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Jahresberichte der Beauftragten 2005

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PROGRAMM PHOTOVOLTAIK

Überblicksbericht zum Forschungsprogramm 2005

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Photovoltaik Made in Switzerland: vom Labor in die Industrie

Die industrielle Umsetzung von Dünnschicht Solarzellen macht Fortschritte:

a) Labor Depositionssystem am Institut de Microtechnique, Uni Neuchâtel (Bildquelle IMT)

b) 100 kWp Pilotproduktion von flexiblen Silizium Solarzellen auf Kunststoff bei VHF-Technologies (Bildquelle VHF-Technologies)

c) Unaxis Solar KAI 1200 Produktionsanlage zur Massenfertigung von Silizium Dünnschicht Solarmodulen (Fläche 1.4 m^2, Durchsatz 550 Module/Tag, Bildquelle Unaxis)

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1. Programmschwerpunkte und anvisierte Ziele

Im Jahr 2005 war das Programm Photovoltaik (PV), insbesondere im Bereich der P+D-Projekte, weiterhin durch die im Entlastungsprogramm 2003 des Bundes beschlossenen Sparmassnahmen gekennzeichnet. Im Bereich der Forschung konnte das Niveau durch eine breite Programmabstützung weitgehend gehalten werden. Die industrielle Umsetzung der bisherigen Forschungsresultate behält hohe Priorität. Das anhaltende Wachstum des internationalen Photovoltaik Marktes bildet – trotz stagnierendem nationalen Markt – eine wichtige Grundlage für den derzeit erfolgenden, deutlichen Ausbau der Photovoltaik Industriebasis in der Schweiz.

Das Programm Photovoltaik verfolgt damit 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 2005 ca. 65 Projekte, wobei alle bekannten Projekte mit einer Förderung der öffentlichen Hand berücksichtigt sind.

Gestützt auf das Energieforschungskonzept der Eidgenössischen Energieforschungskommission CORE [70] verfolgt das Schweizer Photovoltaik Programm in der Periode 2004 – 2007 die folgenden wesentlichen Ziele [71]:

- 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 weiterhin fokussiert auf die Schwerpunkte **Silizium** (amorph, mikrokristallin), Zellen auf der Basis von **Verbindungshalbleitern** (CIGS) sowie **Farbstoffzellen**. Die mit Nachdruck verfolgte Industrialisierung von Produktionsprozessen steht bei den Silizium Dünnschicht Solarzellen in einem fortgeschrittenen Stadium, bei den Verbindungshalbleitern nimmt sie ebenfalls konkrete Formen an. 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 praxisorientierte **Hilfsmittel** 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 fortgesetzt werden. Von übergeordneter Bedeutung war im Berichtsjahr die Schweizer Beteiligung an neuen europäischen Netzwerken (***PV-ERA-NET*** und Europäische Photovoltaik Technologie Plattform).

2. Durchgeführte Arbeiten und erreichte Ergebnisse 2005

ZELL-TECHNOLOGIE

Die **grosse Bandbreite der Schweizer Solarzellenforschung** konnte im Berichtsjahr 2005 dank der breiten Abstützung dieser Forschung mit Erfolg fortgesetzt werden. Im Berichtsjahr begannen neue Industrie-Projekte mit Unterstützung der KTI. Die Beteiligung an EU-Projekten bildete eine weitere 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 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 *Unaxis Solar* (Trübbach, Neuchâtel) und *VHF-Technologies* (Yverdon) statt und stellen einen wichtigen Schwerpunkt des Photovoltaik Programms dar.

Das IMT an der Universität Neuchâtel begann beim Projekt zu **Silizium Dünnschichtsolarzellen** [1] im Berichtsjahr eine neue, dreijährige Projektphase. 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 *Unaxis* und *VHF-Technologies*, welche ihrerseits die am IMT entwickelten Prozesse in ihre Produkte implementieren. Folgende Resultate wurden im Berichtsjahr erreicht: Auf der transparenten Oxydschicht (TCO) aus ZnO auf Glas konnten p-i-n mikrokristalline (μc-Si:H) Solarzellen von 9% und mikromorphe Solarzellen von 11.6% hergestellt werden. Dabei konnte das Parameterfeld (z.B. Füllfaktor FF, Leerlaufspannung V_{oc}) deutlich eingegrenzt werden. Auf PET-Folien wurde für amorphe (a-Si:H) Solarzellen ein Wirkungsgrad von 7.3%, für mikrokristalline Solarzellen 7.6% und für mikromorphe Solarzellen 8.3% erreicht. In Bezug auf die Analytik wurden verschiedene Messmethoden weiterentwickelt und standardmässig eingesetzt (*VIM – variable illumination measurement, FTPS – Fourier transform photocurrent sprectroscopy, IRLIT – infrared lock-in thermography*).

Das KTI-Projekt in Zusammenarbeit mit *Unaxis* für den ***Prozess* der schnellen Abscheidung von mikrokristallinem Silizium** [2] auf der Grundlage der KAI Plasmadepositionsanlagen wurde im Bereichtsjahr fortgesetzt. 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 7.2% Wirkungsgrad hergestellt werden; bei *Unaxis* wurden damit mikromorphe Mini-Module (10x10cm^2) mit einem Wirkungsgrad von 9.5% erreicht.

In einem verwandten KTI-Projekt hat das CRPP an der EPFL zusammen mit *Unaxis* die Entwicklung eines neuen, grossflächigen ***VHF-Reaktors* für die Abscheidung von amorphen und mikrokristallinen Siliziumsolarzellen** [3] weiter verfolgt. Es werden Plasmaanregungsfrequenzen bis 100 MHz untersucht, was eine schnelle Abscheidung ($\geq$ 4 Å/s) erlaubt, jedoch für die Homogenität der Schichten auf einer Fläche von $\geq$ 1 m² besondere Herausforderungen darstellt. Die Bildung der Inhomogenitäten der Schichten konnten im Berichtsjahr erklärt werden. Weitere Arbeiten betreffen die Prozessparameter, insbesondere in Hinsicht auf die unerwünschte Bildung von Silizium Pulver. Ergänzt werden diese Arbeiten durch ein KTI-Projekt am CRPP der EPFL, in welchem ein **numerisches Modell für grossflächige PECVD Reaktoren** entwickelt wurde [4]. Dieses Projekt wurde im Berichtsjahr erfolgreich abgeschlossen.

Ein weiteres KTI-Projekt zwischen dem IMT und *Unaxis* befasst sich mit der **Stabilität der transparenten Oxydschichten** (TCO) aus ZnO in laminierten Solarzellen [5], insbesondere in Hinsicht auf den Dampf-Wärme Test im Rahmen der IEC Tests für Solarmodule (IEC 61646: 1000h @ 85°C & 85% rel. Feuchtigkeit). Es konnte gezeigt werden, dass die im Test geforderte Stabilität erreicht wird.

Das NTB in Buchs setzte zusammen mit *Unaxis* das KTI-Projekt für ein auf die industrielle Produktion ausgerichtetes, spektral aufgelöstes **Photostrom Messgerät** (*Spectral Response Measurement System SRMS*) [6] erfolgreich fort. Im Berichtsjahr wurden bei *Unaxis* zwei Prototypen dieses Geräts installiert; die ersten Erfahrungen sind sehr positiv, insbesondere was die Stabilität der Messmethode anbetrifft. Damit können auf Solarmodulen vollflächige Messungen durchgeführt und entsprechende Bilder dargestellt werden. 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 *Unaxis*.

