYCE service was commercially launched in June 2006 and the first clients have subscribed to SPYCE. The presentation of SPYCE at the 21. Symposium of solar energy in Staffelstein (Germany) and at the solar energy exhibition Intersolar in Freiburg (Germany) rose a lot of interest. Several companies asked for tenders and would like to test SPYCE.

Functional Principle of SPYCE:

Daily a data logger at the location of the monitored PV systems sends the hourly production data to the SPYCE server. For each monitored system the hourly reference energy yield is calculated using satellite derived irradiance data.

Optionally, the data logger can also transmit temperature and irradiance data. In this case, the reference energy yield is calculated with the measured temperature and irradiance data. If several PV systems at the same location are monitored with SPYCE, their production is automatically compared and analysed.

A failure detection routine compares daily the measured and reference energy yields. In case of deviations, the failure detection routine analyses the pattern of measured and reference energy yields and automatically identifies the most probable causes for a defect. The client can choose, if he wants to be informed daily and/or if he wants to be alerted in case of defects. All measured and reference energy yields, the results of the failure detection as well as other analyses are accessible in a password-protected account on the internet. Additionally, SPYCE daily provides graphs with the energy yields that can be included by the clients in their own homepage.

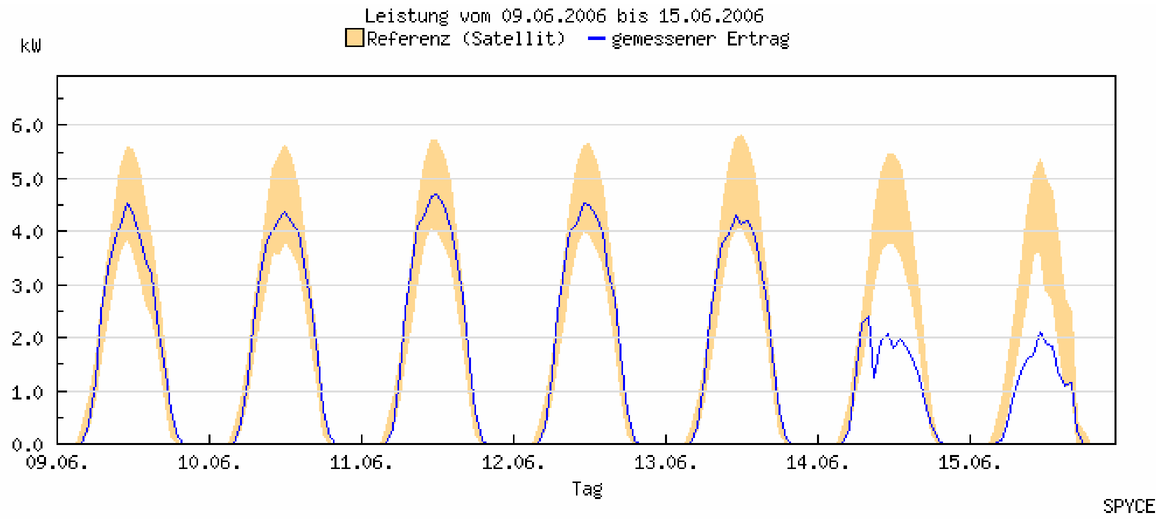

Figure 1: PV System with a string outage starting at the 14th of June. (blue line: measured energy yield, orange bars: reference energy yield).

Main functions of SPYCE

- Visualisation of hourly, daily and monthly yield
- Comparison with satellite data and nearby PV systems
- Visualisation of income
- Visualisation of results of the failure analysis with detailed information about failure sources
- Daily information about the energy yield and status of the PV system by email.
- Alert via email or SMS in case of defects

SPYCE is compatible with most data loggers of big inverter manufacturers and offers also two low cost data loggers on the SPYCE homepage. Actually, SPYCE is compatible with the following data loggers:

manufacturer	**data logger**
Fronius	IG Interface Card / Box mit Tixi Message Modem
KACO	Powador -proLOG L Powador -proLOG XL
MASTERVOLT	Data control pro
SMA	SunnyData Control mit NET Piggy Back
Sunways	Sunways Communicator Sunways Communicator 05
AS Control	SPYCE-log GSM
Meteocontrol	WEBlog Basic WEBlog Light WEBlog pro
SPYCE	PEPPER

Investment Decision

Long term satellite data can be used for site analysis and investment decision for PV systems. Enecolo AG performed site analysis with the aid of satellite data for two PV systems up to now. In both cases no long term ground irradiance data was available. Therefore satellite data from the SoDa data base of Ecole des Mines (www.soda-is.com) was used to extrapolate the irradiance. Long term irradiance data from satellite is also very useful to find suitable locations for PV plants and to compare different regions in respect to solar radiation. Enecolo AG did a study with satellite data about the irradiance distribution in Spain. The surprising result is, that on the continent irradiance depends highly on the latitude. The daily sum of irradiance is more than 2000 Wh/m^2 higher at the south coast of Spain than in the north. But on the Canary Islands, situated about 10° south of the continent, the daily sum of irradiance is only about 200 Wh/m^2 higher than at the south coast of the continent. This awareness is precious for our consulting activities as it showed us, that PV plants in Spain must be located in the very south of the continent to be profitable. But that from the point of view of irradiance it is not necessary to go to the Canary Islands.

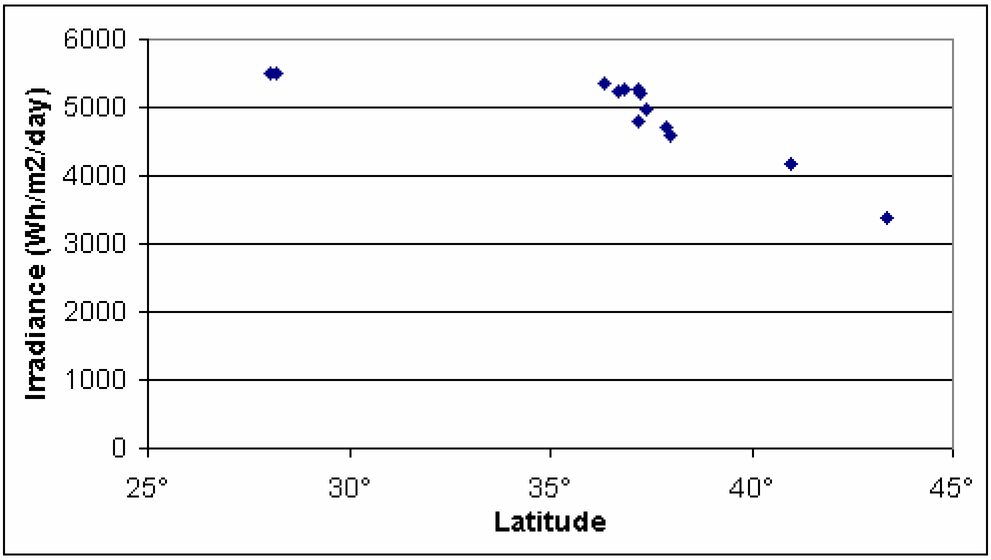

Figure 2: Daily sum of irradiances for several locations in Spain and the Canary Islands

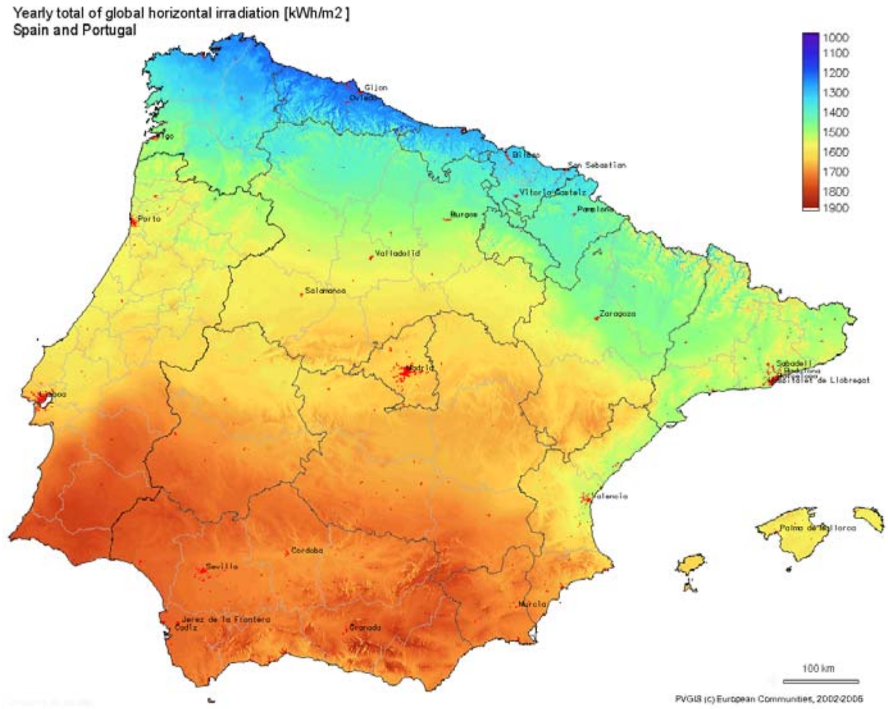

Figure 3: Irradiation map of Spain and Portugal with yearly total of global horizontal irradiation (kWh/m^2)

Problems with satellite derived irradiance data

In general, the quality of the satellite derived irradiance data is satisfying. Especially long term averages of a certain location have about the same accuracy as ground measurements. But when data with high time resolution is needed, as e.g. for plant monitoring, there occur some problems:

- Snow cover: the satellite sometimes has difficulties to distinguish between ice clouds and snow on the ground. This leads to either over- or underestimation of the irradiance. DLR and EHF are working now at better snow detection algorithms.
- Broken cloud situation: at days with highly variable clouds and broken clouds the uncertainty of the irradiance calculation is high, because the spatial and temporal resolution of the satellite pictures is not high enough. However, with the new MSG satellite the spatial resolution was reduced to 3 x 3 km and the temporal resolution from 1 hour to 15 minutes. This leads to a significant improvement of the irradiance calculation on cloudy days.
- Fog and aerosols: Aerosols and fog on the ground are not detected by the MSG satellite. Aerosols are considered with climatological parameters up to now. A new approach is to include images of another satellite in the calculation of the irradiance which can detec areosols. Also fog is often not detected on the MSG images. But it is possible to recognise fog with APOLLO images. Therefore it is planned to include APOLLO images in the irradiacne calculation in future.

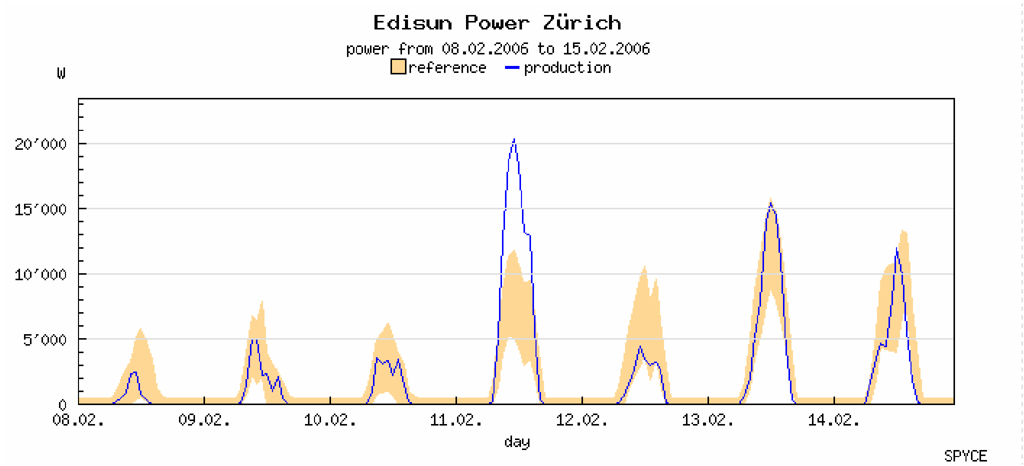

Figure 4: Measured energy yield (blue line) and reference energy yield (orange bar) of a PV system in February 2006. On cloudy days the uncertainty of the satellite data is quite high. And on 11.2.2006, the satellite interpreted snow on the ground as a cloud. Therefore the calculated irradiance and reference yields were much lower than the measured irradiance and energy yield.

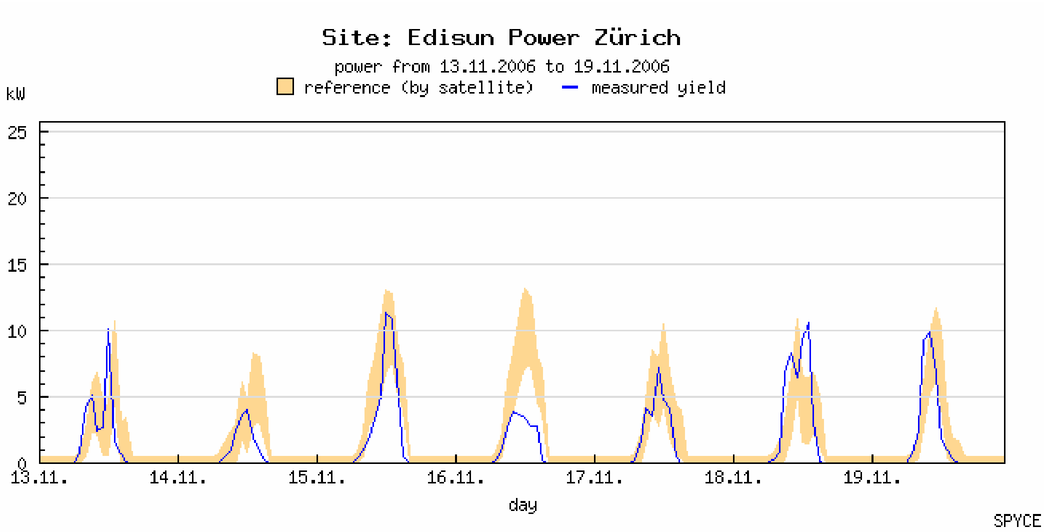

Figure 5: Measured energy yield (blue line) and reference energy yield (orange bar) of a PV system in November 2006. On cloudy days the uncertainty of the satellite data is quite high. And on 16.11.2006 the satellite did not detect the fog on the ground. Therefore the calculated irradiance and reference yield is too high.

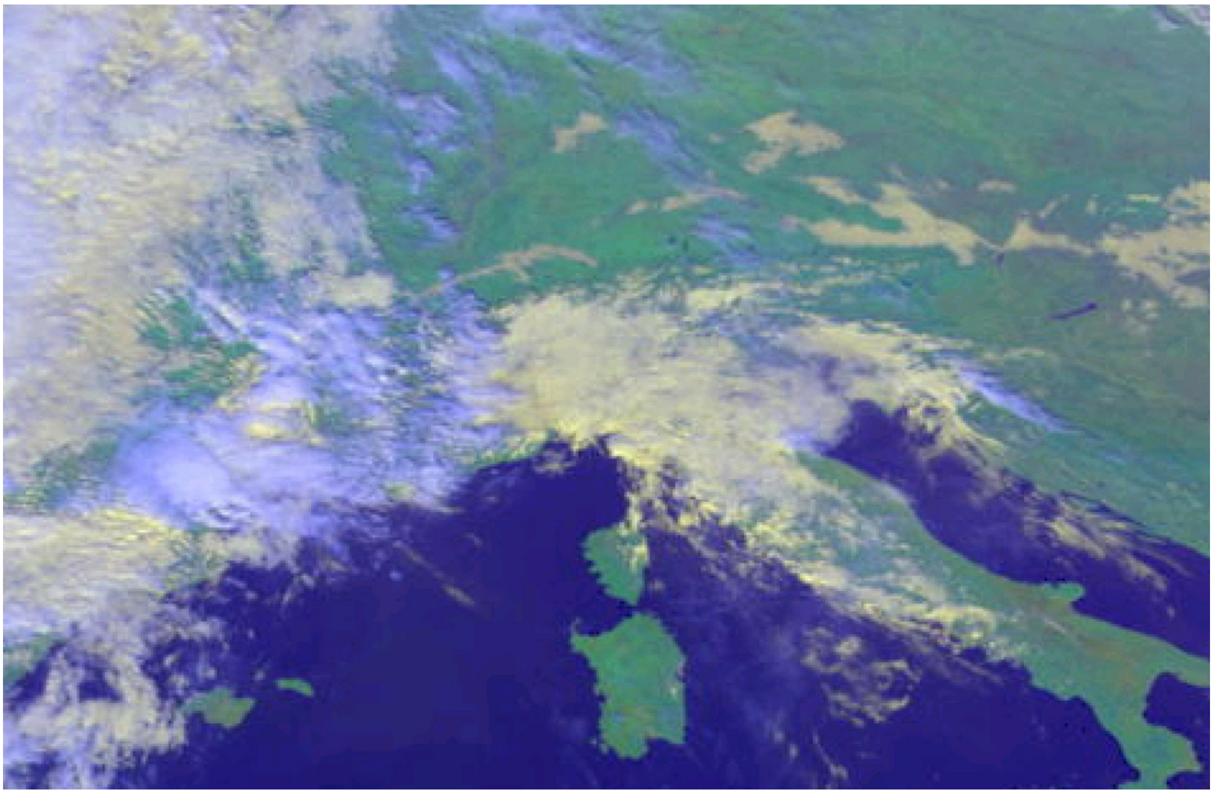

Figure 6: On the APOLLO images, fog in the region of Zurich can be detected easily. It is expected that the integration of APOLLO images in irradiance calculation would improve the quality of the data. Up to now only images of the MSG satellite are used.