Das IMT schloss das KTI-Projekt für die Verwendung von **nanostrukturierten optischen Gittern** zur Verbesserung der Eigenschaften von flexiblen Solarzellen auf Kunststoffsubstraten [7] zusammen mit *VHF-Technologies* und weiteren Partnern im Berichtsjahr ab. Die nanostrukturierten Kunststoffsubstrate (PET, PEN) wurden durch OVD-Kinegram vorbereitet. Am IMT wurden auf texturierten PET Substraten amorphe Solarzellen mit 7.3% stabilem Wirkungsgrad hergestellt. Es konnte gezeigt werden, dass die durch OVD-Kinegram hergestellten, nanostrukturierten Substrate mit dem Fabrikationsprozess von *VHF-Technologies* kompatibel sind. Im Verlauf des Projektes konnte *VHF-Technologies* ihren Fabrikationsprozess deutlich verbessern. Das IMT und *VHF-Technologies* arbeiten seit Herbst 2005 im neuen EU-Projekt ***FLEXCELLENCE*** [8] an diesem Thema weiter. Zum ersten Mal erfolgt dabei im Bereich der Photovoltaik eine Projektkoordination durch einen Schweizer Partner (IMT).

Darüber hinaus hat sich das IMT im Berichtsjahr erfolgreich am neuen EU-Projekt ***ATHLET*** (*Advanced Thin Film Technologies for Cost Effective Photovoltaics*) beteiligt [9]. Dieses, vom HMI in Berlin koordinierte, *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 (vgl. unten); die Arbeiten dazu beginnen anfangs 2006 und werden insgesamt 4 Jahre dauern.

Kristallines Silizium

HCT Shaping Systems beteiligt sich am EU-Projekt ***BITHINK*** [10], in welchem hocheffiziente bifaciale kristalline Solarzellen entwickelt werden (Wirkungsgrad 16+16%). Dabei soll sowohl Material vom Czochralski-Typ wie mulitkristallines Silizium zum Einsatz kommen. Im Verlauf des Projektes werden die Prozesse und die automatisierte Handhabung von Solarzellen von weniger als 130 µm Dicke entwickelt.

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 im BFE-Projekt ***FLEXCIM*** [11] die Entwicklung von flexiblen CIGS-Solarzellen weiter vorangetrieben. 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 im Vorjahr 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. Als weiteres Substrat für die flexiblen CIGS-Solarzellen wird 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 im Berichtsjahr einen Wirkungsgrad von 6.6%; dabei wurde noch kein Natrium eingesetzt.

Das EU-Projekt ***NEBULES*** [12] zum Thema neuer Pufferschichten für CIGS-Solarzellen wurde im Berichtsjahr abgeschlossen. Hier konzentrierte sich die ETHZ-Gruppe auf die strukturelle, chemische und elektronische Charakterisierung der Solarzellen in Abhängigkeit von verschieden hergestellten CdS- sowie InS-Pufferschichten. Im Berichtsjahr wurden die Grenzflächen mit den InS-Pufferschichten in Hinsicht auf Struktur und Zusammensetzung eingehend analysiert. Zum Schluss des Projektes besteht eine gute Übersicht über die verschiedenen Prozesse an diesen Grenzflächen.

Die Gruppe Dünnschichtphysik an der ETHZ setzt diese Arbeiten seit dem Herbst 2005 im neuen EU-Projekt ***LARCIS*** [13] fort. Dabei geht es um die grossflächige Umsetzung verschiedener Schlüsselthemen in die industrielle Produktion. Zudem beteiligte sich die Gruppe im Berichtsjahr ebenfalls erfolgreich am neuen EU-Projekt ***ATHLET*** [14] (*vgl. oben*) und wird in diesem Projekt den Teil zu CIGS-Solarzellen bearbeiten. In Hinsicht auf die industrielle Umsetzung der flexiblen CIGS-Solarzellen wurde im Berichtsjahr das ETHZ Spin-Off Unternehmen *FLISOM* gegründet.

Farbstoffzellen

Die Entwicklung von farbstoffsensibilisierten, **nanokristallinen Solarzellen** [15] wurde am ISIC der EPFL fortgesetzt. Im Berichtsjahr wurden die Partikeleigenschaften der TiO_2 Filme weiter entwickelt. Die Farbstoffsynthese und die Arbeiten zu den eingesetzten Elektrolyten konzentrierten sich auf die Stabilität bei höheren Temperaturen (ca. 80°C). Damit wird eine Lebensdauer der Farbstoffzellen von 10 bis 20 Jahren angestrebt.

Das ISIC arbeitet zusammen mit *Greatcell Solar* am KTI-Projekt zur **Erhöhung der Zellenspannung** von Farbstoffzellen [16]. 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* [72], welches im Dezember 2005 eine Produktionsfirma für Farbstoffzellen in Griechenland angekündigt hat.

Das EU-Projekt ***MOLYCELL*** [17] befasst sich mit flexiblen organischen Solarzellen, wobei sowohl vollständig organische wie hybride nanokristallin–organische Solarzellen entwickelt werden. An der EPFL stehen letztere im Vordergrund, wobei dazu ein fester Heteroübergang zwischen nanokristallinen Metalloxyden und molekularen bzw. polymeren Löcherleitern gebildet wird. Die Lichtabsorption wird durch die molekularen Farbstoffe bzw. die Polymere beeinflusst. Das ISIC stellte im Berichtsjahr erste flexible Farbstoffzellen auf Titanfolien her, wobei bisher ein Wirkungsgrad von ca. 2% erreicht wurde. Prototypen mit dem Metalloxyd-organischen Hybridansatz erreichten einen Wirkungsgrad von ca. 4%.

Solaronix beteiligt sich am EU-Projekt ***FULLSPECTRUM*** [18], 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 mittels Lumineszenzschichten.

Das LTC an der EPFL entwickelt auf der Grundlage der Farbstoffzellen in einem KTI-Projekt zusammen mit *Konarka* ***photovoltaisch aktive Textilien*** [19]. Von dieser Entwicklung werden neuartige Photovoltaik-Anwendungen erwartet.

Antennen-Solarzellen

An der Universität Bern wurden die grundlegenden Arbeiten zu **Antennen-Solarzellen** [20] im Rahmen des Programms Solarchemie und mit Unterstützung des schweizerischen Nationalfonds weitergeführt. Unter Verwendung von farbstoffbeladenen Zeolith-Kristallen wird eine neue Variante farbstoffsensibilisierter Solarzellen angestrebt. Im Vordergrund dieser Grundlagenarbeiten steht die Organisation der Kristalle an der Grenzschicht zu einem Halbleitermaterial im Hinblick auf die elektronische Energieübertragung. Im Berichtsjahr wurden 4 konzeptionelle Varianten von Dünnschicht-Antennen-Solarzellen erarbeitet: A) sensibilisierte Festkörper-Solarzelle, B) sensibilisierte Farbstoff-Solarzelle, C) sensibilisierte Plastik-Solarzelle und D) Dünnschicht-Antennen-Tandemzellen. Für die Variante A wurden die einzelnen Arbeitsschritte ausgetestet und zum Patent angemeldet. Es gilt jetzt, die Bausteine zu einer funktionierenden Solarzelle zusammenzusetzen.

SOLARMODULE UND GEBÄUDEINTEGRATION

Gebäudeintegrierte Anlagen stellen nach wie vor das wichtigste Anwendungsgebiet der Photovoltaik in der Schweiz dar. 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) untersuchte in einem BFE-Projekt die durch die Verwendung von geätztem ***Antireflexglas*** (AR) [21] mögliche Leistungssteigerung von kristallinen Solarmodulen. Um die möglichen Effekte zu quantifizieren, wurden die Gläser wahlweise vor / nach der Lamination im Säurebad geätzt. Die Messungen an den mit diesem Glas hergestellten Solarmodulen zeigten in beiden Fällen eine systematische Leistungssteigerung von ca. 2%, wobei 3% erwartet wurden. Freiluftmessungen bei verschiedenen Einstrahlungswinkeln zeigen, dass die AR-Module den Grenzbereich mit flachen Einstrahlungswinkeln noch etwas besser ausnützen können. Im EU-Projekt ***BIPV-CIS*** [22] sollen die Eigenschaften der Photovoltaik-Gebäudeintegration mit Dünnschichtsolarzellen verbessert werden. Auf der Grundlage von CIS-Zellen werden Dach-, Überkopfglas- und Fassadenelemente entwickelt. Für *3S* steht die Entwicklung des Dachelementes im Vordergrund.