National / international collaboration

Peter Toggweiler is one of the three PV experts in the EMPower program. EMPower seeks to significantly reduce the cost of electricity generated from grid-connected PV (GCPV) and Concentrating Solar Power (CSP) via aggregation of a large-scale global utility market. It is initiated and supported by UNEP, GEF, KfW and SEPA. Operation and management of the project is executed by Morse Associates Inc. in Washington, US. The EMPower program has mandated 6 international recognised experts, 3 for CSP and 3 for PV. In September and October 2006, Peter Toggweiler visited and collaborated with PG&E, SMUD and WE Energies in the US as well as Reliance and NDPL in India. The main focus was to explore the future power production based on photovoltaic solar power plants. An important issue was the solar resource evaluation where satellite pictures are going to be used. Further applications such as NRT and forecast applications were discussed.

In October 2006, Peter Toggweiler visited the Solar Power Conference in San Joé, California. His oral presentation of the EMPower program and poster presentation of SPYCE rose a lot of interest and lead to several contacts with companies in the USA.

Three international ENVISOLAR meetings were held in 2006 (Paris, Nice and Livorgno), where the outcomes and the project status of ENVISOLAR were discussed. In 2006, a new partner joined the ENVISOLAR team: the company flyby from Italy will set up a plant monitoring service and a forecasting service for utilities in Italy.

On a national level, Enecolo AG had a close cooperation with the company Meteotest in Bern, as the service SPYCE is a joint service of Meteotest and Enecolo AG. There were many contacts with companies in Switzerland and in Germany about SPYCE. As a result, the Swiss inverter manufacturer ASE is now a SPYCE client and several other companies have started tests with SPYCE.

Evaluation 2006 and outlook 2007

In 2006 the implementation and set up of the SPYCE service was the main task for Enecolo AG within the ENVISOLAR project. The service is running without any major problems since June 2006. Promotion and marketing was very successful up to now in the sense that a lot of companies contacted SPYCE and wanted to test SPYCE. Up to now, three big companies signed a contract for a SPYCE service. But for all these companies no PV system is monitored up to now. The total number of monitored PV system is therefore still very small. It is assumed that the number of monitored PV systems will rise drastically next year, as several companies are now in a test phase with SPYCE. Therefore next year will be crucial for SPYCE, as it will reveal if SPYCE meets the need of the clients and if SPYCE technically can manage thousands of monitored systems.

The ENVISOLAR project will end in May 2007.

References / Publications

[1] S. Stettler et. al., ***Failure Detection Routine for Grid Connected PV Systems as Part of the PVSAT-2 Project,*** Session PV Systems in Grid-Connected Applications, 20th European Photovoltaic Solar Energy Conference, 6 - 10 June 2005, Barcelona, Spain, p.2490 – 2493

[2] S. Stettler, P. Toggweiler, J. Remund; ***Ertrags-Optimierung dank automatischer Fehlererkennung;*** 21. Symposium Photovoltaische Solarenergie, 8. - 10. März 2006, Kloster Banz, Bad Staffelstein, S. 347 – 352

[3] S. Stettler, P. Toggweiler, J. Remund, ***Ertragsoptimierung dank automatischer Fehlererkennung,*** Bulletin SEV/VSE, 10/06

[4] S. Stettler, P. Toggweiler, J. Remund: ***SPYCE: Satellite Photovoltaic Yield Control and Evaluation,*** Proc. 21th European Photovoltaic Solar Energy Conference, Dresden, 4-8 September 2006

[5] P. Toggweiler, S. Stettler, J. Remund, ***SPYCE: Satellite Photovoltaic Yield Control and Evaluation,*** Solar Power 2006, San Jose, 16-19 October 2006

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[7] Internetseite von SPYCE: ***www.spyce.ch***

[8] Internetseite von ENVISOLAR: ***www.envisolar.ch***

Internationale Koordination

SCHWEIZER BEITRAG ZUM IEA PVPS PROGRAMM - TASK 1

Annual Report 2006

Author and Co-Authors	Pius Hüsser
Company	Nova Energie GmbH
Address	Schachenallee 29, CH-5000 Aarau
Telephone, E-mail, Homepage	062 834 03 00, pius.huesser@novaenergie.ch, www.iea-pvps.org
Project- / Contract Number	11427 / 151 934
Duration of the Project (from – to)	01.01.2006 – 31.12. 2006
Date	15.1.2007

ABSTRACT

The Swiss contribution to the PVPS Programme included:

- **National Survey Report**, a summary of developments in the market and political areas. The report's data is integrated into the IEA's **Trends in Photovoltaic Application Report**
- Acquisition of Swiss contributions to **PV Power**, distribution of the magazine to approx. 250 addresses in Switzerland
- Targeted search for **new contacts** in the PV area
- Contributions/organizations to/of national and international **workshops**
- **PR-work** in Switzerland. Reference to the programme's international publications

The results of these activities include

- **National Survey Report** (NSR) based on the statistics provided by the Swiss Association of Solar Professionals and the Swiss Association of Utilities (grid-coupled installations)
- Distribution of the **PV Power Magazine** in May and November
- 2 **Task 1 meetings** in Vancouver and Vienna
- 2 Workshops in Dresden (September) and Zurich (November)
- Webmastering support for www.iea-pvps.org

Work still to be done:

- Organize a Workshop at the PV conference in Milano (Sept. 2007) and Fukuoka (Dez. 2007)

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:

- **PV POWER**, ein zweimal jährlich erscheinender Newsletter
- **Trends Report** (Trends in Photovoltaic Applications, Survey report of selected IEA countries between 1992 and 2005), ein Jahresbericht zur Markt- und Technologieentwicklung der dem Programm angeschlossenen Ländern
- 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.) mit qualitativ hochstehenden Produkten zu informieren.

Der Schweizer Beitrag innerhalb des PVPS Programmes konzentriert sich auf folgende Schwerpunkte:

- **National Survey Report [1]**, eine Zusammenstellung der Marktentwicklung und des politischen Umfeldes in der Schweiz. Diese Daten werden im **Trends Report** [2] zusammengefasst und publiziert
- Organisieren von Schweizer Beiträgen in **PV Power** sowie Mitarbeit im Editorial Board.
- Distribution von **PV Power** an etwa 250 Adressaten in der Schweiz
- 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.

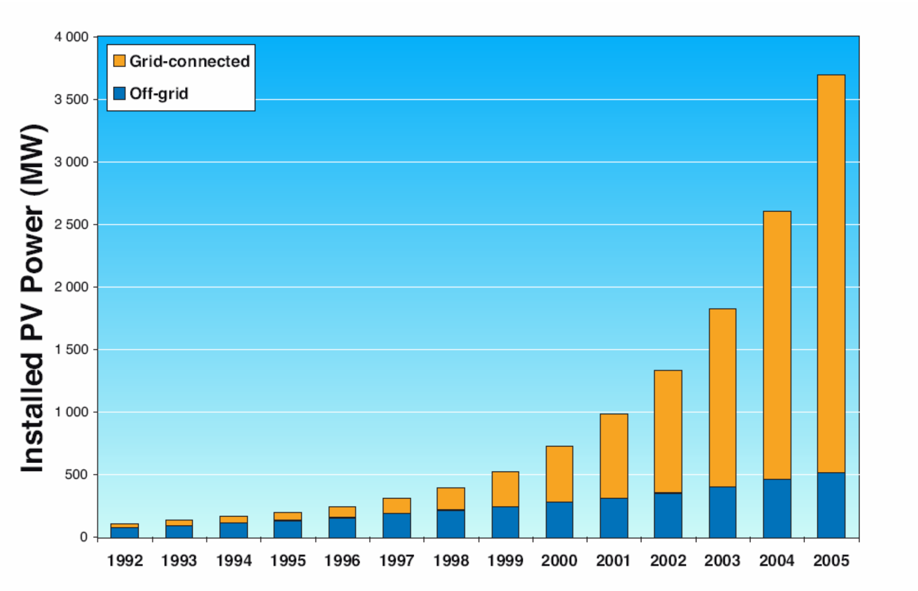


Bild 1: Graphik aus dem Trends Report 2006

Durchgeführte Arbeiten und erreichte Ergebnisse

National Survey Report NSR

Der NSR bildet die Grundlage für den jedes Jahr erscheinenden "**Trends Report**". Als Grundlage 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.

Sub-market/ application	31 Dec. 1992 kW	31 Dec. 1993 kW	31 Dec. 1994 kW	31 Dec. 1995 kW	31 Dec. 1996 kW	31 Dec. 1997 kW	31 Dec. 1998 kW	31 Dec. 1999 kW	31 Dec. 2000 kW	31 Dec. 2001 kW	31 Dec. 2002 kW	31 Dec. 2003 kW	31 Dec. 2004 kW	31 Dec. 2005 kW
off-grid 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*
off-grid non-domestic	70	100	112	143	162	184	190	200*	210*	220*	230*	260*	290*	320*
Grid-connected distributed	2 200	2 900	3 600	4 050	4 850	5'950	7 630	9 420	11 220	13 340	15 140	16 440	18 440	21 240
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**
TOTAL	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

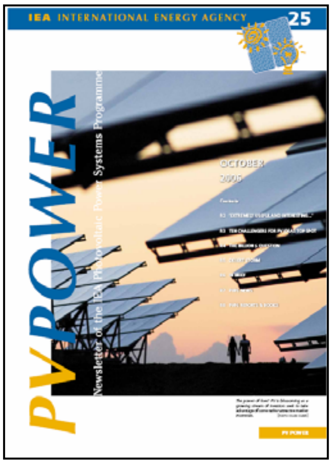
Zwischen den beiden Datenquellen ergeben sich Abweichungen aufgrund der unterschiedlichen Art der Erhebung. Einerseits werden von Importteuren, Distributoren und Installateuren Verkaufszahlen erhoben (in MWp der DC-Leistung der Module).

Unabhängig davon wird die VSE-Statistik der installierten Leistung durch Swissolar und mit Unterstützung des VSE fortgeschrieben. Hier wird die installierte Leistung erhoben. Dabei gibt es Abweichungen zur Verkaufsstatistik einerseits aus terminlichen Gründen (nicht alle verkauften Module sind bereits installiert) andererseits weil zu vermuten ist, dass gewisse Elektrizitätswerke die AC-Leistung der in ihrem Netz installierten Anlage angeben. Dies soll in nächsten Jahrr genauer untersucht werden.

PV Power

PV Power wurde im Berichtsjahr 2 mal ausgeliefert (Juni und Oktober).

Aufgrund der laufenden parlamentarischen Beratung zur Kosten deckenden Vergütung wurde eher zurückhaltend aus der Schweiz berichtet.



Trends Report

Basierend auf den Daten des "National Survey Reports" wurde Mitte September der Trends Report publiziert. Dieser Report ist international sehr anerkannt, da er unabhängig von der Industrie Daten zu Produktion und Markt in 20 Ländern liefert.

Die wichtigsten Daten aus dem Report sind auch im Internet unter www.iea-pvps.org [3] einsehbar. Der ganze Report wie auch einzelne Tabellen können als PDF - Dokumente heruntergeladen werden. Die aktuellen Zahlen sind in der nachfolgenden Tabelle aufgeführt.

Kommentar Photon:
'Extremely useful and interesting...'. That is the verdict of Photon International magazine on the statistics published in the eleventh edition of 'Trends in Photovoltaic Applications'.

Table 1 – Installed PV power in reporting IEA PVPS countries as of the end of 2005

Country	Cumulative off-grid PV capacity (kW)		Cumulative grid-connected PV capacity (kW)		Total installed PV power (kW)	Total installed per capita (W/Capita)	PV power installed in 2005 (kW)	Grid-connected PV power installed in 2005 (kW)
	domestic	non-domestic	distributed	centralized				
AUS	18 768	33 073	6 860	1 880	60 581	2,97	8 280	1 980
AUT	2 895		19 973	1 153	24 021	2,93	2 961	2 711
CAN	5 903	9 719	1 059	65	16 746	0,52	2 862	612
CHE	2 930	320	21 240	2 560	27 050	3,66	3 950	3 800
DNK	70	225	2 355	0	2 650	0,49	360	320
DEU	29 000		1 400 000		1 429 000	17,32	635 000	632 000
ESP	15 800		41 600		57 400	1,32	20 400	18 600
FRA	13 844	6 232	12 967	0	33 043	0,54	7 020	5 900
GBR	227	697	9 953	0	10 877	0,18	2 713	2 567
ISR	809	210	11	14	1 044	0,15	158	2
ITA	5 300	7 000	18 500	6 700	37 500	0,64	6 800	6 500
JPN	1 148	85 909	1 331 951	2 900	1 421 908	11,13	289 917	287 105
KOR	853	4 810	8 028	1 330	15 021	0,31	6 487	6 183
MEX	14 476	4 178	40	0	18 694	0,17	513	30
NLD	4 919		43 377	2 480	50 776	3,12	1 697	1 547
NOR	6 800	377	75	0	7 252	1,58	362	0
SWE	3 350	633	254	0	4 237	0,47	371	60
USA	100 000	133 000	219 000	27 000	479 000	1,62	103 000	70 000
Estimated total	**202 276**	**311 199**	**3 022 416**	**160 909**	**3 696 800**		**1 092 851**	**1 039 917**

Notes: Portugal not included. ISO country codes are outlined in Table 12. Some countries are experiencing difficulties in estimating and/or apportioning off-grid domestic and non-domestic; in some markets the distinction between grid-connected distributed and centralized is no longer clear (eg MW scale plant in the urban environment), and mini-grids using PV are also emerging, with other problems of definition. Where definition has not been made in a national report this is shown in this table, however the totals have been estimated using the most recently available ratio from the national reports applied to the current national data.

Workshops

The PV Bubble: Behind the News
Dresden, Sept. 2006

Ziel dieses Workshops war es, im Gespräch mit unseren Stakeholdern (PV-Publikationen, Industrie, Anlage-Research-Teams) den Prozess der Herstellung des Trends Reports (Datenbeschaffung und Interpretation) zu erklären. Im weiteren wollten wir die Wünsche unserer „Kunden“ soweit möglich besser in die nächstjährige Ausgabe einfließen lassen. Der Workshop war ein voller Erfolg mit sehr guten Diskussionen und Anregungen für Task 1.

Dieser Workshop wurde hauptsächlich durch die Schweiz organisiert.

A Wealth of Investment Opportunities Under the Sun
Zurich, Switzerland - Tuesday 14th November 2006

Zum ersten mal führte Task 1 einen Workshop zielgerichtet für die Finanzwelt durch.
Das Thema des Treffens war dementsprechend gewählt: Investitionsmöglichkeiten in der Solarindustrie.

Es ist uns gelungen, sehr attraktive ReferentInnen für diesen Anlass zu engagieren.
Die Zahl der Teilnehmer war eher etwas knapp, nichtsdestotrotz ergaben sich aber sehr gute Gespräche und positive Signale für eine weitere Zusammenarbeit.

Finanziert wurde der Workshop durch die Teilnehmerbeiträge, einen Beitrag des Schweizer PVPS Pools und dem Sponsor **INrate AG.**
Das Kosten-Risiko wurde durch Nova Energie GmbH und RTS Corporation, Japan, übernommen.

Die Referate können unter www.iea-pvps.org eingesehen werden.

Programme Outline

09:00	**Registration & Coffee**
09:30	**Welcome and Introduction** Dr Stefan Nowak, Chairman IEA PVPS
09:40	**Investing in Energy Efficiency and Climate Change** Danielle Lalive d'Epinay, CEO, INrate, Switzerland
10:00	*Key note speech* **PV: One of our core future energy sources The photovoltaics industry, today and tomorrow** Osamu Ikki, Chairman, RTS Corp, Japan
10:30	**Trends in PV applications - Growth rates, main markets and drivers** Greg Watt, Operating Agent, PVPS Task 1, Australia
10:45	**PV perspectives – Technologies, applications and market prospects -** Stefan Nowak
11:00 – 11:20 Coffee Break	
11:20	**National trends and outlook in key markets:** **Germany** *Dr Winfried Hoffman, President,* Bundesverband Solarwirtschaft (BSW) **Japan** Izumi Kaizuka, Osamu Ikki, RTS Corp, Japan **USA** Susannah Pedigo, NREL, USA **Europe** Michel Viaud, Secretary General, EPIA, Belgium
12:30 – 14:00 Lunch Break & Networking Opportunity	
14:00	**The PV-Industry: Current Investment Risks and Opportunities** Dr. Matthias Fawer, Sarasin Bank, Switzerland
14:20	**A growing demand in emerging countries – Millennium Development Goals** Peter AHM, PA Energy, Denmark
14:40	**Hot Issues Panel Government policies – Opportunities and threats; The solar grade silicon bottleneck – Is it a real threat for future growth? Breakthroughs in new technologies – What can we expect within the next decade? The industry's answer – Innovation and flexibility Investments in PV – What are the sticking points?** Chairman: Greg Watt; Panelists Stefan Nowak, Osamu Ikki, Winfried Hoffmann, Olaf Martin (Vontobel Research), Pius Hüsser (Advisory Board INrate AG), Michel Viaud, Izumi Kaizuka
16:15	**Conclusions** Stefan Nowak
16:30 Close & Cocktail Reception	

5/6

Nationale / internationale Zusammenarbeit

Im Berichtsjahr fanden 2 Task 1 Meetings statt:

März 2006	Vancouver, Kanada Joint Meeting mit Task 2, 9 und 10 Vorbereitung des Trends Reports 2006 Workshop-Konzept für Dresden und Grobplanung Zurich
September 2006	Wien Abschluss des Trends Reports Planung 2007: Workshops, Konferenzen, Trends Report
Konferenzen	Europäische Photovoltaik-Konferenz in Dresden, Oral Presentation (durch Izumi Kaizuka) zum Trends Report 2005
Workshops	Für beide Workshops war die Schweiz federführend für Konzeption, Organisation, Administration

Sarasin Report: Für den durch die Bank Sarasin erstellten jährlichen Report zum Status der Solarenergienutzung lieferte Task 1 zum frühst möglichen Zeitpunkt die Marktzahlen 2005.

Bewertung 2006 und Ausblick 2007

Die internationale Anerkennung unseres Hauptwerks - Trends Report – steigt weiter.
Dank dieser Anerkennung erleichtert es uns auch den Zugang zu besseren Daten als Grundlage für die Länder- und Firmenstatistik.

Am Workshop in Dresden führten wir einen erfolgreichen Dialog mit unseren Stakeholdern mit dem Ziel, die Wirkung unserer Arbeit weiter zu verbessern.

Erstmals führte Task 1 einen Workshop für Finanzfachleute durch. Auch wenn der Teilnehmeraufmarsch nicht berauschend war, haben wir für unsere interne Arbeit sehr viele sehr gute Feedbacks erhalten und wichtige neue Kommunikationskanäle geöffnet.

Ein Problem für unsere Arbeit stellte die mangelhafte Verfügbarkeit unserer Webseite dar. Dies wird ein Hauptpunkt unser Aktivitäten im 2007 bilden: Facelifting und inhaltliche Überarbeitung der Webseite.

Im Moment sind 3 Workshops geplant:

Am Task 1 Meeting in Mexiko (Juni 07) soll ein Workshop mit MitarbeiterInnen der Mexikanischen Regierung durchgeführt werden (Lead: Greg Watt)

In Kombination mit der Europ. PV-Konferenz findet in Milano (Sept. 2007) ein Workshop für die Finanzwelt statt (Lead: Pius Hüsser)

Analog zum erfolgreichen Shanghai-Workshop soll etwas ähnliches anlässlich der asiatischen PV-Konferenz in Fukuoka, Japan im Dezember 2007 durchgeführt werden (Lead: Izumi kaizuka).

Referenzen

[1] P. Hüsser, Th. Hostettler, ***National Survey Report on PV Power Applications in Switzerland 2005***, Mai 2006

[2] ***Trends in Photovoltaic Applications in selected IEA countries between 1992 and 2005***, IEA, PVPS, Task I – 15:2006

[3] Internet site ***www.iea-pvps.org***

[4] G Watt, P Hüsser, I Kaizuka & P Cowley, ***GLOBAL ASPECTS OF PV DEVELOPMENT***
Trends in photovoltaic applications – latest results from the IEA-PVPS Programme surveys
Oral Presentation an der Europ. PV-Konferenz*, Sept. 2006, Dresden*

Schweizer Beitrag zum IEA PVPS Programm Task 2 - 2006

Annual Report 2006

Author and Co-Authors	Thomas Nordmann, Luzi Clavadetscher
Institution / Company	TNC Consulting AG
Address	Seestrasse 141, CH 8703 Erlenbach
Telephone, E-mail, Homepage	+41 (0) 44 991 55 77, mail@tnc.ch, www.tnc.ch
Project- / Contract -Number	14805 / 151935
Duration of the Project (from – to)	January 2006 - December 2006
Date	12.1.2007

ABSTRACT

Switzerland takes part in the Photovoltaic Power Systems (PVPS) programme of the International Energy Agency (IEA), Task 2. The overall objectives of the Task 2 is to improve the operation, sizing, electrical and economic output of photovoltaic systems and components by collecting, analysing and disseminating information on their technical and economic performance and reliability, providing a basis for their assessment, and developing practical recommendations. The actual work of Task 2 is organised in four active Subtasks.

Activities of Phase III, 2004 - 2007

Subtask 1 : Performance Database (enrichment and dissemination of the performance database) This tool has now worldwide more than 3'000 users form 90 different countries. It is being updated at least once a year by the expert-group. The database is now available online at the public website http://www.iea-pvps-task2.org .

Subtask 5 : Technical Assessments and Technology Trends of PV Systems This Task is developing know-how and experience concerning the long-term reliability as well as the user-awareness of PV systems and ways to analyse and predict the performance of PV systems.

Subtask 6 : PV System Cost over Time (Activity leader Switzerland) The global economical survey aims at gathering information on plants, technical performance, maintenance and cost of as many PV systems as possible. With an Internet-based survey tool performance and economic data was collected over the past year.

Subtask 7 : Dissemination Acitivities, Educational Tools.

This project is supported by the Swiss Federal Office of Energy.

Einleitung / Projektziele

Die Ziele von Task 2 sind:

- Verbreitung von technischen Informationen und Know-how zur Performance, Langzeitverhalten und Auslegung von PV-Systemen an die Zielgruppen.
- Die Zielgruppen sind, andere PVPS Tasks und PV Experten, Forschungsstellen, Elektrizitätswerke und Industrie, das heisst Hersteller von Komponenten, System Entwickler und Installateure, Normenverbände und Universitäten und Schulen.

Mitglieder des Task 2 sind folgende Länder und Organisationen :

Deutschland (Taskleitung), European Photovoltaic Industry Association, Europäische Union, Frankreich, Grossbritannien, Italien, Japan, Kanada, Oesterreich, Schweiz, Schweden, Vereinigte Staaten und Polen (als Beobachter).

Task 2 befindet sich in der dritten Phase (2004 - 2007).

Kurzbeschrieb des Projekts / der Anlage

Um die notwendigen Informationen über die Performance und das Langzeitverhalten von PV-Systemen zu erhalten wurde eine Internationale Datenbank (IEA PVPS Performance Database) aufgebaut und den Zielgruppen zugänglich gemacht. Die Anlage- und Betriebsdaten wurden während den letzten Jahren von den Mitgliedern des Task 2 eingesammelt, aufbereitet und verbreitet. Seit Dezember 2006 ist die Datenbank auch interaktiv im Internet verfügbar (http://www.iea-pvps-task2.org/database/).

Durchgeführte Arbeiten und erreichte Ergebnisse

Arbeiten des Task 2:

- Zwei Task Meetings
  4. Vancouver, CAN, März 2006
  5. Wien, AUT, September 2006

Subtask 1:

International Database (DEU)

- Performance Database on the Web

Subtask 5:

Technical Assessments and Technolgy Trends of PV Systems

- PV in the Built Environment (EU)
- Long-term Reliability of PV Systems (AUT)
- User's Awareness of PV System Performance (JPN)
- Performance Prediction (FRA, CAN)

Subtask 6:

PV System Cost over Time (CHE)

Subtask 7:

Dissemination Acitivities

- Educational Tools (ITA)

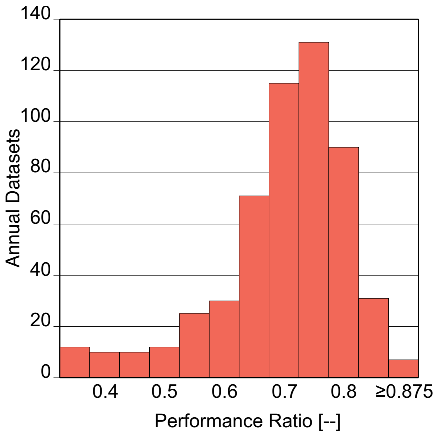
Subtask 1, IEA PVPS Datenbank Internet

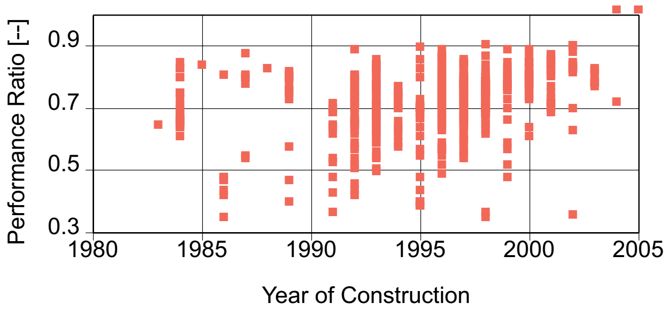
Ein grosser Schritt war die Veröffentlichung der IEA PVPS Performance Datenbank im Internet. Die gesamte Datenbank, mit mehr als 460 Anlagen aus 22 Ländern mit insgesamt 1600 Betriebsjahren, ist seit Dezember 2006 im Internet unter: http://www.iea-pvps-task2.org/database/ , interaktiv verfügbar. Durch die Eingabe von verschiedenen Such kriterien können die Daten der Anlage und Betriebswerte einzelner Systeme oder ausgewählten Gruppen aufgerufen werden. Die Datenbank im Internet wird ständig mit den neuesten Daten aktualisiert.

Subtask 6, PV System cost over time

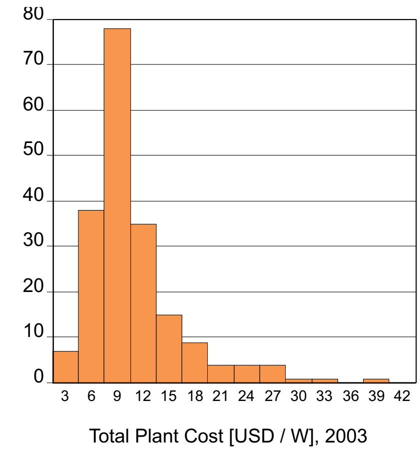
Die Schweiz leitet den Subtask 6. Anlässlich der 20. Europäischen Photovoltaik-Konferenz in Barcelona, Juni 2005 wurde der Global Economic Survey gestartet.

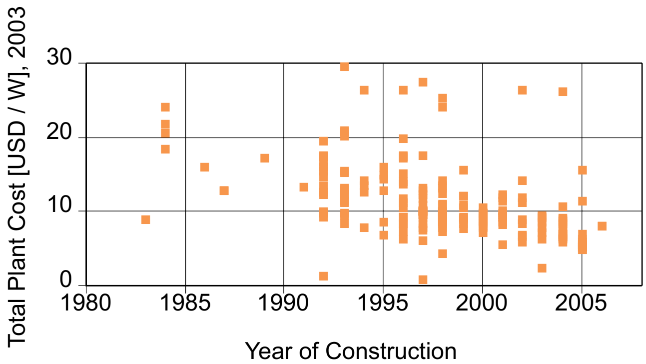
Die Erfassung der Daten wurde im November 2006 abgeschlossen und enthält Oekonomische- und Betriebsdaten von 680 Anlagen aus 19 Ländern. Darin enthalten sind auch zum Teil die Projekte, aus der Performance Database, welche ökonomische Daten enthalten. Erste Auswerten zeigen einen zeitlichen Trend wie zum Beispiel bessere Performance (Figuren 1 und 2) und günstigere Anlagen (Figuren 3 und 4).





Figur 1 und 2, Performance Ratio (PR) von Netzverbundanlagen.





Figur 3 und 4, Investitionskosten [USD/W] für Netzverbundanlagen.

Nach 18 Monaten konnten weniger Daten als erwartet eingesammelt werden. Die Mitglieder des Task 2 haben sich dann geeinigt, das einige Mitglieder zusätzlich noch eine Case Study zum Thema, Performance, Kosten oder Unterhalt von einigen ausgesuchten Anlagen oder Projekten zusammenstellen. Diese Case Studies sind als Ergänzung zu den Daten der Survey gedacht. Alle Daten werden im Jahre 2007 ausgewertet und in einem Report zusammengefast.

Nationale / Internationale Zusammenarbeit

Die internationale Zusammenarbeit innerhalb des Task 2, sowie die Intertask-Kooperation sind ein wesentlicher Bestandteil des IEA PVPS Implementing Agreements. Mit der Task 2 WWW-Homepage und der Online PVPS Performance Datenbank sind Informationen über die Aktivitäten, sowie die komplette Datenbank für die Zielgruppen zugänglich. Die Europäische PV Konferenz in Dresden bot Gelegenheit die Resultate der Aktivitäten des Task 2 vorzustellen.

Bewertung 2006 und Ausblick 2007

Die interaktive Online Datenbank ist ein gutes Werkzeug zur Verbreitung der Arbeiten des Task 2. Im Jahre 2007 ist eine Neuauflage des Country Reports [2] geplant und die Analyse der Daten der Economic Survey, sowie die Case Studies der einzelnen Mitgliedländer soll ebenfalls publiziert werden. Vom Subtask 5, Technical Assessments and Technolgy Trends of PV Systems, sind mehrere Publikationen angekündigt. Im laufenden Jahre werden zwei Task 2 Meetings, in Japan und in der Schweiz durchgeführt.

Referenzen / Publikationen

[1] S. Mau, U. Jahn: ***Performance Analysis of Grid-Connected PV Systems,*** 21st European Photovoltaic Solar Energy Conference and Exhibition, Dresden, Germany, 6BO.7.1, September 2006.

[2] IEA PVPS Task 2, ***Country Reports on PV System Performance,*** Report IEA-PVPS T2-05:2004, December 2004.

[3] IEA PVPS Task 2, ***Analysis of Photovoltaic Systems,*** Report IEA-PVPS T2-01: 2000.

[4] International Electrotechnical Commission (IEC), ***Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange and Analysis***, Standard IEC 61724.

[5] ***Guidelines for the Assessment of Photovoltaic Plants,*** Document A: ***Photovoltaic System Monitoring***, Issue 4.2, June 1993, Document B: ***Analysis and Presentation of Monitoring Data***, Issue 4.1, June 1993, JRC, E.S.A.S. I-21020 Ispra Italy.

Datenbank

[6] ***Performance Database***, Version 1.19, Edition: Sept 2006, auf CD-ROM für EUR 20.- erhältlich bei der Taskleitung: Ulrike Jahn, ZAE Bayern, D-91058 Erlangen, E-Mail: jahn@zae.uni-erlangen.de , als Download oder interaktiv auf der Task 2 Homepage: http://www.iea-pvps-task2.org/database/.

IEA PVPS

Info auf Webseite: http://www.iea-pvps.org/

SWISS INTERDEPARTMENTAL PLATFORM FOR RENEWABLE ENERGY PROMOTION IN INTERNATIONAL CO-OPERATION (REPIC)

Annual Report 2006

Author and Co-Authors	S. Nowak , G. Favaro
Institution / Company	NET Nowak Energie & Technologie AG
Address	Waldweg 8, CH-1717 St. Ursen
Telephone, E-mail, Homepage	+41 (0) 26 494 00 30, info@repic.ch, http://www.repic.ch
Project- / Contract Number	SECO UR-00123.01.01
Duration of the Project (from – to)	March 2004 – June 2007 (Phase I)
Date	January 2007

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 founded a interdepartmental platform for the promotion of renewable energy in international cooperation. The REPIC-Platform contributes to the implementation of global climate protection agreements and to a sustainable energy supply in developing and transition countries, as well as in Switzerland, and represents an important part in the implementation of the Swiss policy for sustainable development on the international level. The REPIC Platform thereby represents an important contribution to the creation of a coherent policy and strategy in Switzerland, for the promotion of renewable energy in international cooperation.

The specific goals of the REPIC platform in relationship with renewable energy in international co-operation are:

1. Information and awareness of the actors
2. Knowledge of local framework conditions and improvement of capacities
3. Project promotion and project realisation
4. Contribution to international networks
5. Co-ordination and quality control

The measures of the REPIC Platform are subsidiary to national and international promotion instruments which already exist. The measures are meant to support these instruments, especially in the area of finance (project lines of the governmental agencies involved, SOFI, mixed credits, WB, IFC, GEF, and similar) and climate policy instruments (Kyoto-mechanisms). Furthermore, the measures of the REPIC-Platform should provide for synergies between activities from the private sector and the civil society.