Telsonic beteiligte sich am EU-Projekt ***CONSOL*** [23], in welchem die elektrische Kontaktierung von CIGS-Solarzellen optimiert werden soll. Als Technologien werden dazu elektrisch leitende Klebebänder und Ultraschall-Schweissen eingesetzt. Die wichtigen Messgrössen Adhäsion und Kontaktwiderstand werden in Funktion von Klimatests erfasst und für beide Technologien optimiert. Für *Telsonic* steht als Hersteller von entsprechenden Anlagen die Optimierung des Ultraschall-Schweissens im Vordergrund. Die erzielbaren Kontakteigenschaften und die Eignung der Verfahren auf unterschiedlichen Substraten konnten bestimmt werden. Das Projekt wurde im Berichtsjahr abgeschlossen.

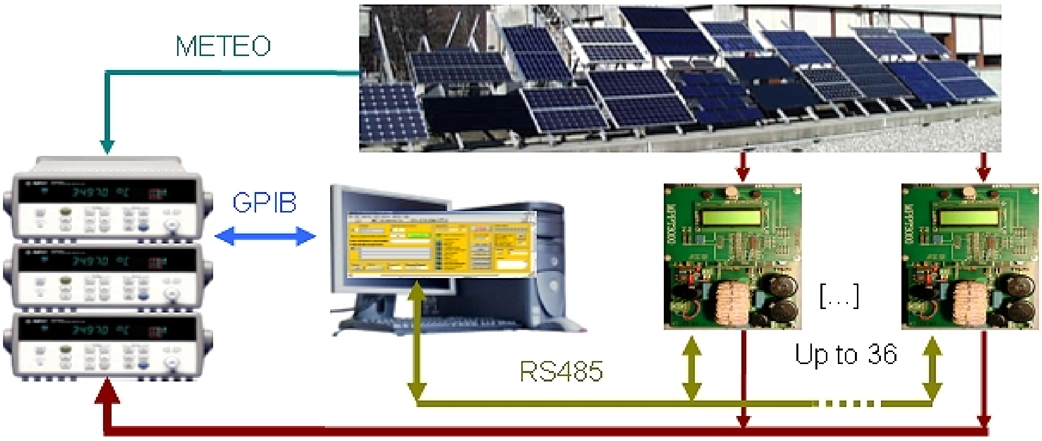
Verschiedene weitere neue Konzepte und Produkte zur Photovoltaik-Gebäudeintegration wurden im Rahmen von P+D-Projekten erprobt (siehe entsprechendes Kapitel).

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 LEEE-TISO an der SUPSI hat im Berichtsjahr seine Testmessungen an Solarmodulen im Projekt ***Centrale LEEE-TISO 2003-2006*** [24] fortgesetzt. Das gemäss ISO 17025 für Messungen zertifizierte Labor mit dem Sonnen-Simulator der Klasse A wurde erneut einem jährlichen Audit unterzogen und konnte seine Präzision von ±1% bestätigen. Im Berichtsjahr wurden mehr als 2600 I-V Kennlinien (Blitztests) gemessen, davon gut 10% für Dritte. Es wurden Vergleichsmessungen mit anderen zertifizierten Labors in Europa (ESTI-JRC und ECN) durchgeführt und ein vom NREL koordinierter internationaler *Round Robin* Test von Solarmodulen fortgesetzt. Die Labormessungen des LEEE-TISO erwiesen sich dabei als zuverlässig mit den Abweichungen I_{sc}: -1.8%, FF: 0.3%, P_{max}: -0.6%. Für Dünnschicht Module verfügt das Labor neu über ein Verfahren zur Berücksichtigung der spektralen Abweichung (*spectral mismatch*). Bei den Aussenmessungen begann im Berichtsjahr der 10. Testzyklus an kommerziellen Modulen; es wurden 14 Modultypen ausgewählt (8 mc-Si, 2 sc-Si, 1 HIT, 2 a-Si, 1 CdTe). Neu werden 3 anstelle von 2 Modulen gemessen. Das dritte Modul wird dabei kurzzeitig auf einem *Sun-Tracker* vermessen, insbesondere in Hinsicht auf die Erstellung der Leistungsmatrix $P_m(G_i,T_a)$. Die Messdatenerfassung und das *Maximum Power Point Tracking* (MPPT) wurden neu konzipiert (siehe Fig. 1) und ein Spektroradiometer reinstalliert. Entsprechend der Strategie des LEEE soll in Zukunft als neues Thema auch die Photovoltaik-Gebäudeintegration verstärkt bearbeitet werden.

Das LEEE-TISO ist Partner im EU-Projekt ***PV Enlargement*** [25], welches ein europaweites Demonstrationsprojekt in 10 Ländern (5 davon in Osteuropa) mit 32 Anlagen von insgesamt 1.15 MWp Leistung darstellt. Ende 2005 waren davon insgesamt 20 Anlagen mit 860 kWp in Betrieb. Dabei ist das LEEE-TISO für die wissenschaftliche Begleitung, insbesondere für Kalibrierungsaufgaben der verwendeten Messsysteme und Performance-Messungen der verwendeten Solarmodule, zuständig. Seit Projektbeginn im Januar 2003 wurden 151 von 210 geplanten Solarmodulen verschiedener Technologien (c-Si, a-Si, CIS, CdTe) und Hersteller geprüft. Im ersten Testzyklus wurden 101 kristalline Module (17 verschiedene Typen) ausgemessen und die Anfangsdegradation der Module quantifiziert. Die Unterschiede zu den gemäss neuer EU-Norm EN50380 deklarierten Module wurden in Klassen aufgeteilt. Es wurden bisher 50 Dünnschicht Module vermessen.

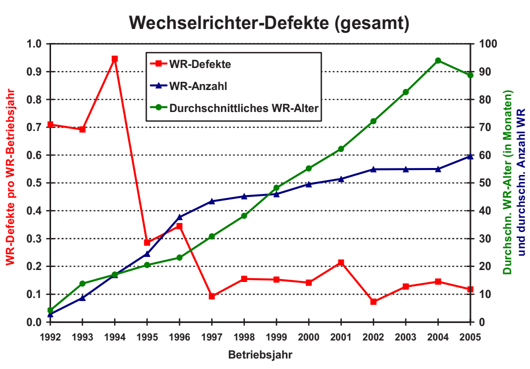


Figur 1: *Messdatenerfassung mit neuen MPPT Reglern (Bildquelle LEEE-TISO)*

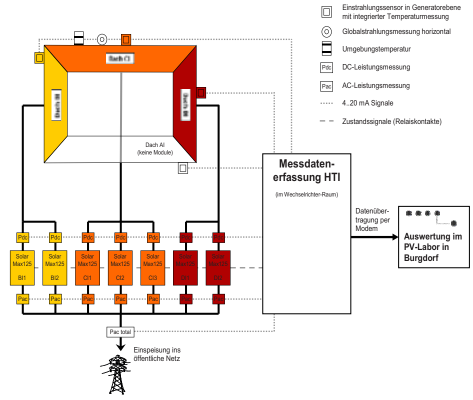
Darüber hinaus hat sich das LEEE-TISO im Berichtsjahr erfolgreich am neuen EU-Projekt ***PERFORMANCE*** (*A science base on PV performance for increased market transparency and customer confidence*) beteiligt [26]. Dieses, vom Fraunhofer Institut für Solare Energiesysteme in Freiburg koordinierte, *Integrierte Projekt* befasst sich mit allen prenormativen Arbeiten von Solarzellen bis hin zu Systemen und von Momentanmessungen bis zu Langzeitanalysen. Das Projekt beginnt anfangs 2006 und wird insgesamt 4 Jahre dauern.