Einleitung

Die seit 2004 bestehende REPIC-Plattform zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit – Renewable Energy Promotion in International Co-operation – 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). Die REPIC Plattform stellt eine neue Form der interdepartementalen Zusammenarbeit dar. Während bisher die einzelnen an der REPIC-Plattform beteiligten Ämter in der Regel individuell und punktuell Projekte mit erneuerbaren Energien in der internationalen Zusammenarbeit gefördert haben, erfolgt mit dieser Initiative ein koordinierter Ansatz zur Förderung solcher Projekte. Damit wird eine bessere Koordination zwischen den beteiligten Ämtern und ein einheitlicheres Vorgehen angestrebt. Die REPIC-Plattform wirkt subsidiär zu bestehenden Instrumenten der beteiligten Ämter und entfaltet insbesondere dort Wirkung, wo bisher keine oder wenig Aktivitäten stattgefunden haben.

Die REPIC-Plattform trägt zur Umsetzung der globalen Klimaschutzvereinbarungen und zur Förderung einer nachhaltigen Energieversorgung in Entwicklungs- und Transitionsländern ebenso wie in der Schweiz bei und ist ein wichtiger Bestandteil der Umsetzung der schweizerischen Politik der nachhaltigen Entwicklung auf internationaler Ebene. Damit leistet die REPIC-Plattform einen wichtigen Beitrag zur Schaffung einer kohärenten Politik und Strategie der Schweiz zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit. Der vorliegende 3. Jahresbericht beschreibt die Aktivitäten, Resultate und Erfahrungen im 3. Jahr der REPIC-Plattform.

Kurzbeschrieb

REPIC versteht sich als marktorientiertes Dienstleistungszentrum zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit. Unter Berücksichtigung der vorhandenen Erfahrungen ermöglicht diese Plattform neue konkrete Projekte mit erneuerbaren Energien unter vermehrter Mitwirkung von Schweizer Unternehmen und Organisationen. Sie baut dazu kontinuierlich ein Netzwerk zur Information und Sensibilisierung interessierter Kreise auf, pflegt den Erfahrungsaustausch zwischen verschiedenen Akteuren und fördert die Kenntnis von lokalen Rahmenbedingungen und Projektmöglichkeiten. Zur Realisierung erfolgversprechender Projekte mit erneuerbaren Energien kann die REPIC-Plattform Beiträge zu einer Anschubfinanzierung leisten. Darüber hinaus erfolgt über die REPIC-Plattform die Mitwirkung in internationalen Netzwerken.

Die REPIC-Plattform umfasst die folgenden Arbeitsebenen:

1. Strategische Leitung, gebildet durch die Direktoren der beteiligten Bundesämter
2. REPIC-Steuergruppe, gebildet durch Vertreter der beteiligten Bundesämter
3. REPIC-Sekretariat, bei NET Nowak Energie & Technologie angesiedelt

Die einzelnen Ansprechpartner sind im REPIC-Leitfaden [1] aufgeführt.

Ziele 2006

Nachdem während dem ersten Jahr das Sekretariat zusammen mit der REPIC-Steuergruppe die Detailausführung der Plattform (die Prozeduren, die Kriterien, die Hilfsmittel zur Projektförderung und das Kommunikationskonzept) erarbeitet und umgesetzt hatte, wurden im zweiten Jahr die ersten Erfahrungen mit geförderten Projekten gesammelt, sowie eine effiziente Gesuchsbearbeitung und Projektabwicklung umgesetzt. Für das Jahr 2006 waren folgende Themen aktuell:

konzeptionell:

- die Sammlung und die Analyse von Erfahrungen mit geförderten sowie nicht geförderten Projekten (Erfolge, Misserfolge, Schwierigkeiten)
- die Einschätzung der Auswirkungen der verschiedenen REPIC Aktivitäten (geförderte Projekte, verwendete Technologien, Mobilisierung, Koordination, Wirkung, Effizienz)
- Ist/Soll-Vergleich mit den REPIC-Grundlagen (Konzept, Mandat)
- Vorbereitung der Evaluation und Strategiediskussion
- Notwendige Änderungen und Fokussierung
- Bedarf und Möglichkeiten der Fortsetzung ab 2007

operationell:

- eine wirkungsvolle Gesuchsbearbeitung und eine plangemässe Projektabwicklung
- die systematische Kommunikation durch die REPIC Website und Berichterstattung
- punktuelle Kommunikationsmassnahmen
- Optimierung der Abläufe
- systematische Koordination und Schnittstellenbearbeitung
- Netzwerktätigkeit

Entsprechend den für 2004 und 2005 definierten Elementen und aufgrund der Erfahrungen in den ersten zwei Jahren wurden im Jahr 2006 die folgenden Schwerpunkte verfolgt:

1) **Erfahrungen** und **Wirkung** der bisherigen REPIC-Strategie
2) Punktuelle Erweiterung von **Information, Kommunikation und Mobilisierung**
3) Bearbeitung und Formalisierung von **Projekteingaben**, Stellungnahmen und Entscheidfindungen; Unterstützung und Begleitung von Projekten, Berichterstattung
4) **Dialog** mit anderen Organisationen (z.B. Swissflex, Stiftung Klimarappen)

Evaluation und **Strategiediskussion** für eine mögliche **Verlängerung** von REPIC ab 2007

Durchgeführte Arbeiten und erreichte Ergebnisse

Projektarbeit

Im Verlauf von 2006 wurden 18 neue Vorschläge bearbeitet; davon wurden 10 durch die REPIC-Steuergruppe behandelt und entschieden. Von den 10 entschiedenen Vorschlägen mündeten 3 in eine direkte finanzielle Unterstützung durch die REPIC-Plattform, 2 erfolgten in der Form der Organisation von Veranstaltungen (SAEE Jahrestagung und Biofuels Seminar), kein Vorschlag wurde nach eingehender Evaluation abgelehnt und auf 6 Vorschläge wurde nicht näher eingetreten. Von den restlichen 7 Vorschlägen befanden sich Ende 2006 noch 2 Vorschläge in weiterer Klärung, die übrigen 5 wurden nach den erfolgten Erstkontakten von den Gesuchstellern vorderhand nicht weiterverfolgt. Bei den durch REPIC neu unterstützten Projektvorschlägen betreffen zwei Projekte die Biomasse und ein Projekt den Wind. Damit ergibt sich für 2006 das Bild gemäss Tabelle 1.

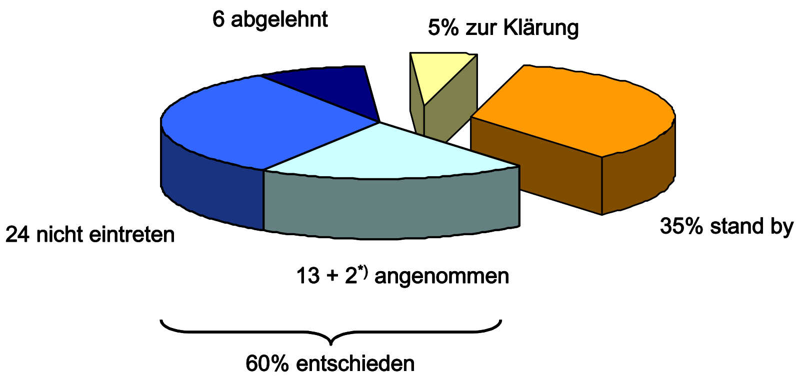
Tabelle 1 : Stand der Vorschläge 2006

Status	angenommen	abgelehnt	zur Klärung	stand by	Total
Anzahl	3+2*)	6	2	5	18

**) 3 technische Projekte und 2 Tagungen mit REPIC Organisation (SAEE Jahrestagung und Biofuels Seminar)*

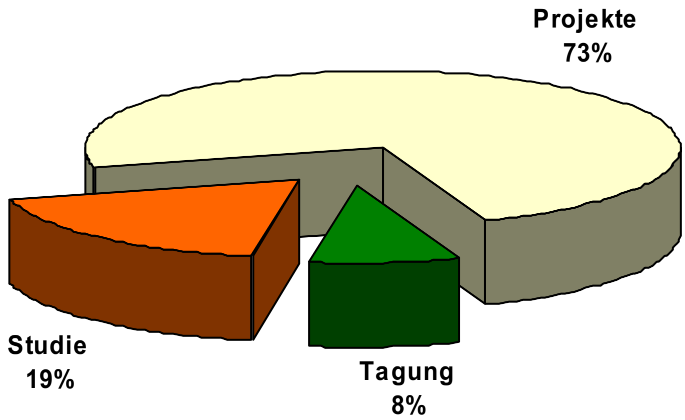
Mit einem Total von 18 Anfragen erfolgten 2006 insgesamt etwas weniger Anfragen als 2005 (22 Anfragen) und 2004 (35 Anfragen). Dieser Sachverhalt wird nicht als sinkendes Interesse sondern eher als Resultat einer zielgerichteten Vorgehensweise und Kommunikation gesehen. Dies wird auch dadurch belegt, dass die Ausrichtung und Qualität der Anfragen im 3. Jahr besser geworden ist: 27% der 2006 eingereichten Anfragen wurden unterstützt (2005 waren es 22% und 2004 waren es demgegenüber nur 14%).

Damit wurden seit Beginn der REPIC-Plattform bis Ende 2006 insgesamt 75 Projektanfragen eingereicht. Figur 1 stellt den Stand dieser Anfragen zusammen. Allgemein entsprachen 2006 die Anfragen besser den REPIC Zielsetzungen. Bei einzelnen Projektanfragen stellen sich aber trotzdem Abgrenzungsfragen zwischen der REPIC-Plattform und anderen Fördermechanismen. Ein umfassendes Verständnis der verschiedenen Instrumente im Bereich der internationalen Zusammenarbeit ist bei vielen Akteuren noch nicht oder nur teilweise vorhanden.

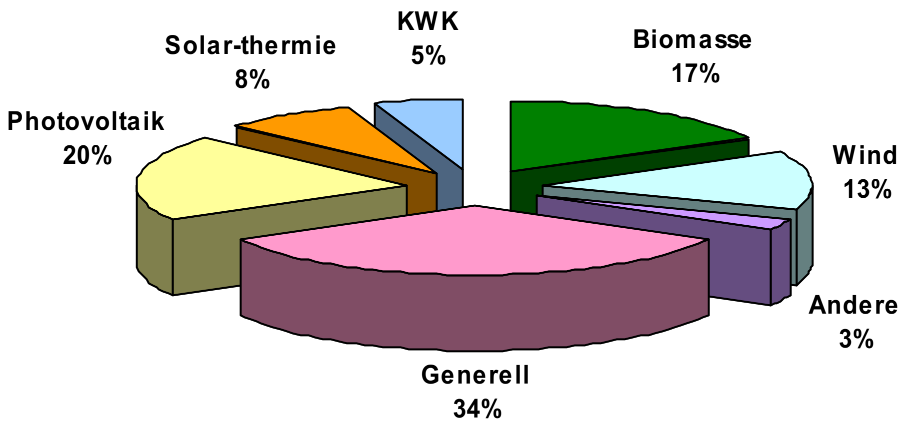


Figur 1 : *Stand der Anfragen und Vorschläge (Periode 2004 - 2006)*

**) 12 Projekte, 1 Tagung mit finanziellem Beitrag und 2 Tagungen mit REPIC Organisation*



Figur 2 : *Art der Projektanfragen (Periode 2004 - 2006) 55 technische Projekte, 14 Studien und 6 Tagungen*



Figur 3: *Verteilung der Projektvorschläge (Periode 2004-2005)auf die verschiedenen Technologien*

In Bezug auf die geografische Verteilung der neu unterstützten Projekte betrafen zwei die Zielregion Afrika, eines Südamerika, eines Asien und eines hat keinen spezifischen geografischen Fokus.

Kommunikation und Information

Die laufende Information wurde einerseits durch die regelmässig nachgeführte REPIC Website (www.repic.ch) sichergestellt. Die Website ist in 3 Sprachen (d/f/e) aktiv und enthält ausführliche Angaben zur REPIC-Plattform, allgemeine Dokumente sowie spezifische Informationen zu unterstützten Projekten. Andererseits wurden, entsprechend dem REPIC Kommunikationskonzept, Projekt-Leitfaden [1] und Flyer [2] regelmässig verteilt.

Im Jahr 2006 hat REPIC zwei Veranstaltungen mitorganisiert: die Jahrestagung der *Swiss Association for Energy Economics (SAEE) „Economic Prospects for New Energy Technologies in Emerging Markets“* und das Biofuels Seminar *„Growing Fuel in Developing Countries : Lessons from Brazil and India“* (siehe unten). Zusätzlich wurde REPIC auch an der Konferenz *Swiss Renewables* der Agentur für Erneuerbare Energien (AEE) vom 29.11.06 vorgestellt.

SAEE Jahrestagung, Economic Prospects for New Energy Technologies in Emerging Markets

Die SAEE Jahrestagung *„Economic Prospects for New Energy Technologies in Emerging Markets”* fand am 1. September im Bern statt. Die Ziele der SAEE (Schweizerische Fachvereinigung für Energiewirtschaft) sind unter anderen die Verbesserung des Informationsflusses über energieökonomische Erkenntnisse zwischen Hochschulen, Unternehmungen, öffentlichen Verwaltungen, Politik usw. und die Förderung der wissenschaftlichen Aktivitäten im Bereiche der Energiewirtschaft und Energiepolitik. Während der Tagung wurde die Rolle der Schweiz in Energiemärkten von Schwellenländer diskutiert und Beispiele von wirtschaftlichen Aussichten für erneuerbare Energien in neuen Märkten präsentiert. Die einzelnen Beiträge sind öffentlich zugänglich [3].

Biofuels Seminar, Growing Fuel in Developing Countries, Lessons from Brazil and India

Auf Grund einer Initiative der DEZA fand am 31.Oktober 2006 in Bern ein Seminar zum Thema Biofuels in Entwicklungsländern statt. Das Seminar wurde in Zusammenarbeit mit dem *International Institute for Sustainable Development (IISD)* in Genf organisiert. Die Ziele des Seminars waren zum Einen eine aktuelle Übersicht über das Thema Biofuels, insbesondere zu Potentialen und Einschränkungen zu gewährleisten, zum Anderen über spezifische Erfahrungen aus Brasilien und Indien zu berichten.

Das Seminar richtete sich an Mitglieder der Bundesverwaltung sowie ausgewählter Organisationen mit Aktivitäten oder Interesse an diesem Thema. Rund 60 Teilnehmer aus Verwaltung, Forschung, Privatsektor, NGO’s und internationalen Organisationen bestätigten die Aktualität des Themas. Das Seminar war in drei Teile strukturiert: eine Eröffnungssession, eine Session mit Fallstudien aus Brasilien und Indien sowie eine Session über künftige Perspektiven und Herausforderungen. Eine CD-ROM [4] mit der Zusammenfassung des Seminars enthält alle Beiträge sowie weitere wichtige Berichte und Publikationen.

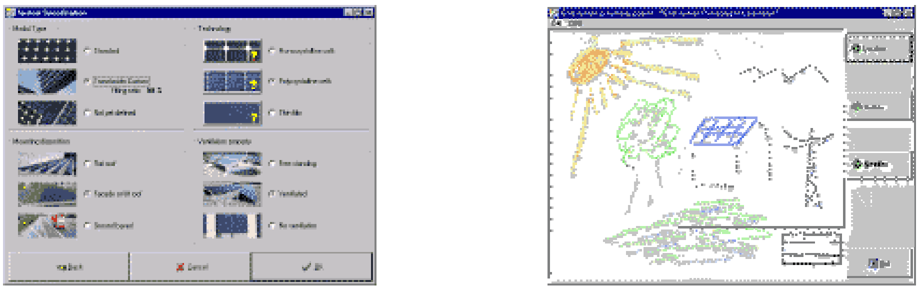
Figur 4: *Eindruck vom Biofuels Seminar*

AEE Veranstaltung, Swiss Renewables 2006

Die Agentur für erneuerbare Energie und Energieeffizienz (AEE) hat am 29.11.2006 in Biel die auf grosses Interesse stossende Konferenz *Swiss Renewables* durchgeführt. Die Konferenz war der Bedeutung der erneuerbaren Energien für die Versorgungssicherheit gewidmet und wollte damit neue Impulse für Wirtschaft und Politik schaffen. Fachleute aus dem In- und Ausland beleuchteten in Biel die These der erneuerbaren Energieversorgung aus drei Blickwinkeln: Sicherheit, Wirtschaft und Entwicklungszusammenarbeit sowie energetisches Potenzial. Die einzelnen Beiträge sind öffentlich zugänglich [5].

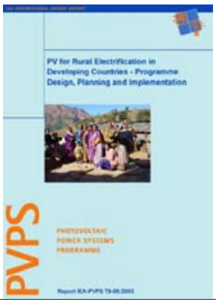
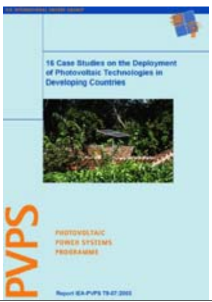
Unterstützte Projekte

Insgesamt hat die REPIC-Plattform bisher 13 Projekte unterstützt (vgl. oben). Ausführliche Informationen zum Stand und den Resultaten aller Projekte sind dem REPIC-Jahresbericht zu [6] entnehmen. Im Folgenden werden hier nur die Photovoltaik Projekte aufgeführt.

Beitrag an die Erweiterung der Simulationssoftware PVSyst für solare Wasserpumpen	
Projektart	Massnahmen zur Ausbildung und Qualitätssicherung
Schweizer Partner	Centre Universitaire d'étude des problèmes de l'énergie – CUEPE www.unige.ch/cuepe/
Technologie	Photovoltaik
Beschreibung	Dieses Projekt hat zum Ziel, eine generell verwendbare Simulations- und Optimierungsprozedur für photovoltaisch betriebene Wasserpumpen zu erarbeiten und diese der verbreiteten Software PVsyst einzubauen. Dies beinhaltet in erster Linie die Ausarbeitung eines allgemeinen Modells des elektrischen und hydraulischen Verhaltens der Pumpe, welches für alle Betriebszustände in einem Photovoltaik System Gültigkeit besitzt. Dieses Modell sollte aufgrund der üblichen Spezifikationen der Hersteller erstellt werden können. Das Modell muss sodann in den Simulationsprozess des gesamten Systems eingebaut werden. Dazu erfolgt eine stündliche Simulation, welche den Umgebungsbedingungen (Wetter, Bedürfnisse des Nutzers, Verhalten der Quelle) sowie den aktuell verfügbaren Technologien (direkte DC Kopplung, Wechselstrombetrieb, Stützbatterie, usw.) Rechnung trägt. Das zu erarbeitende Werkzeug richtet sich an Projektentwickler von solaren Wasserpumpen, welche mehrheitlich in südlichen Ländern zum Einsatz kommen. Es wird nebst den technischen auch pädagogische und didaktische Elemente enthalten, welche das Verständnis des Verhaltens dieser Anwendungen fördern und hat damit auch Bedeutung für die technische Ausbildung.
Land	Global
Schweizer Beitrag	Dieses Projekt ergänzt die bereits erfolgreich eingesetzte Software PVSyst um die Komponente solare Wasserpumpen. PVSyst wurde seit 1993 mit der Unterstützung des Bundesamtes für Energie an der Universität Genf entwickelt und ist heute eines der international weit verbreiteten Programme zur Simulation von Photovoltaik Systemen.
Projektstatus	abgeschlossen
Dokumentation	Schlussbericht „Technico- economical Optimization of Photovoltaic Pumping System“ [7] zu beziehen bei NET Nowak Energie und Technologie AG, CUEPE (Université de Genève) oder www.repic.ch. Weitere Informationen: www.pvsyst.com  ***Fig 7 :*** *Screenshot der PVsyst Software*

Resultate gemäss Schlussbericht

Die erste Version der Datenbank der PVSyst Software enthält ca. 100 verschiedene Pumpenmodelle. Die Simulation behandelt 3 Typen von Pumpensystemen (tiefe Quellen, Wasser aus Seen und Flüssen sowie Wasser aus Drucksystemen); fast jede Konfiguration von Pumpensystem kann gewählt werden. Die Resultate der Simulation zeigen die Performanz und die Schwächen von ausgewählten Konfigurationen. Es können Vergleiche zwischen verschiedenen Optionen erstellt werden. Diese zeigen, dass DC-Systeme im Allgemeinen schwieriger richtig zu planen sind und immer weniger effizient sind als Lösungen mit Wechselrichter.

Schweizer Beitrag im IEA PVPS Projekt „Photovoltaic Services for Developing Countries“	
Projektart	Internationales Projekt im Rahmen der IEA-Zusammenarbeit
Schweizer Partner	entec AG, St. Gallen ; www.entec.ch
Technologie	Photovoltaik
Beschreibung	Gestützt auf die umfangreichen weltweiten Erfahrungen mit Photovoltaik Anlagen in Entwicklungsländern, strebt dieses Projekt die Erhöhung von erfolgreich und nachhaltig betriebenen Anlagen dieser Art für unterschiedliche Zwecke an. Die internationale Expertengruppe umfasst auf diesem Gebiet eine breite Projekterfahrung und konzentriert ihre Arbeit insbesondere auf die nicht-technischen Aspekte dieser Anwendungen. Durch den Status eines internationalen Netzwerkprojektes ist die Expertengruppe in permanentem Kontakt mit zahlreichen internationalen Entwicklungsorganisationen.
Land	Internationales Projekt
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.
Projektstatus	laufend – IEA PVPS - PV SDC, die Arbeitsgruppe der Internationalen Energie Agentur - Photovoltaik Power Systems - Photo Voltaic Services for Developing Countries, hat sich zu zwei regulären Arbeitssitzungen getroffen (14th and 15th experts meeting): • Vancouver, Canada, 27.-28. März parallel zu drei weiteren PVPS Arbeitsgruppen Sitzungen (Task 1,2 und 10) • Makuhari, Japan, 10.-11. Oktober parallel zur Renewable Energy 2006 International Conference, Japan Die Arbeitsgruppe besteht aus Experten der folgenden Länder : Australien, Dänemark, Deutschland, England, Frankreich, Italien, Kanada, Schweden, Schweiz und neu aus einem Vertreter der „European Photovoltaic Association“ EPIA. In dieser Arbeitsgruppe wurde ein Dokument mit dem Arbeitstitel *„Deployment strategies for Renewable Energy options for rural electrification in developing countries: 10 key-recommendations from the IEA PVPS PV SDC expert team*” erarbeitet [8]. Unter Federführung der Schweiz ist ein Workshop *„PV-water pumping“* in Vorbereitung, bei welchem die bisherigen Erfahrungen von PV Wasserpumpen Projekten aufgearbeitet werden sollen.   
Dokumentation	Publikationen IEA PVPS Task 9, siehe www.oja-services.nl/iea-pvps/tasks/i_task09.htm

Förderung der Solarenergie für eine nachhaltige Entwicklung in Timbuktu, Mali	
Projektart	Infrastrukturorientiertes Projekt
Schweizer Partner	Wirz Solar GmbH – SolSuisse GIE Mali ; www.sundance.ch
Technologie	Photovoltaik
Beschreibung	Das Pilotprojekt SolSuisse Mali fördert die Entwicklung eines lokal verankerten Marktes und einer Infrastruktur für Solarenergie im Norden Malis und setzt ein Signal zu privatwirtschaftlichen Investitionen in dem bisher vernachlässigten Gebiet in und um Timbuktu. Zugang schaffen zu (erneuerbaren) Energien bedeutet besseren Zugang zu wirtschaftlichen Innovationen, zu verbesserten Einkommensmöglichkeiten, zu verbesserter Bildung und Ausbildung, zur Schaffung von Arbeitsplätzen und lokaler Märkte und damit zur Verbesserung des Lebensstandards und letztendlich zur Konsolidierung des Friedens in der Region. Das Projekt beinhaltet den Aufbau eines Ausbildungszentrums für lokale Solartechniker, eines Verkaufs- und Unterhaltsnetzes, die Installation von 2000 Solar Home Systems in der Region Timbuktu und den Bau von 8 solaren dörflichen Wasserversorgungen sowie die Mithilfe beim Aufbau eines lokal verankerten Mikrofinanzsystems.
Land	Mali
Schweizer Beitrag	Schweizer Erfahrungen in der solaren Wasserversorgungen und Ausbildung / Förderung des lokalen Know-Hows bezüglich erneuerbaren Energien bilden die Grundlage dieses Projektes. Im Projekt besteht eine gute Partnerschaft mit geeigneten lokalen Partnerinstitutionen.
Projektstatus	Die erste Phase ist abgeschlossen, ein Folgeantrag wurde angenommen und das Projekt ist zur Zeit laufend. Im Bereich Ausbildung konnten zwei Kurse (einer für die Brunnenwarte der bestehenden SunDance Wasserversorgungen und ein anderer zur Ausbildung von Solarinstallateuren) durchgeführt werden. Infolge mangelnder externer Finanzierung verzögerte sich das Projekt zum Aufbau des Ausbildungszentrums. Mit der Zusage zur Ko-Finanzierung der Pilot-PV-Windkraftanlage auf dem Gymnasium Timbuktu durch die Solarstrombörse des Kantons Basel-Stadt im August 2006 wurde der Weg frei zu deren Aufbau, der im November 2006 begann. Das grösste Defizit ist das noch fehlende Mikrofinanzsystem, für welches aber bedeutende Vorarbeiten geleistet wurden: so konnte mit Oikocredit eine internationale Mikrofinanz-Partnerorganisation gefunden werden, welche die Einführung dieser wichtigen Finanzierungsquelle vorbereitet. Solsuisse hofft, dass diese Option bis spätestens in einem Jahr funktioniert, denn dies ist eines der grössten Hindernisse, um v.a. die Elektrifizierungsprojekte voranzutreiben.  

Evaluation

Die von 2004 bis 2006 gemachten Erfahrungen mit der REPIC-Plattform bildeten im Berichtsjahr Gegenstand einer Evaluation, welche die bisherigen Aktivitäten und Resultate beurteilen und Empfehlungen für eine Fortsetzung der REPIC-Plattform formulieren sollte. Diese Evaluation umfasste eine interne Evaluation [9] durch das Sekretariat, die REPIC-Steuergruppe und die beteiligten Ämter sowie eine externe Begutachtung [10] durch eine international ausgewiesene Fachperson. Die wichtigsten Ergebnisse dieser Evaluation sind hier wiedergegeben:

Mit der REPIC-Plattform wurde gegenüber den Akteuren aus der Privatwirtschaft und der Zivilgesellschaft ein „one-stop-shop“ geschaffen, welcher die einschlägigen Fragestellungen mit den beteiligten Bundesämtern koordiniert und gemeinsam abgestimmte Antworten formuliert. Die REPIC-Plattform versteht sich damit als Kompetenz- und Dienstleistungszentrum in ihrem Aufgabenbereich und stützt sich für ihre Arbeit auf die Expertise in den Bundesämtern, den Energieforschungsprogrammen und fallweise beigezogenen Experten. Die REPIC-Steuergruppe begleitet die REPIC-Plattform in ihrem Tagesgeschäft und trifft die anfallenden Entscheidungen im Konsens. Die strategische Leitung (durch die Amtsdirektoren) beschliesst über die Strategie der REPIC-Plattform, das Jahresarbeitsprogramm und nimmt ihre Tätigkeitsberichte ab. Die Prozeduren der REPIC-Plattform haben sich weitgehend bewährt.

In der Periode 2004 – 2006 wurden (bis September 2006) insgesamt 73 Anfragen bearbeitet. Davon mündeten 44 in eine Entscheidung durch die REPIC-Steuergruppe. 12 Projekte erhielten einen finanziellen Beitrag, bei 2 weiteren – es sind dies Tagungen – war die REPIC-Plattform aktiv in die Vorbereitung mit einbezogen. Die Projekte sind technologisch, geografisch und wirtschaftlich betrachtet sehr unterschiedlich. Bisher (Stand September 2006) wurden 3 technische Projekte abgeschlossen, 4 weitere befinden sich in der Abschlussphase. Bei den abgeschlossenen Projekten konnten grosse Folgeprojekte ausgelöst werden.

Die REPIC-Plattform konnte der bisherigen projektbezogenen Nachfrage zeitlich und finanziell weitgehend nachkommen. Dies wird auch damit begründet, dass das Thema grosse Erfahrungen in einem komplexen Umfeld erfordert, die Kriterien der REPIC-Plattform hoch gesetzt sind und in der Schweiz entsprechendes Know-how im internationalen Kontext noch nicht sehr verbreitet ist. Die relevanten Zielgruppen seitens der Privatwirtschaft konnten gut erreicht werden, die Akteure der Zivilgesellschaft sind dagegen schwieriger für das Thema zu mobilisieren. Die Resultate der bisher geförderten Projekte und die damit verbundenen grossen Folgeprojekte zeigen aber auch, dass das Potenzial vorhanden ist, hier mit einem guten Verhältnis von Kosten und Nutzen viel zu erreichen.

Die REPIC-Plattform hat ihre konkreten Ziele in der Laufzeit 2004 – 2006, soweit diese in der zur Verfügung stehenden Zeit bemessen werden können, zahlenmässig gut erreicht. Hingegen ist man bei den übergeordneten Zielen noch weit entfernt und es stellt sich die Frage, ob diese Ziele richtig gesetzt wurden.

Die Initiative der REPIC-Plattform hat sich in den Augen der REPIC-Steuergruppe in ihren allgemeinen Zielsetzungen und in ihrem operativen Ansatz bewährt. Das gemeinsame Engagement der vier Bundesämter auf dem Gebiet der internationalen Zusammenarbeit in der hier praktizierten Form ist innovativ und stellt eine neue Form der interdepartementalen Zusammenarbeit dar. Die REPIC-Plattform stellt in ihren allgemeinen Ansätzen eine geeignete Schweizer Antwort auf das strategisch bedeutsame und wachsende Thema der erneuerbaren Energien in der internationalen Zusammenarbeit dar.

Die externe Evaluation hatte zum Ziel, die bisherigen Aktivitäten und Resultate der REPIC-Plattform kritisch zu würdigen sowie Empfehlungen und Vorschläge für die Planung einer 2. Phase von REPIC zu formulieren. Die externe Evaluation bestätigt die wesentlichen Aussagen der internen Evaluation. Die bisherige Umsetzung der REPIC-Plattform wird als erfolgreich und effizient beurteilt; die Qualität der unterstützten REPIC-Projekte wird allgemein als hoch eingestuft. Insgesamt wird der REPIC-Plattform eine günstiges Kosten-Nutzen Verhältnis bescheinigt. Gemessen am Aufwand hat die REPIC-Plattform in den Augen der externen Evaluation in ihrer ersten Phase eine günstige Wirkung gezeigt, indem verschiedene grosse Folgeprojekte ausgelöst werden konnten.

Verbesserungspotenzial wird bei der Formulierung der Ziele und der erwarteten Wirkung, bei den Beurteilungskriterien für Projekte, sowie allgemein bei proaktiven Massnahmen seitens der REPIC-Plattform geortet. Zudem sollten Finanzkreise stärker in die REPIC-Aktivitäten einbezogen werden.

Die Schlussfolgerungen der externen Evaluation empfehlen ohne Einschränkungen die Durchführung einer 2. Phase von REPIC. Dabei werden spezifische strategische, operative und administrative Vorschläge zur Verbesserung gemacht. Diese sollten, zusammen mit den Empfehlungen aus der internen Evaluation, die Grundlage bilden für die Ausrichtung und Ausgestaltung der REPIC-Plattform in einer nächsten Phase.

Ausblick

Die erste Phase der REPIC-Plattform gelangt im Jahr 2007 zum Abschluss. Die vier zuständigen Ämter haben beschlossen, die REPIC Plattform für eine Periode von 3 Jahren zu verlängern. Die zweite Phase der REPIC Plattform wird ab Juli 2007 beginnen und wird die Energieeffizienz als zusätzliches Thema zu berücksichtigen. Die entsprechende Strategie wird im Verlauf von 2007 festgelegt.

Referenzen / Publikationen

[1] ***REPIC-Leitfaden***, zu beziehen bei NET Nowak Energie & Technologie AG oder http://www.repic.ch

[2] ***REPIC-Flyer***, zu beziehen bei NET Nowak Energie & Technologie AG oder http://www.repic.ch

[3] ***SAEE Jahrestagung 2006*** *"***Economic Prospects for New Energy Technologies in Emerging Markets",** Bern, 1. September 2006 (Präsentationen zur Verfügung auf der Website http://www.saee.ch)

[4] ***Biofuels Seminar: "****Growing Fuel in Developing Countries, Lessons from Brazil and India"*, Bern, 31. Oktober 2006. Zusammenfassung und CD ROM zu beziehen bei NET Nowak Energie und Technologie AG oder http://www.repic.ch

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[7] Schlussbericht ***„Technico-economical Optimization of Photovoltaic Pumping System***" zu beziehen bei NET Nowak Energie und Technologie AG, CUEPE (Université de Genève) oder http://www.repic.ch

[8] ***Deployment strategies for Renewable Energy options for rural electrification in developing countries: 10 key-recommendations from the IEA PVPS PV SDC expert team***

[9] ***REPIC - Interner Evaluationsbericht 2004 – 2006,*** Oktober 2006, REPIC Sekretariat

[10] ***REPIC - Evaluation Report for Phase I from 2004 to 2006***, January 2007, Wolfgang Mostert

IEA PVPS TASK 10 - SWISS CONTRIBUTION

Annual Report 2006

Author and Co-Authors	Pierre Renaud, Pierre Bonhôte
Institution / Company	Planair SA
Address	Crêt 108a, CH- 2314 La Sagne
Telephone, E-mail, Homepage	+41 32 933 88 40, pierre.renaud@planair.ch, www.planair.ch
Project- / Contract Number	101562 / 151862
Duration of the Project (from – to)	February 2006 – December 2008
Date	November 28, 2006

ABSTRACT

The challenge for Task 10 is to translate the results of the research on PV in built environment (buildings + grid) and to expand the work to a wider range of stakeholders necessary to mainstream urban-scale applications. Several stakeholder values must be combined in order for urban scale PV values to exceed the price and become a sustained market of urban energy solutions. Switzerland is active in subtask 2 (Urban Planning, Design and Development) and 3 (Technical Factors).