Am Photovoltaiklabor an der FH Burgdorf wurde das Projekt ***Photovoltaik-Systemtechnik PVSYTE*** [27] fortgesetzt. Eine neue 3·5 kW AC/DC-Quelle wurde in das Testprogramm für Wechselrichter integriert; es ermöglicht die Untersuchung des Wechselrichterverhaltens bei ungewöhnlichen Netzzuständen (Über- und Unterspannungen, starke Rundsteuersignale, Über- und Unterfrequenz, usw.). Im Berichtsjahr wurden die bisherigen Wechselrichtertests durch Messungen an den aktuellen Geräteserien von *Sputnik* und *ASP* ergänzt. Die einzelnen, detaillierten Wechselrichter-Testberichte können eingesehen werden [73]. Im Teilprojekt zum Langzeitverhalten von PV-Anlagen wurde die seit 1992 geführte Ausfallstatistik weitergeführt. Im Berichtsjahr sank die Ausfallrate leicht auf 0.12 Wechselrichterdefekte pro Betriebsjahr (siehe Fig. 2). Die PV-Anlage von 855 kWp auf dem *Stade de Suisse* in Bern wurde neu in das Messprogramm aufgenommen, welches damit eine total installierte Leistung von 1.62 MWp (Feinmessprogramm 1.52 MWp) und 62 Wechselrichter umfasst. Die Messdaten der Anlage *Stade de Suisse* sind, wie für andere Anlagen, online einsehbar [74] (siehe Fig. 3). Weitere ausführliche Langzeitmessungen erfolgen zu den Anlagen *Newtech* (Dünnschichtzellen), Mont-Soleil und Jungfraujoch. Bei letzterer wurde für 2005 ein neuer Rekordertrag von 1537 kWh/kWp gemessen.

Solaronix ist am EU-Projekt ***EURO-PSB*** [28] zur Entwicklung einer Polymer Solar Batterie beteiligt. Es handelt sich dabei um eine kleine, selbstaufladende Batterie für mobile Anwendungen. Das Prinzip baut auf der Kombination einer neuartigen Polymer Solarzelle (organische Solarzelle) und einer wiederaufladbaren Lythium-Polymerbatterie auf. *Solaronix* ist in diesem Projekt für die elektrische Verbindungstechnik zwischen Solarzelle und Batterie sowie den gesamten Verbund zuständig. Im Berichtsjahr wurden funktionelle Prototypen (Thermometer) mit flexiblen Farbstoffsolarzellen auf Titanfolien sowie mit organischen Solarzellen auf Glas zusammengebaut. Damit wurde das Projekt im Berichtsjahr abgeschlossen.



Figur 2: *Beobachtete Wechselrichter-Defekte (Bildquelle HTI Burgdorf)*



Figur 3: *Blockschaltschema Stade de Suisse (Bildquelle HTI Burgdorf)*

ERGÄNZENDE PROJEKTE UND STUDIEN

Das LESO an der EPFL beteiligt sich am EU-Projekt ***SUNtool*** [29], welches ein allgemeines Modellierungswerkzeug zur Nachhaltigkeit im urbanen Kontext darstellt. Es soll typischerweise eine Gruppe von Gebäuden bis zu einem Stadtviertel (< 1 km^2) energetisch und stoffflussbezogen abbilden können. Das Werkzeug baut auf umfassenden Modellen zu den einzelnen Aspekten auf und soll diese mit einem graphischen Benutzerinterface zusammenführen. Die EPFL entwickelt dazu entsprechend stochastische Benutzungsmodelle und hat diese weitgehend validiert. Die Gemeinden Lausanne und Morges stellten für Fallstudien Daten zur Verfügung. Aufgrund von Projektverzögerungen erfolgt der Projektabschluss anfangs 2006.

Enecolo ist am EU-Projekt ***PVSAT2*** beteiligt [30]. In diesem Projekt wurde die satellitengestützte Performance Überwachung weiterentwickelt, indem einerseits präzisere Satellitendaten verwendet werden und andererseits die Produktionsdaten der PV-Anlagen zentral erfasst werden. Insgesamt sollte dadurch ein zuverlässiges und kosteneffizientes System zur Überwachung von kleinen Photovoltaik-Anlagen entstehen, für welche eine Messdatenerfassung vor Ort zu aufwendig wäre. Im Berichtsjahr konzentrierte sich *Enecolo* auf die im PV-SAT Verfahren entwickelte Fehlerdetektionsroutine (Fehler von PV-Anlagen). Die Testphase zeigte, dass PV-SAT-2 Prozedur für die Fernüberwachung von PV-Anlagen nützlich ist; verschiedene Fehler konnten detektiert werden (z.B. Leistungsbegrenzung durch unterdimensionierte Wechselrichter, Wechselrichterausfall, Schneeabdeckung, usw.). Es zeigte sich aber auch, dass das System weiter verbessert werden kann, insbesondere in Bezug auf den eingesetzten Datenlogger, die Fehlerdetektionsroutine, eine genügende Anlagenbeschreibung, Ausschluss von nicht behebbaren Fehlern (z.B. Wechselrichter, Verschattung, Degradation) sowie bezüglich der Strahlungsberechnung. Das Projekt wurde im Berichtsjahr abgeschlossen. Zur kommerziellen Umsetzung der Resultate hat *Enecolo* zusammen mit *Meteotest* die neue Dienstleistung *SPYCE* [75] entwickelt. *Enecolo* ist auch am verwandten Projekt der esa ***ENVISOLAR*** [31] beteiligt. In diesem Vorhaben sollen die der esa zur Verfügung stehenden Daten aus der Erdbeobachtung marktorientiert (http://www.eomd.esa.int) verarbeitet werden, insbesondere in Hinsicht auf das Thema *Solarstrahlung für Energieanwendungen*.

Das CUEPE an der Universität Genf beteiligt sich am EU-Projekt ***Heliosat 3*** [32] zur energiespezifischen Bestimmung der Solarstrahlung aus Meteosat-Daten. *Heliosat3* nutzt u.a. die neuen Meteosat Second Generation (MSG) Satelliten und erarbeitet Solarstrahlungsdaten mit höherer Auflösung in zeitlicher, räumlicher und spektraler Hinsicht. Diese Daten können die Entscheidungsgrundlagen für Investitionen, Planung und Management im Solarenergiebereich verbessern. Als mögliche Anwendungsbeispiele im PV-Bereich werden Standortoptimierung, Anlagen- und Netzmanagement genannt (s. auch *ENVISOLAR*). Im abschliessenden Projektjahr wurde besonderes Gewicht auf die Validierung des Solarstrahlungsschemas gelegt.

Mit Unterstützung der interdepartementalen Plattform (seco, DEZA, BUWAL (neu BAFU), BFE) zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit *REPIC* [76] erarbeitet das CUEPE ein Modul für die Photovoltaiksoftware *PVSYST* [77], welches **Photovoltaik Wasserpumpen** [33] simuliert.

Das LEEE-TISO und *Solstis* sind Partner im EU-Projekt ***PV-Catapult*** [34]. Dieses Querschnittprojekt hat zum Ziel, in verschiedenen strategischen Bereichen der Photovoltaik, sowohl in Forschung, Umsetzung wie Markt, entsprechende Aktionen zur Marktbeschleunigung zu identifizieren und auszulösen. Unter anderem wurde dazu eine SWOT-Analyse der europäischen Photovoltaik durchgeführt. Das LEEE-TISO bearbeitet in diesem Projekt Fragen der Performanzmessungen und –voraussage während sich *Solstis* an einer Roadmap für das Thema des PV-thermischen Hybridkollektors beteiligt.

Das PSI beteiligt sich im Rahmen des *Integrierten* EU-Projektes ***FULLSPECTRUM*** [35] 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.