During this first year of the project, in-depth knowledge of the Task was acquired, international contacts were taken by the participation to two meetings (in Vancouver and in Malmö). A work plan was established for substask 2 and, on that basis, a questionnaire was developed for a standardized analysis of the present and future urban policy related to PV.

Buts du projet

Le projet vise à favoriser l'intégration urbaine du photovoltaïque, en particulier du point de vue de **l'urbanisme** (sous-tâche 2, pilotage par la Suisse) et des **réseaux électriques** (sous-tâche 3, collaboration). Il doit permettre de déterminer les meilleures conditions présentes et futures pour le développement du photovoltaïque dans le milieu bâti, permettre d'identifier les obstacles et les moyens de les surmonter, ainsi que les partenaires à mobiliser.

Brève description du projet

Pour ce qui concerne la **sous-tâche 2**, une analyse des politiques menées dans les pays participants à la Tâche 10 et au projet européen parallèle PV-UPSCALE sera réalisée au travers d'une étude détaillée portant sur deux ou trois villes par pays. L'analyse devra permettre une comparaison sur une base standardisée pour :

A. définir et comparer les politiques menées en matière de photovoltaïque ;

B. évaluer les obstacles existants et les instruments à mettre en place ou à renforcer pour favoriser le développement du photovoltaïque en milieu urbain ;

C. évaluer les problèmes que pourrait engendrer le développement rapide du photovoltaïque en milieu urbain et définir les instruments propres à assurer une bonne intégration au milieu bâti.

Pour ce qui concerne la **sous-tâche 3**, la contribution Suisse consistera en une étude de cas, basée sur la situation de la ville de Neuchâtel, par simulation des effets de l'intégration d'une forte proportion de photovoltaïque dans l'approvisionnement, combinée à une production éolienne telle que déjà planifiée.

Travaux effectués et résultats acquis

Les travaux effectués au cours de l'année 2006 ont consisté en un rassemblement des bases de connaissance nécessaires à préparer l'analyse des politiques urbaines actuelles et futures. Les questions à traiter ont été soumises aux partenaires de la Tâche 10 et du projet européen parallèle PV-UPSCALE et discutées dans le cadre du la rencontre conjointe de Malmö, en septembre. Sur cette base, un **questionnaire** a été élaboré, qui doit permettre une analyse standardisée des politiques, permettant des comparaisons et des conclusions. Il a été convenu que Planair assumerait la **direction de la sous-tâche 2** pour une période d'une année.

A la demande du mandant, Planair a procédé à la relecture et à la correction de la version française du **guide « électricité solaire »** pour la Suisse.

Planair a examiné l'ébauche de document intitulé **« revenue protection »**, mis en consultation dans le cadre de l'activité 4.4 « stakeholder perceptions » ainsi que le document intitulé **« Environmental Benefits of PV systems in OECD Countries »** mis en consultation dans le cadre de l'activité 1.1 « value analysis ». Ce document vise à évaluer les réductions de rejets de CO_2 et de déchets nucléaires que permet la production d'électricité photovoltaïque dans les pays de l'OCDE.

Energiebüro a fourni la contribution suisse à la collection d'**études de cas** du « IEA PVPS Task 2 and Task 10 Educational Tool » (http://www.iea-pvps-task10.org/article.php3?id_article=38) avec une présentation de l'installation du Stade de Suisse.

Collaboration nationale et internationale

Par principe, les projets de l'AIE sont internationaux. La contribution suisse à la Tâche 10 est menée en étroite collaboration avec les responsables des contributions des autres pays participants.

Planair a pris part à la **rencontre des experts** des tâches 1, 2, 9 et 10 à Vancouver, les 27 et 28 mars. A cette occasion, il a été proposé que Planair prenne la direction internationale de la sous-tâche 2. Cette option a été confirmée ultérieurement, avec approbation du mandant.

Planair a également participé à la **réunion des participants à la Tâche 10 de l'AIE et au projet européen PV-UPSCALE**, tenue à Malmö du 11 au 13 septembre 2006).

Évaluation de l'année 2006 et perspectives pour 2007

La compréhension du fonctionnement des Tâches des programmes de l'AIE et la définition de la contribution suisse, avec en particulier la fixation d'un contour plus précis à la sous-tâche 2, a occupé la première moitié de l'année 2006. Ensuite, notamment après les deux rencontres internationales auxquelles Planair a participé, il a été possible de commencer un travail concret visant à l'élaboration d'un outil d'analyse des politiques urbaines liées au photovoltaïque.

La participation à une Tâche de l'AIE nécessite en outre une collaboration avec les partenaires sous la forme de revue et de critique d'études ou de documents fournis par eux, ou de livraison de contributions pour la Suisse.

L'année 2007 devrait permettre d'exploiter le questionnaire élaboré pour l'analyse des politiques. Le succès dépendra largement de l'engagement des partenaires des autres pays participants pour le retour de questionnaires remplis. En Suisse, le questionnaire devrait être appliqué aux cas de Neuchâtel et de Zurich. Les réponses seront définies dans le cadre d'ateliers ou d'entrevues avec les responsables concernés.

Pour ce qui concerne la sous-tâche 3, des simulations de production photovoltaïque seront menées et comparées avec la courbe de consommation de la ville de Neuchâtel afin de déterminer l'impact d'une production élevée dans le futur, couplée à une production éolienne.

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IEA SHC TASK 36: SOLAR RESOURCE KNOWLEDGE MANAGEMENT

GLOBAL RADIATION FORECAST

Annual Report 2006

Author and Co-Authors	Jan Remund and Mario Rindlisbacher
Institution / Company	Meteotest
Address	Fabrikstrasse 14, 3012 Bern
Telephone, E-mail, Homepage	0041 (0)31 307 26 26, remund@meteotest.ch, www.meteotest.ch
Project- / Contract Number	101498 / 151784
Duration of the Project (from – to)	July 2005 – June 2010
Date	8.12.2006

ABSTRACT

In the framework of IEA Solar Heating and Cooling (SHC) task 36 Meteotest investigates mainly the possibilities and quality of global radiation forecast. In the first year a short validation of the global radiation forecast of Meteotest's operational MM5 model was made. The root mean squared error for a 36 hour forecast was about 30 %. This result is in the same range as the forecasts of the two other IEA team members dealing with forecast. Next year more detailed validation and the introduction of model output statistics are planned.

Introduction

In the framework of IEA Solar Heating and Cooling (SHC) task 36 “Solar Resource Knowledge Management” Meteotest investigates mainly the possibilities and quality of global radiation forecast.

The task 36 is divided into 3 main subtasks:

a) Standard qualification for solar resource products (includes benchmarking of different radiation estimation models based on satellite measurements).

b) Common structure for archiving and accessing solar resource products (includes prototype of online tool for accessing data).

c) Improved techniques for solar resource characterization and forecast.

The aim radiation forecast subtask is to define the quality of the existing models and to enhance the quality. A further aim is also to check the quality of forecasted PV production data. Main partners in this subtask are University Oldenburg and New York State University at Albany.

Work done and first results

Meteotest made a short analysis of the operational global radiation forecast of the MM5 model, which runs with input data of GFS (global model of US National Weather Service).

The global radiation was used in form of direct model output. We tested the hourly values at 5 different stations in Switzerland (Basel, Geneva, Sion, Lugano and Schaffhausen). The validation was made with measured values from the automated network ANETZ of MeteoSwiss.

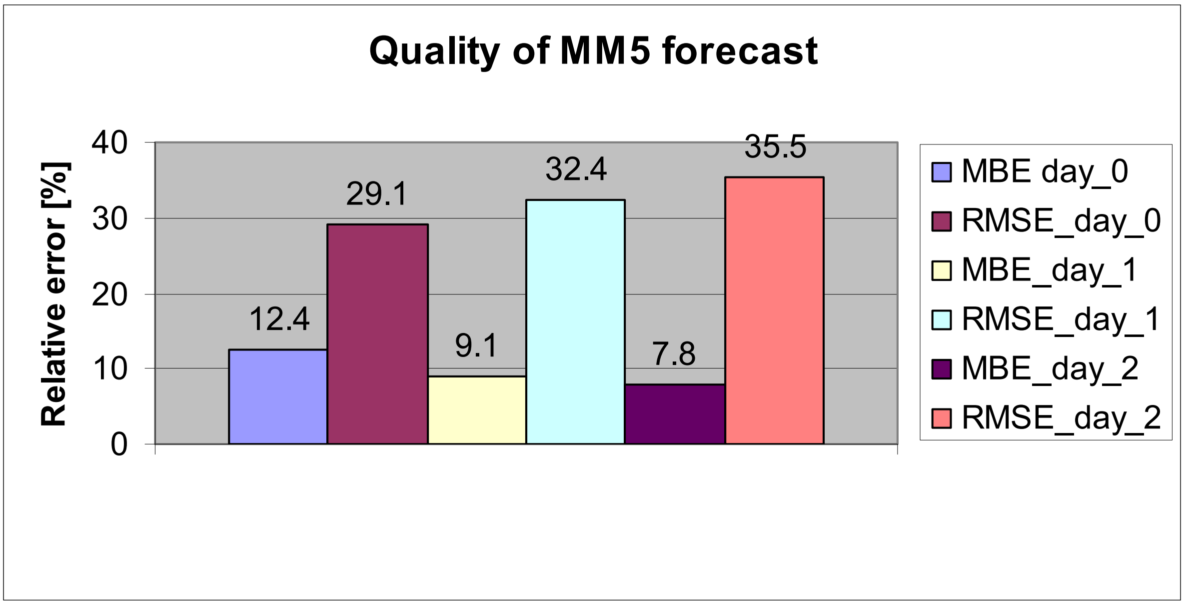
The validation forecast ranges are defined as:

- day_0 (+9, +12 and +15 h forecast time),
- day_1 (+33, +36, +39 h) and
- day_2 (+57, +60, +63 h).

The test period was June 8-28 2006 (20 days).

The first validation showed the following results:

1. General overestimation of radiation (+12 %).
2. The root mean squared error (RMSE) (hourly values) is about 29 % of the measured values for day_0, 32.4 % for day_1 and 35.5 % for day_2.
3. The mean biased error (MBE) has better values with longer forecast range.
4. The quality is better for sites with more stable weather.



The first validations of the two other subtask members showed very similar results, though very using different methods and other test regions: New York State University at Albany used digital weather forecast of cloud cover of US National Weather Service and University of Oldenburg ECMWF (European weather model) model output statistics data.

National / international cooperation

The work was done in the framework of IEA Solar Heating and Cooling task 36. From Switzerland there is also University of Geneva part of the task team.

Outlook

The validation will be carried on. First the time period will be enlarged (to at least 6 months). Secondly a common test area will be defined by the subtask team members. Thirdly the quality is planned to be enhanced by introducing model output statistics. Additionally a new worldwide atmospheric turbidity climatology will be tried to achieve.

References

Homepage of IEA Solar Heating and Cooling task 36:

http://re.jrc.cec.eu.int/iea-shc-task36/index.htm

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NORMENARBEIT FÜR PV SYSTEME

Annual Report 2006

Author and Co-Authors	Markus Real, Thomas Hostettler
Institution / Company	Swissolar, Schweizerischer Fachverband für Sonnenenergie
Address	Neugasse 6, 8005 Zürich
Telephone, E-mail, Homepage	+41 (0)44 250 88 33 (Swissolar), +41 (0)44 383 02 08 (Alpha Real AG), alphareal@access.ch / info@swissolar.ch / www.swissolar.ch

Project- / Contract Number	17967 / 151661
Duration of the Project (from – to)	1.1.2005 – 31.12.2006
Date	January 2007

ABSTRACT

The worldwide use of Photovoltaic IEC standards supports international trade of uniform high-quality PV products, systems and services and assists conformity assessment such as certification and issuing quality label(s). International standards establish objective specifications that both buyer and seller can rely on. For buyers, they widen the range of choices and lower costs, primarily because they often increase the number of competitors. For sellers, global standards broaden the number of potential customers and reduce the cost of meeting their needs.

The Scope of IEC TC82 is to prepare international standards for systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system. In this context, the concept "photovoltaic energy system" includes the entire field from light input to a solar cell to and including the interface with the electrical system(s) to which energy is supplied.

TC 82 has six active working groups developing standards for the photovoltaic industry. Some of the 25 current work program topics include: safety of inverters and charge controllers, islanding prevention measures for grid connected PV Systems, design qualification and type approval of solar modules, on site IV curve measurements, minimum requirements for system documentation, commissioning tests, and inspection requirements for Grid connected PV systems, requirements of PV arrays. Under the administrative lead of TC 82 is a Joint Coordination Group with TC 21, TC 88 and TC 105 which is developing a series of 10 new standards dealing with various aspects of renewable energy system integration and project management.

Switzerland, once a leading pioneer in grid connected PV systems, has in spite of shrinking federal budgets a market of about 2-3 MW/a, mainly driven by green pricing. There are several important Swiss manufacturers for plugs, grid connected and stand-alone inverters, alu-profiles to facilitate mounting of PV modules and laminates, and turn key operators as well as many consulting and engineering companies, active both in Switzerland and abroad. Next to a direct involvement in the IEC work, all relevant documents are discussed in detail in the national standard committee TK82, in order to formulate Switzerland's interest in adequate, simple and effective standards for PV. There are particular interests of the leading plug manufacturer Multicontact to elaborate more specific standards for plugs in PV array cabling. The strategic decision during last TC82 meeting on elaborating standards to avoid dangerous arcs is of interest to Prof. Heinrich Häberlin. Swissolar is evaluating to offer a workshop on standard issues, once the feed in tariffs has been adopted by the Swiss Parliament.

Einleitung / Projektziele

Normenarbeit

Normenarbeit ist Konsensfindung unter Experten. Bei der IEC (International Electrotechnical Committee) ist dieser Prozess vom Entwurf zur definitiven internationalen Norm streng formalisiert und wird durch schriftliche Stellungnahmen der nationalen Komitees erreicht. Wichtige Phasen einer IEC Norm sind: New Work Item, Committee draft (CD), CD for voting (CDV) und FDIS (Eine Übersicht der Begriffe befindet sich in den Referenzen am Schluss dieses Berichts). Die Arbeiten im Photovoltaikbereich werden durch das Technical Committee 82 (TC82) koordiniert und überprüft. Die eigentliche Normenarbeit wird je nach Bereich in einem der sechs Working Groups (WG) durchgeführt, wobei jeweils jede Norm in Arbeit als Projekt mit einem verantwortlichen Projektleiter strukturiert ist.

Wichtig dabei ist, die Meinung des Nationalen Komitees in einem bereits sehr frühen Stadium einfliessen zu lassen, weil grössere Korrekturen später kaum mehr möglich sind, ausser die Norm wird zurückgestuft, weil (i) ein voting negativ ausgefallen ist oder (ii) weil der vorgegebene Zeitrahmen nicht eingehalten wurde oder (iii) die Länder zwar positiv dafür stimmen, aber sich nicht genügend Experten zur Mitarbeit nominieren lassen.

Die Mitgliedschaft im nationalen Normenkomitee TK 82 ermöglicht einen beschränkten Zugriff auf relevante Arbeitsdokumente, erfordert aber eine gewisse Übung. Deshalb wird eine Konstanz in der Mitarbeit angestrebt, Neumitglieder jedoch sehr willkommen sind. Interessenten für die Mitarbeit im Schweizer Nationalkomitee melden sich bei Electrosuisse, dem Sekretär des TK 82, Herrn Josef Schmucki (Josef.Schmucki@electrosuisse.ch, 044 956 11 74), Herrn Thomas Hostettler vom Schweizerischen Fachverband Swissolar oder dem Hauptautor dieses Berichtes und Vorsitzenden des TK 82 (Kontaktadressen siehe Deckblatt). In den Referenzen befindet sich eine Tabelle mit den einzelnen Working Group des TK 82.

Warum Normen, warum internationale IEC Normen?

Normen sind in jeder Technik wesentlicher Bestandteil der Produktentwicklung, der Tests und der Qualitätsüberprüfung. Der sich rasch entwickelnden PV Industrie fehlen noch eine ganze Reihe von wichtigen, international anerkannte Normen, wobei sich die Lücke dank dem wachsenden Interesse an Normen nun schnell zu schliessen beginnt. Während den letzten Jahren konzentrierte sich die PV Entwicklung im Wesentlichen auf Pilot- und Demonstration der Technik. Deshalb galt die Normenarbeit vorab der Festlegung der Begriffe und der Definition der Performance der Komponenten, insbesondere den Modulen, den Invertern und dem Monitoring.