Das symbolträchtige Projekt ***SOLARIMPULSE*** [36] von Bertrand Piccard und verschiedenen Partnern wurde im Berichtsjahr fortgesetzt. Das Ziel dieses Projekts ist die ununterbrochene Weltumrundung mit einem photovoltaisch betriebenen Flugzeug. Das Projekt ist eine grosse Herausforderung in Hinsicht auf Material und Design sowie insbesondere auf die Energieversorgung und das Energiemanagement unter extremen Bedingungen (z.B. UV-Strahlung, Feuchtigkeit, Temperaturen, Frost, Alterung, mechanische Vibrationen). Die photovoltaische Energieversorgung des Flugzeugs und ein äusserst sparsamer Energieeinsatz müssen dabei genügend Energie für den momentanen Antrieb, die Heizung des Flugzeugs und die Speicherung in Hinsicht auf den Nachtflug bereitstellen. Im Jahr 2005 wurde das technische Konzept erstellt. Gemäss dem aktuellen Stand der Arbeiten wird das Flugzeug 80m Spannweite, 220m^2 Flügelfläche, ca. 2 t Gewicht, 8 kg/m^2 Flügelbelastung und rund 40 kWp PV-Leistung haben; gemittelt über 24 Stunden soll die Motorenleistung 10 kW betragen. Das Flugzeug soll bei Tag auf 12'000 m steigen und nachts langsam absinken.

INTERNATIONALE ZUSAMMENARBEIT IEA, IEC, PV-GAP

Die Beteiligung am Photovoltaikprogramm der IEA (IEA PVPS) wurde im Berichtsjahr mit Kontinuität fortgesetzt, sowohl auf der Projektebene wie im *Executive Committee (ExCo)* [78]. Die Schweiz hält weiterhin den Vorsitz dieses weltweiten Programms inne. Für die Beteiligung an ausgewählten Projekten im Rahmen des IEA PVPS Programms ist es im Berichtsjahr gelungen, einen gemeinsamen Schweizer IEA PVPS Pool zu gründen. Dieser Pool wird derzeit getragen durch das Elektrizitätswerk der Stadt Zürich (ewz), den Kanton Basel Stadt und die *Gesellschaft Mont-Soleil*. Weitere Partner sind derzeit noch in Abklärung und neue Partner sind weiter erwünscht. Mit diesem Ansatz soll der stärkere Einbezug verschiedener Zielgruppen in die Arbeiten im Rahmen von IEA PVPS sichergestellt werden.

Nova Energie vertritt die Schweiz in Task 1 von IEA PVPS, welcher allgemeine ***Informationsaktivitäten*** [37] zur Aufgabe hat. Im Berichtsjahr wurde ein weiterer nationaler Bericht über die Photovoltaik in der Schweiz bis 2004 [79] erstellt; auf dieser Grundlage wurde die 10. Ausgabe des jährlichen internationalen Berichtes über die Marktentwicklung der Photovoltaik in den IEA-Ländern erstellt [80]. Dieser Bericht wurde im Berichtsjahr insbesondere auch für die aktuellen Analysen der Photovoltaik durch den Finanzsektor verwendet [81, 82, 83]. Im Berichtsjahr wurde anlässlich der 20. Europäischen Photovoltaik-Konferenz in Barcelona unter Schweizer Leitung ein Workshop zum Thema Umweltaspekte der Photovoltaik organisiert; dieses Thema wird das PVPS Programm weiter beschäftigen, möglicherweise als neuer Task. Der *IEA PVPS-Newsletter* [84] informiert regelmässig über die Arbeiten in und rund um das IEA-Programm.

In IEA PVPS Task 2 über ***Betriebserfahrungen*** [38] stellt *TNC* den Schweizer Beitrag. Die PVPS-Datenbank *Performance Database* (Ausgabe Juni 2005 [85]) wurde mit neuen Daten ergänzt und umfasst nun 431 Photovoltaik-Anlagen aus 21 Ländern mit insgesamt rund 15‘500 Monats-Betriebsdaten und 12.3 MWp Anlagenleistung. Aus der Schweiz sind 64 Anlagen mit einer totalen Leistung von 2 MWp in der Datenbank enthalten. In diesem Teilprojekt soll eine breit abgestützte Informations- und Datenbasis für die Entwicklung der PV-Systempreise und Unterhaltskosten geschaffen werden. Dazu können die verfügbaren Projekt- und Betriebsdaten für einen *Global Survey* eingeben werden [86]. Die so gesammelten Daten, aus möglichst vielen Regionen der Welt und aus möglichst verschiedenen Zeitperioden, werden von Task 2 bezüglich der Kostenentwicklung analysiert.

Im Rahmen der interdepartementalen Plattform (seco, DEZA, BUWAL (neu BAFU), BFE) zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit *REPIC* [76] leistet *entec* den Schweizer Beitrag zu IEA PVPS Task 9 über die **Photovoltaik-Entwicklungszusammenarbeit** [39]. Die Schweiz ist in diesem Projekt für die Koordination der Arbeiten mit multilateralen und bilateralen Organisationen verantwortlich. Im Berichtsjahr wurden im Rahmen dieses Projektes nebst den üblichen Projekttreffen Workshops in Vietnam, Burkina Faso und China durchgeführt. Task 9 war zudem an Konferenzen in Bangkok, Washington und Barcelona vertreten.

Meteotest [40] und das CUEPE an der Universität Genf [41] erbringen zusammen den Schweizer Beitrag zum neuen 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).

Alpha Real vertritt im Namen des Fachverbandes SOLAR (neu SWISSOLAR) die Schweiz im TC 82 der IEC und leitet die Arbeitsgruppe, welche internationale **Normenvorschläge** [42] für Photovoltaiksysteme vorbereitet und verabschiedet. *Alpha Real* beteiligt sich ausserdem an *PV-GAP* [43] (PV Global Approval Program), einem weltweiten Programm zur Qualitätssicherung und Zertifizierung von Photovoltaik-Systemen.

Die Beteiligung am EU-Projekt ***PV-ERA-NET*** [44], welches Programmkoordinationsstellen und verantwortliche Ministerien aus 13 Ländern unter dem ERA-NET Schema [87] zusammenführt, wurde durch die Photovoltaik Programmleitung (BFE, *NET Nowak Energie & Technologie*) sichergestellt. Die

Schweiz leitet in diesem Projekt das ersten Arbeitspaket zum Informationsaustausch über Europäische Photovoltaik Programme. Im Berichtsjahr wurden ausführliche Berichte zu den Ausrichtungen und Inhalten dieser Programme zusammengestellt und Hinsicht auf eine verstärkte Zusammenarbeit analysiert [88].

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 BUWAL (neu 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. Als konkretes Beispiel dieser erfolgreichen Zusammenarbeit ist der im Berichtsjahr neu geschaffene IEA PVPS Pool zu erwähnen (vgl. oben).

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 2005 waren es 16 Projekte im 5. bzw. 6. Rahmenforschungsprogramm der EU, die Beteiligung an zwei neuen *Integrierten Projekten* beginnt anfangs 2006. Ein weiteres Projekt fand mit der esa statt. Die Schweizer Photovoltaik konnte sich damit sehr erfolgreich an den Ausschreibungen im 6. Rahmenforschungsprogramm der EU beteiligen. Es findet ein regelmässiger Kontakt mit Programmverantwortlichen in EU-Ländern statt, ebenso mit den zuständigen Einheiten bei der Europäischen Kommission.

Aufgrund des Berichtes *A Vision for Photovoltaic Technology* [89] des *Photovoltaic Technology Research Advisory Council (PV TRAC)* der Europäischen Kommission wurde 2005 die Europäische Photovoltaik Technologie Plattform gegründet [90]. 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. Andererseits wird im Rahmen einer Technologie-Plattform ein strategischer Forschungsplan definiert und umgesetzt. Dieser ist für die Photovoltaik insbesondere auf die Ausgestaltung des 7. Rahmenforschungsprogramms der EU von Wichtigkeit. Durch die Gründung dieser Photovoltaik Technologie Plattform wird die langfristige strategische Bedeutung der Photovoltaik hervorgehoben. Die Schweiz ist sowohl im Steuerungsausschuss wie in einzelnen Arbeitsgruppen vertreten.

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

Die aufgrund des Entlastungsprogramms 2003 des Bundes beschlossenen Kürzungen sind seit 2004 vorab für die Mittel für P+D Vorhaben wirksam und haben damit eine einschneidende Wirkung auf die Ausgestaltung und die Möglichkeiten im Programm Photovoltaik. Im Berichtsjahr 2005 konnten wie bereits 2004 **keine neuen P+D Projekte** mit BFE-Mitteln unterstützt werden. 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. Dies trifft die Photovoltaik zu einem Zeitpunkt, in dem sich nach langem Aufbau eine verstärkte Umsetzung im Programm Photovoltaik abzeichnet.

Der weltweite Photovoltaikmarkt boomt aufgrund grossangelegter Förderprogramme bzw. Einspeisevergütungen immer mehr Länder weiterhin mit jährlichen Wachstumsraten von mehr als 35 %. 2005 erreichte die weltweite Modulproduktion mehr als 1500 MWp. Damit sind zur Zeit gute Exportmöglichkeiten für innovative Produkte vorhanden. Demgegenüber stagniert der schweizerische Photovoltaikmarkt seit rund 10 Jahren bei einem Jahreswert von ca. 2 MWp. Dank der Initiative einzelner innovativer Stromversorger, welche Grossprojekte realisiert haben, beträgt der Jahreswert im 2005 über 4 MWp.

Die noch verbleibenden Photovoltaik P+D Projekte behandelten schwerpunktmässig weiterhin die Thematik der **Photovoltaik Gebäudeintegration**, insbesondere für Anlagen auf Flachdächern und die Verwendung von Dünnschicht Modulen.

EINIGE P+D ERFOLGE DER LETZTEN JAHRE IM ÜBERBLICK

An dieser Stelle wird auf eine Auswahl von **erfolgreichen Photovoltaik P+D Projekten** der letzten Jahre hingewiesen, die entweder nachhaltig im Markt umgesetzt wurden, oder die mit verschiedenen Auszeichnungen die Innovationskraft dieser Projekte und Produkte belegen.

Das mit der 15 kWp Anlage in Trevano erstmals im Massstab 1:1 getestete *Sarnasol* System bestehend aus amorphen Dünnschichtzellenmodulen verbunden mit einer dichten Kunststofffolie [45] wird von Sarnafil in Zusammenarbeit mit *Solar Integrated* neu unter dem Namen *Solar Dach* oder *Smart*Roof*!* ® vermarket. Bisher konnten mit diesem System diverse Anlagen erfolgreich realisiert werden (siehe Fig. 4).

Mit etwas verzögerter Wirkung konnte das Projekt 'Montagesystem AluTec' (Abschluss 2002 [47]) bzw. die Weiterentwicklung 'Montagesystem AluStand®' [48] (siehe Fig. 5) erfolgreich umgesetzt werden. Im Jahr 2005 wurden vor allem in Deutschland Profile für eine PV Leistung von 10 MWp verkauft. Insgesamt konnten mit diesem System seit der Markteinführung bisher Anlagen mit einer Leistung von rund 30 MWp installiert werden.

Figur 4: *188 kWp Solar Dach in Fulda (Bildquelle Sarnafil)*

Figur 5: *27 kWp Anlage Alustand Hünenberg (Bildquelle Urs Bühler Energy Systems)*

Figur 6: *Solarmax 2000 / 3000 (Bildquelle: Sputnik Engineering)*

Figur 7: *5 MWp Dachintegration Sonnenfleck (www.sonnenfleck.com)*

Geradezu beispielhaft konnte die Firma Sputnik Engineering im Rahmen von Photovoltaik Forschungs- und P+D Projekten in Zusammenarbeit mit der Bieler Fachhochschule die notwendigen Grundlagen im Bereich der Photovoltaik Wechselrichtertechnologie erarbeiten, Prototypen entwickeln und im praktischen Einsatz 1:1 testen. Die SolarMax® Geräte (siehe Fig. 6) sind heute die Nummer 3 auf dem Europäischen Markt. 2005 wurden Wechselrichter für eine PV Anlagenleistung von rund 125 MWp produziert (mehr als das 50-fache des Schweizer Markts), was im In- und Ausland bei Sputnik und den Zulieferfirmen rund 120 Arbeitsplätze sichert.

Ein weiteres Beispiel aus der Liste erfolgreicher Projekte ist die von den beiden Firmen Schweizer Metallbau und Enecolo in Zusammenarbeit realisierte Photovoltaik P+D Entwicklung 'Dachintegrationsrahmen SOLRIF®' [51] (siehe Fig. 7). Seit der Markteinführung wurden auf dem Europäischen Markt SOLRIF® Rahmen für dachintegrierte Anlagen mit einer Gesamtleistung von über 10 MWp ausgeliefert.

Wie SolarMax®, SOLRIF® oder AluStand® beispielhaft aufzeigen, bildeten innovative Photovoltaik Forschungs- und P+D Vorhaben in Vergangenheit immer wieder die Basis für die erfolgreiche Umsetzung von Produkten im Binnenmarkt und im Export.

LAUFENDE P+D PROJEKTE

Bei den laufenden Projekten zeigte die integrierte 15.4 kWp Flachdachanlage CPT Solar (Centro Professionale Trevano) mit amorphen Dünnschichtzellen [45] (siehe Fig. 8) das Potential dieses Konzepts auf. Der bisher erreichte hohe Ertrag von deutlich über 1000 kWh/kWp (2004: 1070 kWh/kWp; 2005 1077 kWh/kWp) belegt die optimale Planung und Auslegung dieser Installation mit nahezu horizontal (3°) ausgerichteten Modulen.

Die noch bis Sommer 2006 laufenden Untersuchungen zur 25 kWp Gründachanlage 'Solgreen Kraftwerk 1' [49] (siehe Fig. 9) belegen deutlich, dass die Kombination von Gründach und Photovoltaik aus Sicht der Solarstromerzeugung und aus Sicht der Dachbegrünung eine erfolgreiche Variante darstellt. Mit rund 1000 kWh/kWp liegt die Jahresproduktion auf einem vergleichsweise hohen Niveau. Bei allen verwendeten Bodensubstraten liegt der pH-Wert im neutralen Bereich und ist für die im Boden verankerte Unterkonstruktion unproblematisch. Bei allen Bodensubstraten findet eine mehr oder weniger starke Dachbegrünung statt. Auf extensiven Flächen überschritten keine Pflanzen die Modulunterkanten, auf humusreicheren Versuchsflächen traten vereinzelt höhere Pflanzen auf, die aus Beschattungsgründen entfernt werden mussten.

Figur 8: *15.4 kWp PV Flachdachintegration CPT (Bildquelle: NET)*

Figur 9: *Solgreen Kraftwerk 1 (Bildquelle: NET)*

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 Dünnschichtzellenmodule; Leitung: *Zagsolar / Wyss Aluhit)* [52]

Anlagen

- 15.4 kWp Flachdachintegration CPT Solar (Pilotmässiger Einsatz einer neu entwickelten Kombination von amorphen Dünnschichtzellenmodulen mit einer dichten Kunststofffolie; Leitung: *LEEE-TISO*) [45] (siehe Fig. 8)
- 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]
- 17.6 kWp Flachdachanlage mit Dünnschichtzellenmodulen ETHZ (Optisch diskrete Flachdachanlage mit amorphen Zellen; Leitung: *BE Netz*) [55]
- 12 kWp Solight Pilotanlage (Pilotmässige Umsetzung von zwei verschiedenen Solight Varianten; Leitung: *Energiebüro*) [56]
- 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*) [58]
- 25 kWp Gründachintegration Solgreen Kraftwerk 1, Zürich (Piloteinsatz einer neu entwickelten Modulhaltekonstruktion für den Gründachbereich; Leitung: *Enecolo*) [49] (siehe Fig. 9)

Messkampagnen

- Messkampagne Wittigkofen (Detaillierte Messungen und Auswertungen mit Visualisierung der Daten zur 80 kWp Fassade Wittigkofen; Leitung: *Ingenieurbüro Hostettler*) [59]