Im Bereich Sicherheit und Qualität zeigt sich nun in den letzten Jahren ein wachsender Bedarf an Normen, weil die Fragen der Sicherheit, Qualität und die damit zusammenhängenden Verantwortlichkeiten in den letzten Jahren allgemein mehr Gewicht erlangten und weil nun die meisten Netzverbundanlagen oberhalb der Kleinschutzspannung gebaut werden. Diese erreichen auf der Gleichspannungsseite meist Spannungen grösser als 500V, und die Zahl der Anlagen wächst sehr rasch. Zudem wird ganz allgemein das Regelwerk der Normen in der EU konstant ausgebaut, eine eigentliche Vorbedingung für den freien Warenaustausch. Auch hier sieht man nun die Resultate der vermehrten Anstrengung, Normen zu erarbeiten und die Lücke für noch fehlende Normen wird kleiner.

Im Bereich PV konnte trotz der IEC nicht verhindert werden, dass viele nationale Normen entstanden. Diese wurden meist im Rahmen von nationalen Energieprogrammen initiiert und zum Teil auch finanziert. Auch die grossen Finanzinstitute wie die Weltbank, UNDP oder GTZ haben in vielen Ländern wie z.B. Uganda, Indien, China, Pakistan etc die Normenarbeit mitfinanziert, um die Grundlagen für ihre Projekte zu schaffen.

Diese bereits bestehenden Normen erleichtern nun zum Teil die Arbeit in der IEC, indem auf ein breites Wissensreservoir zurückgegriffen werden kann und nicht alle Normen von Anbeginn neu formuliert werden müssen. Auf der anderen Seite erschweren die vielen nationalen Normen und Vorschriften aber auch die Harmonisierung auf internationalem Niveau. Gerade im Bereich der Systeme war eine frühe Einführung von internationalen Normen meist schwierig, weil die Entwicklung sehr schnell war und immer wieder neue, und damit meist bessere Lösungen auf die (lokalen) Märkte kamen.

In den letzten Jahren sind das Interesse und der Wille gestiegen, dass nun diese nationalen Normen im Rahmen der internationalen IEC harmonisiert werden sollen. Griffige Normen sind notwendig um den Marktteilnehmern die Arbeit zu erleichtern und Verantwortlichkeiten zu regeln.

Dabei ist zu unterscheiden zwischen Regeln, welche die Performance betreffen und solchen, welche die Sicherheit oder die Qualität der Komponenten und Anlagen bzw. der Benutzer betreffen. Fragen zur Sicherheit sind traditionell eher national ausgerichtet, und es ist auch anderen Normenkomitees mit bisher wenigen Ausnahmen nicht gelungen, im Bereich Sicherheit eine IEC Norm als verbindliche Norm auch national als Norm einzuführen. Allerdings ist auch hier ein starker Druck spürbar, regionale oder nationale Normen durch internationale Normen zu ersetzen.

Eine Ausnahme dazu bildet nun seit einigen Jahren die EU, welche das Parallelvoting für IEC Normen für Cenelec Normen eingeführt hat. Bei positiver Annahme werden dann die IEC Normen mit einer entsprechenden Einführungszeit automatisch Cenelec-Norm und ersetzen damit entsprechende nationale Normen. Andere Länder wie etwa die USA anerkennen im Bereich Sicherheit bisher nur nach UL-Kriterien getestete Geräte und Systeme.

Information der Branche als wichtiges begleitendes Element
Begleitend dazu soll die Branche über die bestehenden sowie die zu erwartenden Normen informiert werden, so dass sie die nötigen internen Prozesse starten können. Insbesondere soll in einem Workshop neben dem aktuellen Stand auch die Bedeutung der Normierung aufgezeigt werden.

Durchgeführte Arbeiten und erreichte Ergebnisse

Im vergangenen Jahr wurde vom Central Office im Bereich des TC82 über 100 Mal ein Versand von Dokumenten durchgeführt, welche den Teilnehmern des TK82 zugestellt wurden. Eine genaue Liste über den Stand kann auf der IEC Seite eingesehen werden, ebenfalls unter den Minutes des Letzten TC82 vom Oktober 2006. Die wichtigsten Arbeiten aus Sicht des Schweizer Vertreters:

WG 1: Glossary

IEC 61836 Ed 2.0 draft Technical Specification

Die Norm zur Festlegung der Terminologie ist bereit zur Publikation. Auf der IEC Webseite wird diese gratis einsehbar sein, allerdings leider in gekürzter Form, so dass der (auch etwas pädagogisch gestaltete) Aufbau der Norm dort nicht einsehbar ist.

WG 3: Systems

IEC 62246 Grid connected PV systems – Minimum requirements for system documentation, commissioning tests, and inspection requirements

Dieses Dokument dürfte für die Systemintegration wichtig werden, weil es als vereinfachtes Abnahme und Dokumentationsprofil gedacht ist. Angestrebt wird, dass das Dokument schlussendlich wie die Installationsvorschriften in die Serie 364 (Elektrische Hausinstallationen) einfliessen wird, und der Stoff auch im normalen Lehrgang für Elektriker vermittelt wird.

IEC 62257-7-1 PV array installation – Follow up of IEC62234 safety guidelines for PV systems mounted on buildings

Zurzeit wird ein Dokument, das insbesondere auf Arbeiten der australischen Kollegen basiert, als TS (technical specification) publiziert. WG 3 wird den Inhalt prüfen und versuchen, Teile davon als Standard zu Publizieren, in Ergänzung zu 60364-7-712 (NIN 64712). Damit würde 62257-7-1 hinfällig, das in dieser Ausführlichkeit ohnehin nicht in die IEC 62257 Serie der „Technical specifications“ passt.

IEC 61724 – PV System Performance Monitoring, Maintenance

Hintergrund: Die Guidelines wurden im Wesentlichen von Ispra übernommen. Konflikte insbesondere in der Definition der Systemgrenzen (was wird gemessen, was in der Berechnungen mitberücksichtigt bzw. ausgeklammert) wurden von Experten der IEA erkannt. (IEA Report: http://www.iea-pvps.org/products/download/rep2_01.pdf) Es wurde beschlossen, verschiedene Systemgrenzen zu definieren und diese ohne Präferenz für die eine oder andere Variante aufzuführen.

NWIP “Portable Solar Photovoltaic (PV) Lanterns – Design Qualification and Type approval”

Ein NWIP wurde ausgearbeitet, zusammen mit dem Standard, der von PVGAP im Auftrag der Weltbank ausgearbeitet wurde und publiziert ist (PVRS11, www.pvgap.org)

IEC 62253 DIRECT COUPLED PV PUMPING SYSTEMS – DESIGN QUALIFICATION AND PERFORMANCE MEASUREMENT Project leader (Peter Kremer)

Zirkuliert zur Abstimmung. Ausgang noch ungewiss. Scheint angenommen, aber es fehlen Nominationen von Experten von den P Members.

On Site Measuring of IV Characteristics of Crystalline Silicon

Wichtiges Dokument, da immer mehr auch für Grossanlagen die IV Curve für die Inbetriebsetzung verwendet werden. Beschlossen wurde, dass WG2 die Extrapolation der Messdaten für STC Werte ausarbeitet, und WG3 das Messverfahren bestimmt. Chuck Whitacker hat sich als Projektleiter zur Verfügung gestellt. Ein Draft wird im März 2007 zirkulieren.

IEC 61194 Characteristic parameters of stand alone PV systems (maintenance)

Das Dokument ist nicht (mehr) wichtig, aber ein Update wird in Betracht gezogen.

WG 4: PV energy storage systems

Keine wesentliche Aktivität auf TC82 Ebene. Batterien sind eine Schlüsselkomponente mit einem ungenügenden Standard fürs Testing. Es gibt keinen internationalen Konsens über Testverfahren, ausser dass normale Testzyklen Monate dauern und zu teuer sind, und kein Konsens über abgekürzte Zyklenzahlen existiert.

WG 6: Balance-of-system components

Zwei Dokumente sind zurzeit in Zirkulation zur Abstimmung: IEC 62116 als CDV und Battery Charge Controller – Dokument als NP. Die Zirkulation von den zwei Dokumenten IEC 62109 als CD2 wurde fallengelassen. Anstatt dessen werden direkt zwei CDVs zur Abstimmung verschickt.

IEC 62109-1, -2 and -3 Ed. 1.0, Safety of power converters for use in photovoltaic power systems.

Ein für die Schweiz sehr wichtiges Dokument. Erfolgreiche Involvierung der Schweizer Wechselrichter Hersteller in den Prozess. Projektleiter: Tim Zgonena.

Der Status der drei Dokumente ist wie folgt:

- IEC 62109-1: General Requirements, CDV zur Zirkulation 4.Q 2006
- IEC 62109-2: Inverter Requirements, CDV zur Zirkulation 4.Q 2006
- IEC 62109-3: Charge Controller Requirements, NWIP zur Zirkulation Feb 2007

IEC 62116 Ed. 1.0, Testing procedure – Islanding prevention measures for power conditioners used in grid connected photovoltaic (PV) power generation systems

Project Leader: Izumi Tsuda

History: NWIP approved Fall 2004, CD – Oct 2005

Status: Ein CDV (82-447-CDV) zur Zirkulation Aug 2006. Abstimmungsresultat Jan 2007.

Performance and Functioning of Photovoltaic Battery Charge Controllers, NWIP

Project Leader: Nigel Wilmot, Status: Ein New Work Item Proposal (82-445-NP) zur Zirkulation Juli 2006; Abstimmungsresultat November 2006.

WG 7: Concentrator modules

Es fehlen ein Schweizer Vertreter und ein unmittelbares Interesse in der Schweiz, da keine Anwendung für die Schweiz sichtbar.

Steckverbinder für PV-Systeme – Sicherheitsanforderungen und Prüfungen

Die Norm, welche während den vergangenen zwei Jahren für PV-Steckverbindungen im DKE-Arbeitskreis erarbeitet wurde ist nun offiziell bei CENELEC deponiert. Ziel: Die Norm gilt für Verbinder der Klasse A (gemäss IEC 61730-1) zur Verwendung in PV-Systemen mit Systemspannungen bis 1'000 V_{DC} und Strömen bis 500 A pro Kontakt. Kontaktperson in der Schweiz: Markus Kohler, m.kohler@multi-contact.ch.

Lichtbögen, fehlerhafte Kontakte

Dieses Thema, ausgelöst insbesondere auch durch die Fehlerserie bei BP Solar, wurde im TC82 Plenum als strategisch wichtige Arbeit definiert. Kontaktperson in der Schweiz: Prof. Heinrich Häberlin, Heinrich.Haeberlin@hti.bfh.ch.

Qualitätslabel PV GAP

Das PVGAP Qualitätslabel ist ein für den Konsumenten (aber auch Systemintegrator, Zwischenhändler etc) leicht erkennbares Zeichen, dass das Produkt die diesbezüglichen Anforderungen für Performance und Qualität erfüllt. Das Ziel von PVGAP war und ist, ein solches Label auf internationaler Ebene einzuführen, bevor weltweit eine Fülle von nationalen Labeln den internationalen Handel wieder erschwert:

i. Das Interesse an Qualität ist stark gewachsen, nicht zuletzt auch durch die von PV GAP initiierten Bestrebungen zur Markteinführung eines global anerkannten Qualitätslabels. Qualität ist aber ohne Normen nicht oder nur schlecht objektiv messbar, und eine Positionierung via Qualität ist auf dem Markt dadurch schlechter kommunizierbar.

ii. Neu hat nun in Deutschland RAL ein nationales, eigenes Gütesiegel geschaffen. Der Güteschutz-Solar soll eine umfassende Gütesicherung für Solarenergieanlagen in den Bereichen Solarwärme (Solarthermie) und Solarstrom (Photovoltaik) sicherzustellen. Dies wird durch ein detailliertes auf den anerkannten Regeln der Technik und der guten fachlichen Praxis basierendes Regelwerk erreicht. Auch hier sind Normen die Voraussetzung zur Festlegung der Qualität.

PVGAP konnte im vergangenen Jahr mit der IECEE ein Memorandum of Understanding unterschreiben, dass die Zusammenarbeit zwischen PVGAP und IECEE regelt. Ein entsprechender Vertrag, das den Transfer der Rechte für das Label an IECEE regeln soll, ist in Ausarbeitung. Der Transfer soll noch 2007 stattfinden. Damit würden die Arbeiten für PVGAP eine erfolgreiche Weiterführung in IECEE finden.

Workshop Normierung

Aufgrund der im Jahr 2006 noch unklaren Ausgangslage für die Einführung einer Kostendeckenden Vergütung in der Schweiz wurde auf die Durchführung des Workshops verzichtet. Eine Durchführung macht erst bei klaren politischen Randbedingungen Sinn.

Hingegen wurde die Information der Branche über den PV-Newsletter des Fachverbands Swissolar verstärkt gepflegt und wird im Jahr 2007 weiter ausgebaut. So können sich die Branchenmitglieder rechtzeitig über die aktuellen Trend informieren.

Nationale / internationale Zusammenarbeit

IEC Normenarbeit ist per Definition internationale Zusammenarbeit.

Bewertung 2006 und Ausblick 2007

Die Arbeiten innerhalb der TC82 haben an Effizienz zugenommen und 2006 konnten eine Reihe von wichtigen Normen publiziert werden. Weitere wichtige Normen wurden stehen kurz vor der Fertigstellung.

Für die Schweiz hat die nun die vermehrte Aktivität und die zunehmende Bedeutung der IEC Normen positive Auswirkungen:

i. Die aufwendige Erarbeitung nationaler Normen entfallen

ii. Der Austausch von Produkten mit dem Ausland vereinfacht sich und trägt langfristig zu Preisreduktionen bei

iii. Die Sicherheit der Hersteller und Installateure wird vergrössert, da der Stand der Technik damit immer besser dokumentiert wird, und die kostspielige Erarbeitung individueller Lösung entfallen.

Im letzten Jahr konnten vor allem auch die Schweizer PV Komponenten-Hersteller noch besser in die Normengestaltung eingebunden werden. Das TK 82 besteht heute aus 14 aktiven Experten.

Die Normierungsarbeiten werden künftig vom Schweizerischen Fachverband für Sonnenenergie, Swissolar direkt getragen. So kann sowohl die Wahrung der Interessen als auch die Information der Branche noch besser gewährleistet werden.

Referenzen

Nomenklatur und Abkürzungen in der IEC-Normierung

- Eine vollständige Liste der Publikationen der IEC Normen erhält man gratis unter www.iec.ch
- Nationale Normen sind unter dem Projekt "Quality in the PV Sector" zusammengestellt worden und finden sich unter www.pv-quality.org.
- Ad interim Standards, die bereits internationalen Anerkennung haben, und bis zur Publikation einer entsprechenden IEC Norm Geltung finden, sind publiziert unter www.pvgap.org

Abkürzungen für den Bearbeitungsstand der IEC-Dokumente

NP	New work item proposal
RVD	Results of voting on FDIS
RVN	Result of voting on new work item proposal
FDIS	Final Draft international standard
PAS	Public available Specifications
prEN	Draft EN standard
TR	Technical report
MCR	Maintenance cycle report
CAB	Conformity assessment board
INF	Information
CC	Compilation of comments

Working Group des TK 82

Die Arbeiten an den verschiedenen Themen sind auf die folgenden Gruppen aufgeteilt:

WG 1: Glossary

WG 2: Modules, non-concentrating

WG 3: Systems

WG 4: PV energy storage systems

WG 6: Balance-of-system components

WG 7: Concentrator modules

PV ERA NET

NETWORKING AND INTEGRATION OF NATIONAL AND REGIONAL PROGRAMMES IN THE FIELD OF PHOTOVOLTAIC (PV) SOLAR ENERGY RESEARCH AND TECHNOLOGICAL DEVELOPMENT (RTD) IN THE EUROPEAN RESEARCH AREA (ERA)

Author and Co-Authors	[1] S. Nowak, [1] M. Gutschner, [1] S. Gnos; [2] U. Wolfer
Institution / Company	[1] NET Nowak Energy & Technology Ltd; [2] Bundesamt für Energie
Address	[1] Waldweg 8, CH-1717 St.Ursen; [2] 3063 Ittigen (Bern)
Telephone, E-mail, Homepage	[1] +41 (0)26 494 00 30, [2] + 41 (0)31 322 56 39, [1] stefan.nowak@netenergy.ch, [1] http://www.netenergy.ch; [2] urs.wolfer@bfe.admin.ch, [2] http://www.bfe.admin.ch
Project- / Contract Number	CA-011814-PV ERA NET
Duration of the Project (from – to)	1 October 2004 – 30 September 2008
Date	December 2006

ABSTRACT

PV ERA NET is a European network of programme coordinators and managers in the field of photovoltaic solar energy (PV) research and technological development (RTD). The consortium comprises major key stakeholders in the field of national and regional RTD programmes involving photovoltaics (PV). The consortium comprises 19 participants from 12 states with more than 20 national RTD programmes (or parts of programmes) and three regional RTD programmes.

The mission of PV ERA NET is to carry out activities towards networking and integration of national and regional programmes in the field of PV RTD in the European Research Area (ERA).

The overall strategic objective of PV ERA NET is to strengthen Europe's position in photovoltaic (PV) technology by improving the cooperation and coordination of PV RTD programming efforts across Europe, supporting long-term perspectives in European research policies as well as supporting related policies in order to establish a strong European Research Area and to create a durable structuring effect and impact in terms of coherence, innovation and economic growth.

Introduction and Goals

PV ERA NET is a European network of programme coordinators and managers in the field of photovoltaic solar energy (PV) research and technological development (RTD). The consortium comprises major key players in the field of national and regional RTD programmes involving photovoltaics (PV), which is considered a key technology and industry. The consortium comprises 19 participants from 12 states with more than 20 national RTD programmes (or parts of programmes) and three regional RTD programmes.

The mission of PV ERA NET is to carry out activities towards networking and integration of national and regional programmes in the field of PV RTD in the European Research Area (ERA).

The major goals related to the above mentioned overall strategic objective are:

1. To enhance coordination, cooperation and coherence of photovoltaic RTD programming activities, namely:

- To establish an efficient structure for continued information exchange and mutual knowledge as well as sound dissemination strategies
- To assess and implement best practice in photovoltaic RTD programming
- To identify gaps, overlaps and possible synergies and opportunities
- To identify the key issues (e.g. priorities and complementarities, legal issues, patenting / co-ownership) potentially facilitating and enabling (or hindering) an increased level of sustained co-operation between different photovoltaic RTD programmes
- To develop and corroborate long term needs and perspectives in photovoltaic RTD strategies
- To investigate opportunities and provide a strategy for pilot joint activities
- To implement joint activities and approaches for sustained cooperation and coordination.

2. To improve and corroborate the structure and effectiveness of photovoltaic RTD activities and to foster the European Research Area (ERA), namely:

- To increase coordination and cooperation of national and regional programmes (considering that at least 75% of photovoltaic research in Europe is financed at national / regional level)
- To contribute to overcome the traditional fragmentation of research efforts in Europe through better coordination and cooperation
- To provide a positive durable structuring effect in photovoltaic research programmes and programming on a European level
- To encourage technology transfer from R&D to the industry
- To mobilise / pool resources (human / personnel; financial; infrastructure / equipment) in order to achieve critical mass in specific photovoltaic RTD issues
- To strengthen the excellence of photovoltaic RTD and the competitiveness of related industries in Europe
- To stimulate innovation and economic growth and, subsequently, contribute to create jobs in a sustainable manner.

PV ERA NET

Figure 1: Logo of PV ERA NET

Brief Description of the Project

Expected Outcomes

At present, Europe has a high level of photovoltaic research and development – both in qualitative and quantitative terms - contributing to a fast growing industry. Through its activities, PV ERA NET will establish a strong photovoltaic RTD programme network, thereby strengthening the individual programmes, their mutual links and their links to the EC programmes, the industry and other organisations.

It is expected that PV RTD programmes will commonly and mutually improve coherence, efficiency and effectiveness thanks to increased coordination and cooperation level and quality. Striving for excellence and building on the most successful approaches, PV ERA NET will thus ultimately contribute to strengthen the position of the European RTD and market in the world-wide context.

By systematically addressing the important interfaces with other key technology areas (e.g. materials RTD, nanotechnology, photochemistry, molecular chemistry, etc.), those related to production and applications (e.g. grid interconnection, building integration, etc.) as well as those with other (renewable and other) energy technologies (e.g. intermittency, hybrid use, storage, etc.), PV ERA NET will identify subjects for further interaction, aiming at opportunities for stronger cooperation between different technology areas.

Operational Level

The networking activities are subdivided into three major, logically sequenced work packages, plus a work package for the coordination and management of the networking activities.

The first two work packages "Information Exchange and Best Practice" and "Strategy Issues" build the common ground for joint (transnational) activities between national / regional programmes. The third work package "Joint (Transnational) Activities" is about preparing, e.g. by developing schemes, and actually implementing "real" joint transnational activities. This work package comprises a set of concrete joint (transnational) activities and asks for the most important, dynamic and continued efforts.

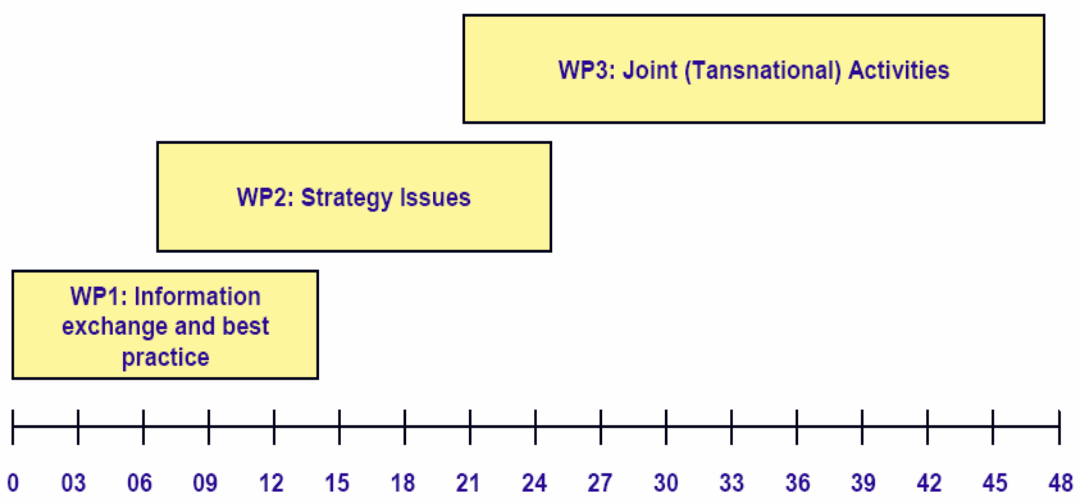

Figure 2: The set-up of the work packages of PV ERA NET reflects the stepping-up of the levels of coordination and cooperation. The scale at the bottom indicates the project duration in months (since Oct 2004).

Accordingly, the activities and objectives specific to the work packages are:

WP1: Information Exchange and Best Practice: The main activity was in the first year of the project, to improve the information and communication and, subsequently, build trust among programme managers and, second, to exchange experience on good practice. Information was about photovoltaic RTD programmes - their contents, approaches and context - in participating programmes. Country reports and survey reports with condensed information on horizontal issues as well as workshops allowed for improving mutual knowledge of each other's programmes. The work done provides some ground for the work on Strategy Issues (WP2) and Joint (Transnational) Activities (WP3).

The main goal was to provide structured information exchange and to exchange experience on good practice in photovoltaic RTD programming

WP2: Strategy Issues: The main activity in the past year was the identification of gaps, overlaps and possible synergies and opportunities and the analysis of the issues (e.g. priorities and complementarities, legal issues, patenting / co-ownership) potentially facilitating and enabling (or hindering) an increased level of sustained cooperation between different photovoltaic RTD programmes. Based on the experience during first project years and of other ERA NETs', an assessment of first common interest in programming issues and common thematic scope was carried out.

The main goal was an overview of gaps, overlaps and possible synergies and opportunities as well as an analysis of the issues potentially facilitating and enabling (or hindering) an increased level of sustained cooperation between different PV RTD programmes.

WP3: Joint (Transnational) Activities: The main activity is about the investigation, preparation and, ultimately, the implementation of joint activities. The level of cooperation is increasing through a follow-up of structured and regular information exchange activities at higher programming level providing the basic mutual input and subsequent investigation of possible opportunities and the preparation and implementation of joint activities. Innovative cooperation forms between national RTD programmes, e.g. sharing the evaluation of projects and/or programmes (ex post), RTD concept definition, impact, etc.) are explored. Developing schemes and mechanisms and arranging cooperation agreements are important activities in this work package. The activities follow logically sequenced steps allowing to gain more experience and practice allowing to implement more relevant joint activities.

The main goal is to investigate, prepare and implement joint (transnational) activities

Work Performed and Results Achieved

Information exchange – structured and continued

The first step in the project towards transnational cooperation is information exchange. Presentations, questionnaires, reports, peer reviews and workshops have been means to learning from other's programmes.

Each country reported on its programme(s) with respect to contents, approach, context and international orientation. In a first major step, comprehensive information has been made available by describing some 25 (sub-) programmes dealing with PV RTD based on a common structure with the following key topics:

- Programme Contents: key features, objectives, priorities, budgets and spends, overview over projects and other PV RTD activities
- Programme Approach: general strategy on the programme level, assessment and evaluation of the programme, funding, procedure from proposal to project, dissemination and communication, technology transfer, good practice and lessons learnt
- Programme Context: community, interaction and stakeholder involvement, framework and environment, international orientation, current transnational activities, future transnational activities and opportunities as well as barriers and gaps

Networking and scope

On the international level, PV is seen as an important issue, which is reflected in FP6 / FP7 research, the European PV Technology Platform and the IEA-PVPS programme. The international context and some of the national expectations indicate a great potential for increasing the cooperation and coordination level between RTD programmes. PV ERA NET contributes to networking on the international level both between the states and different international / European initiatives. Different transnational activities, e.g. direct information exchange between programmers, common expertise and evaluators' pool, specific technical R&D topics, bring about results and tools that are also of interest in other international initiatives on-going (for instance, Mirror Group of the European PV Technology Platform). In terms of finding topics of common interest, the list of research areas developed by PV TRAC (the Photovoltaic Technology Research Advisory Council) was used, which again is a basic element of and for the Strategic Research Agenda.

Topical Areas: Complementarities, Gaps and Opportunities

The results out of last year's work is presented in synoptic tables for different sets of subjects and topics with the qualified marks provided by the partners show a wide range of potential complementarities, gaps and opportunities. They can be subdivided into the following three basic categories potentially interesting for joint transnational activities:

1. Thematic areas that are of crosscutting nature and hence by definition of transnational relevance. They most likely relate to system oriented research (examples: balance of systems, grid-connected systems, stand alone systems, grid integration and storage, supportive research). For this category, the aspect of complementarities between national approaches prevails; tackling these issues on a transnational level can have direct benefits for standardisation and cost reduction.
2. Thematic areas which are either sub-critical on the national level and/or scattered across Europe. They mostly relate to new concepts and, more generally speaking, interdisciplinary subjects (examples: polymer and organic solar cells, basic R&D). In this category, the existing gaps between individually (on a national level) developed approaches can be addressed..
3. Finally, a third category can be identified for very specific thematic subjects in mostly well established areas. By their nature, such subjects are more of ad-hoc nature and can best be addressed individually on a case-by-case basis (examples: specific needs for analytical methods, access to special technologies, vertical complementarities along the value chain). In this category, complementarities can be addressed specifically, e.g. through clustering of activities and projects.

Common interest can be found for various reasons. For instance, competences in different states can be complementary and mutually strengthen competences in these countries. Or a topic can reach critical mass.

The overall picture indicates an important potential for joint transnational activities thanks to i) the expected complementarities in order to mutually improve competences, or ii) to opening new opportunities in fields where individual programmes could pool (and maybe increase) their resources in order to reach critical mass. This actually shows that there is considerable potential to strengthen both individual research programmes and PV research in Europe as a whole. This could finally help overcome the two main weaknesses in the European RTD landscape, i.e. fragmentation of national R&D programmes and (too slow) technology transfer from research to application. Cooperation offers here use of untapped synergies and effectively addressing key issues in research and technology development.

Working in a Joint Call Laboratory

The pilot joint transnational activities are followed in a Joint Call Laboratory where model calls are developed in order to check the formal, administrative, legal and financial aspects. The key subject chosen was *Polymer and molecular solar cells*.

International Cooperation

According to the very mission of the ERA NET scheme, increased coordination and cooperation between the national and regional programmes on a multi-lateral level is the main focus of activities carried out in this project. 19 organisations from 12 states representing some 20 RTD programmes are involved in PV ERA NET. Further organisations with programming responsibilities can join the consortium by fulfilling a certain set of criteria.

Table 1: States and (sub) Programmes Participating in PV ERA NET

States	Partners	Programmes and Sub-programmes Involved
Austria	Federal Ministry for Transport, Innovation and Technology / Bundesministerium für Verkehr, Innovation und Technologie Austrian Research Promotion Agency Ltd / Österreichische Forschungsförderungsgesellschaft GmbH	• Austrian Technologies for Sustainable Development (at:sd) • Building of Tomorrow • Factory of Tomorrow • Energy Systems of Tomorrow
Denmark	Danish Energy Authority / Energistyrelsen	• Energy Research Programme (EFP) • Public Service Obligation (PSO) programme • Strategic Research in Renewable Energy
Flanders	Ministry of Flanders, Science and Innovation Administration / Ministerie van de Vlaamse Gemeenschap	• SOLAR+
France	French Agency for Environment and Energy Management / Agence de l'environnement et de la maîtrise de l'énergie	• ADEME's Photovoltaic Programme • ANR's Solar Photovoltaic Research Programme
Germany	Project Management Organisation Jülich Projektträger Jülich	• 5th Energy Research Programme
Greece	General Secretariat for Research and Technology, Ministry of Development / Γενική Γραμματεία Έρευνας και Τεχνολογίας, Υπουργείο Ανάπτυξης Centre for Renewable Energy Sources / Κέντρο Ανανεώσιμων Πηγών Ενέργειας	• Operational Programme for Competitiveness (ORC) • ORC - Research & Technology Development (RTD)
The Netherlands	SenterNovem – Agency for Sustainability and Innovation SenterNovem – Agentschap voor Duurzaamheid en Innovatie	• Energy Research Strategy • Energy Research Subsidy Long Term (EOS-LT) • Energy Research Subsidy Demonstration (EOS-DEMO) • New Energy Research (NEO) • The Innovation Subsidy for Collaborative Projects (IS)

North-Rhine-Westphalia	Research Center Jülich GmbH, Project Management Organisation Energy, Technology, Sustainability / Forschungszentrum Jülich GmbH, Projektträger Energie, Technologie, Nachhaltigkeit	• Efficient use of energy and of renewable energy sources – technical development and demonstration projects • Solar Energy Association NRW
	Ministry of Innovation, Science, Research and Technology / Ministerium für Innovation, Wissenschaft, Forschung und Technologie	
	Ministry of Economic Affairs and Energy / Ministerium für Wirtschaft, Mittelstand und Energie	
Poland	Ministry of Science and Information Society Technologies / Ministerstwo Nauki i Informatyzacji	• Polish PV Network (POL-PV-NET) (set of coordinated activities)
	Warsaw University of Technology	
Spain	Ministry Education and Science / Ministerio de Educación y Ciencia	• National Energy Programme (NEP)
Sweden	Swedish Energy Agency / Statens energimyndighet	• Long-term research energy programme • Swedish national co-financed programme for PV systems and applications (SolEl) (package of RTD activities)
Switzerland	Swiss Federal Office of Energy / Bundesamt für Energie / Office fédéral de l'énergie / Ufficio federale dell'energia	• Swiss Photovoltaic RTD programme
	NET Nowak Energy & Technology Ltd. / NET Nowak Energie & Technologie AG	
United Kingdom	Department of Trade and Industry	• Technology Programme • Engineering and Physical Sciences Research Council (EPSRC) programmes • Major Photovoltaics Demonstration Programme

Evaluation 2006 and Outlook 2007

A great wealth of information collected is made available in different format (reports with strategic information, as tools, etc.) that allowed for achieving the goals set by the consortium in terms of structured exchange of information on the programmes and mutual knowledge about the programmes.

Working groups were set up to deal with specific programming issues and cooperation forms between different RTD programmes (e.g. thematic opportunities, clustering, joint projects, evaluation). There are manifold critical issues to be looked at: common thematic scope, eligibility / accessibility of foreign partners, administrative proposal-to-project process, evaluation criteria, call and funding cycles and schemes, etc.

Major achievements so far are:

- A web-based project database was developed and is about to provide a detailed overview of on-going RTD projects in the participating PV RTD programmes.
- Evaluation procedures and criteria as well as barriers and opportunities were assessed in view of future joint activities.
- Topics for first joint transnational RTD activities have been systematically analysed and prioritised.
- A joint call laboratory may soon result in a concrete joint call to be launched by programmes / states involved in PV ERA NET.
- Additionally, PV ERA NET has established a stronger link to the European PV Technology Platform with its Strategic Research Agenda as well as with the ongoing and foreseen activities in the European 7th Framework Programme for Research.

A first ongoing example was a joint French-Dutch project proposal designed by two prominent research actors. The project proposal has been prepared on the initiative of Dutch and French PV programme managers participating in PV ERA NET.

PV ERA NET and its members will play a complementary and essential role in defining the future PV RTD in the European Research Area by carrying out important national and regional programmes dealing with PV RTD, by improving information exchange and cooperation between the programmes and by participating in different pan European initiatives – all aiming at strengthening the individual programmes and PV research as a whole in Europe.

Referenzen

[1] Survey Report: ***Organisation, Set-up, Strategy, Objectives and Priorities of Photovoltaic Research and Technological Development Programmes in PV ERA NET States.*** Update. November 2006, it can be found on: www.pv-era.net -> States & Programmes or -> Publications.

[2] ***Further reports:*** www.pv-era.net -> Results and Publications

[3] www.pv-era.net: The website provides information on participating RTD programmes and ERA NET with respect to PV technology and to possible cooperation forms between the RTD programmes.