Studien - Hilfsmittel - diverse Projekte

- Photovoltaikstatistik der Schweiz 2004 (Leitung: *Ingenieurbüro Hostettler*) [60]
- Solarstrom vom EW (Leitung: *Linder Kommunikation*) [61]
- Solar *Electri* City Guide - Schweizer Solarstromführer für die Gemeinden (Leitung: *NET*) [62]
- Solarenergie Potential in Genf (Studie zum Flächenpotential für thermische Solaranlagen und Photovoltaikanlagen im Gebäudepark der öffentlichen Hand im Kanton Genf (Leitung: *NET*) [63]

IM JAHR 2005 ABGESCHLOSSENE PROJEKTE

Im Jahr 2005 wurden die folgenden P+D Projekte abgeschlossen (in chronologischer Reihenfolge):

Anlagen

- 23.5 kWp PV Anlage Zollhof Kreuzlingen (Flachdach Demonstrationsanlage mit Grossanzeige an gut frequentierter Lage; Leitung: *Böhni Energie und Umwelt*) [64] (siehe Fig. 10)
- 62 kWp Flachdachanlage mit PowerGuard Solardachplatten (Multifunktionale PV Flachdachanlage mit gleichzeitiger thermischer Isolation des Dachs, wobei die thermischen Dämmelemente auch die Funktion der Modulhaltekonstruktion übernehmen; Leitung: *Zagsolar*) [53] (siehe Fig. 11)
- Photovoltaik Anlagen Corvigliabahn und Piz Nair St. Moritz (Realisierung einer 17.8 kWp Anlage entlang der Corvigliabahn und einer 9.7 kWp und 13.5 kWp Fassadenintegration in die Talstation, bzw. die Bergstation der Piz Nair Seilbahn; Leitung: *SunTechnics Fabrisolar*) [65]
- 27 kWp Anlage AluStand Hünenberg (Demonstrationsanlage mit Verwendung der Flachdachvariante des Modulhaltesystems AluTec (AluStand®); Leitung: *Urs Bühler Energy Systems and Engineering*) [48] (siehe Fig. 5)
- 3 kWp Anlage Ferme Amburnex (Inselanlage mit Hilfs-Dieselaggregat zur elektrischen Versorgung einer Alp, autonome Anlage; Leitung: *Services Industriels Lausanne*) [66]
- RESURGENCE - Renewable Energy Systems for Urban Regeneration in Cities of Europe (Realisierung von total 1.3 MWp PV Anlagen im städtischen Raum in den 5 Ländern England, Holland, Dänemark, Deutschland und der Schweiz, EU Projekt; Leitung Schweizer Teil: *Enecolo*) [50]

Messkampagnen

- PV DünnFilmTest Migros Zürich (18 Testanlagen mit PV Dünnschichtzellen-Modulen im direkten Vergleich, Gesamtleistung: 24.5 kWp; Leitung: *Energiebüro*) [57] (siehe Fig. 12)
- Monitoraggio dell'impianto PV da 100 kWp AET III (Detaillierte Messkampagne zur revidierten 100 kWp PV Anlage entlang der SBB Linie Bellinzona-Locarno; Leitung: *LEEE-TISO*) [46] (siehe Fig. 13)
- Messkampagne 100 kWp Anlage A 13 (Leitung: *TNC Consulting*) [67]

Studien - Hilfsmittel - diverse Projekte

- Integration der neuen IEC Norm 60364-7-712 für Photovoltaik in die nationalen Installationsnormen NIN (Aktualisierung, bzw. Ersatz der veralteten PV Normen; Leitung: *Electrosuisse*) [68]
- GISS Gebäude-Integrierte-Solarstrom-Systeme (Studie zur besseren Umsetzung von gebäudeintegrierten Solarstromsystemen durch Abbau von Hindernissen und Informationsmängeln und Erhöhung der Fachkompetenz bei Planern, Investoren und Bauherren; Leitung: *SZFF Schweizerische Zentralstelle für Fenster- & Fassadenbau*) [69]

Figur 10: *PV Anlage Zollhof Kreuzlingen (Bildquelle NET)*

Figur 11: *62 kWp Anlage mit PowerGuard Modulen (Bildquelle: Zagsolar)*

Figur 12: *PV DünnFilmTest (Bildquelle NET)*

Figur 13: *Messkampagne zur 100 kWp Anlage AET III (Bildquelle: TISO)*

6. Bewertung 2005 und Ausblick 2006

Global war das Jahr 2005 für die Photovoltaik ein überaus erfolgreiches Jahr. In einer durch hohes Wachstum gezeichneten Marktdynamik konnte die Photovoltaik Industrie ihren Ausbau fortsetzen. Die von der Landesbank Baden-Württemberg publizierte Branchenanalyse [81] bringt die Entwicklung mit einem Satz auf den Punkt: „Das industrielle Zeitalter beginnt“. Durch das rasche Wachstum hat sich aber ein Engpass in der Verfügbarkeit von Rohsilizium eingestellt. Dieser Engpass führt zu enormem Druck für die Industrie, Produktionskapazitäten können nicht ausgelastet werden, Produkte können nicht geliefert werden und zudem steigen damit naturgemäss auch die Preise. Silizium ist dabei keine wirkliche Mangelware, bekanntlich gibt es davon sprichwörtlich wie „Sand am Meer.“ Aufgrund des schnellen Marktwachstums der Photovoltaik wurde aber die sich abzeichnende Verknappung des Rohsiliziums früher als erwartet erreicht, insbesondere früher als die neu geplanten Fertigungskapazitäten von Silizium bereit stehen. Es wird allgemein erwartet, dass diese Situation während 2006 anhalten und frühestens 2007 eine Entspannung auftreten wird. Für die Dünnschichtsolarzellen entsteht aber aufgrund dieser angespannten Situation ein interessantes „window of opportunity“ – sprich Chancen für diese Technologien.

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 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 2005 auf mindestens 80 Mio. Fr. geschätzt. Zusammen mit dem Heimmarkt kann der Gesamtumsatz der Schweizer Photovoltaik mit mindestens 100 Mio. Fr. beziffert werden.

Die bisherigen Anstrengungen im Schweizer Photovoltaik Programm bilden die wissenschaftlich-technische Ausgangslage, um im rasch wachsenden 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.

Nebst der bekannten Tatsache, dass die Schweiz bezüglich den Rahmenbedingungen am Markt international zusehends ins Hintertreffen gerät, zeichnet sich aber auch im Bereich der Forschung in letzter Zeit eine ähnliche Entwicklung ab. Internationale Erhebungen zeigen, dass die Aufwendungen für die Photovoltaik Forschung in vielen Ländern steigen und die Bedeutung der Forschung generell zunimmt. Nicht zuletzt wird dies auch durch die Schaffung der Europäischen Photovoltaik Technologie Plattform unterstrichen. Demgegenüber wird die Situation in der Schweiz, trotz breiter Abstützung des Programms, immer schwieriger. Damit entsteht eine weitere internationale Diskrepanz, welche der bisherigen Leistung der Schweizer Photovoltaik, sowohl in Forschung wie in der Industrie, nicht gerecht wird. Bestens international auf allen Ebenen vernetzt und mit einem weltweit anerkannten Know-how hat die Schweizer Photovoltaik das Potenzial, im rasch wachsenden Markt eine bedeutende Rolle zu spielen.

Das Programm Photovoltaik wird auch in Zukunft bestrebt sein, durch die breite Abstützung eine kritische Grösse zu bewahren. Dazu soll von allen möglichen Fördermechanismen Gebrauch gemacht werden und diese gleichzeitig optimal koordiniert und zielführend eingesetzt werden. Dies wird aber allein nicht genügen, um das Potenzial der Schweizer Photovoltaik nachhaltig umzusetzen. Gefragt sind Massnahmen und eine Trendumkehr in der Entwicklung der finanziellen Mittel, welche es erlauben, auch in der Forschung international mitzuhalten. Die Schweizer Photovoltaik hat in den letzten Jahren eindrücklich den Beweis erbracht, dass sie zu Spitzenleistungen in der Lage ist, welche mutige Schritte in diese Richtung rechtfertigen.

Die EMPA organisierte im April 2005 ein Fachseminar zur Solarzellenforschung [91]. Die Schweizer Photovoltaik war auch an der 20. europäischen Photovoltaik Konferenz im Juni in Barcelona mit ihren Beiträgen gut vertreten [92]. Bei den SIG in Genf fand im November 2005 die besonders aus Industriekreisen gut besuchte 6. Nationale Photovoltaik Tagung statt [93]. Der nationale Informations- und Erfahrungsaustausch bleibt damit in der Schweiz weiterhin ein wichtiges Thema. Die Photovoltaik Webseite http://www.photovoltaic.ch beinhaltet alle wesentlichen Informationen sowie Berichte und dient damit als wichtiges Informationsinstrument, das laufend unterhalten wird.

7. Liste der F+E-Projekte

(JB) Jahresbericht 2005 vorhanden
(SB) Schlussbericht vorhanden (siehe www.energieforschung.ch unter den angegebenen Publikationsnummern in Klammern)
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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[7] V. Terrazzoni, C. Ballif (vanessa.terrazzoni@unine.ch), IMT, UNI-Neuchâtel*, Neuchâtel:* ***Optical nano-gratings and continuous processing for improved performance flexible solar cells*** (JB) / www.unine.ch/pv

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[15] M. Grätzel, A. McEvoy (michael.graetzel@epfl.ch), EPFL, *Lausanne:* ***Dye - sensitised Nanocrystalline Solar Cells*** (JB) / http://isic.epfl.ch/graetzel_e.htm

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8. Liste der P+D – Projekte

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10. Für weitere Informationen

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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.energie-schweiz.ch
BUWAL	Bundesamt für Umwelt, Wald und Landschaft heisst neu Bundesamt für Umwelt BAFU	http://www.umwelt-schweiz.ch/buwal/de/
CORE	Eidgenössische Energieforschungskommission	http://www.energie-schweiz.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
DEZA	Direktion für Entwicklung und Zusammenarbeit	http://www.deza.admin.ch
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt	http://www.empa.ch
EPFL	Ecole Polytechnique Fédérale Lausanne	http://www.epfl.ch
ETHZ	Eidgenössische Technische Hochschule Zürich	http://www.ethz.ch
HTI Burgdorf	Hochschule für Technik und Informatik HTI	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	Kommission für Technik und Innovation	http://www.bbt.admin.ch/kti/profil/d/index.htm
LEEE - TISO	Laboratorio di Energia, Ecologia ed Economia - Ticino Solare	http://www.leee.supsi.ch
LESO	Laboratoire d'Energie Solaire EPFL	http://lesomail.epfl.ch/
LTC	Laboratory of Polymer and Composite Technology EPFL	http://dmxwww.epfl.ch/ltc/ltc_main.htm
NIN	Nationalen Installationsnormen	http://www.electrosuisse.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
SIG	Services Industriels de Genève	http://www.sig-ge.ch/
SUPSI	Scuola universitaria professionale della Svizzera Italiana	http://www.leee.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/Renewable_Energies.85.0.html
GEF	Global Environmental Facility	http://www.gefweb.org
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit	http://www.gtz.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
NREL	National Renewable Energy Laboratory	http://www.nrel.gov/
PV GAP	PV Global Approval Programme	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

	Unaxis	http://www.unaxis.ch

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
Top Nano	Technologie Orientiertes Programm Top Nano 21	http://www.ethrat.ch/topnano21/
BFS	Bundesamt für Statistik	http://www.bfs.admin.ch
IGE	Eidgenössisches Institut für Geistiges Eigentum	http://www.ige.ch
	Bundesamt für Metrologie und Akkreditierung metas	http://www.metas.ch/
	Swiss Education and Research Network Switch	http://www.switch.ch
Swissolar	Schweizerischer Fachverband für Sonnenenergie	http://www.swissolar.ch
SOLAR	Schweizerischer Fachverband für Solarenergie ab 01.01.06 Swissolar	http://www.solarpro.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

Annual Report 2005

Thin film silicon solar cells: advanced processing and characterization

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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 (process 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 standardize new advanced characterization systems
- Work on process reproducibility by revisiting several fabrication steps, from solar cell patterning to individual layer optimization.

In 2005, an important step was achieved by fabricating for the first time high efficiency p-i-n micro-crystalline (9%) and micromorph tandem solar cells (11.6% initial) directly on LPCVD-ZnO coated glass substrates. The ZnO layers were specially tailored to allow the fabrication of high efficiency devices.

Using "industry compatible" processes, high efficiency 7.3% amorphous single junction, and 8.3% micromorph tandem solar cells were prepared on plastic textured PET substrates, whereas microcrystalline cells with 7.6% efficiency could be prepared on flexible steel foils.

The projects with industrial partners could directly benefit from this SFOE project, using both the know-how gained in processing and the new infrastructures of the laboratory (deposition and characterisation systems).

Introduction

Thin film silicon based modules from several companies (Kaneka, Mitsubishi HI, Unisolar, Sharp, Fuji..) are now entering the commercial market. They already represent one of the best options in terms of price per W_p and their potential for significant cost reduction remains unsurpassed.
The establishment of such thin films modules as a competitive energy source in the future still requires, however, a strong effort both at the academic and at the industrial level: high quality production equipments have to become available, so that companies can start production with limited risks. Higher device efficiencies should also be demonstrated, allowing the technology to become even more cost effective in the long term.

Description of the project

IMT is, on one hand, involved in technology transfer and research support with two Swiss companies (Unaxis Solar, VHF-Technologies), and needs, on the other hand, to continue achieving a high level of innovation in thin film photovoltaic technology. In this context, this 3 year long research project aims at reaching the following objectives

- Introducing new concepts for higher efficiency thin film micromorph devices on glass substrates (>14%)
- 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 best infrastructure (process know-how, fabrication and characterization systems) to support industrial partners in the frame of projects funded by other sources

To reach these objectives, a strong effort has been made in 2005 to improve the laboratory infrastructures: new deposition systems and new characterization tools have been installed, and several older systems have been upgraded.
In parallel, the process reliability and robustness has been improved. The word “process” refers here to the fabrication of front and back electrodes, to the deposition of the semiconducting amorphous and microcrystalline layers, and to the patterning steps needed to define the device structures.

Results

High efficiency solar cells on glass substrates

The initial objective is to improve the performance of the microcrystalline, amorphous and micromorph solar cells in the superstrate configuration (p-i-n devices deposition on glass). The final objective of this part of the project is the achievement of a stable conversion efficiency of **14% for the micromorph** solar cell.

Ground work had to be undertaken to reach this ambitious goal. It consisted in the identification of the critical parameters and the development of standard and reliable processes.

- the large spread of the electrical performances initially measured for the p-i-n solar cells were preventing further improvement in device reliability
- the second limitation for high efficiency was the low current density (final report project 100 045) of the microcrystalline silicon solar cell. Indeed, the current obtained with the ‘old’ state-of-the-art microcrystalline solar cell was of 19mA/cm^2 for 1.2μm thick device (device with 7% efficiency).

Both issues were addressed by introducing a new patterning technique, by the introduction of tailored LPCVD ZnO coatings as front and back electrodes and by a full re-optimization of the processes for microcrystalline p-i-n solar cells on glass.

Patterning of the solar cells

The patterning technique of the solar cells was the first to be adapted in the fabrication process: we changed from a wet etching technique to a lift-off technique. The application of the new lift-off process, described in the reference [Gra05], enabled a dramatic decrease in the spread of the values of the electrical characteristics of the cells. The results in Fig.1 are represented in a box-plot[1] and illustrate the difference between the two patterning techniques. We observe that maximum FF and V_{oc} are the same with both patterning techniques. However, the spread of the data for FF and V_{oc} is strongly reduced when patterning by lift-off rather than by the wet etching technique.

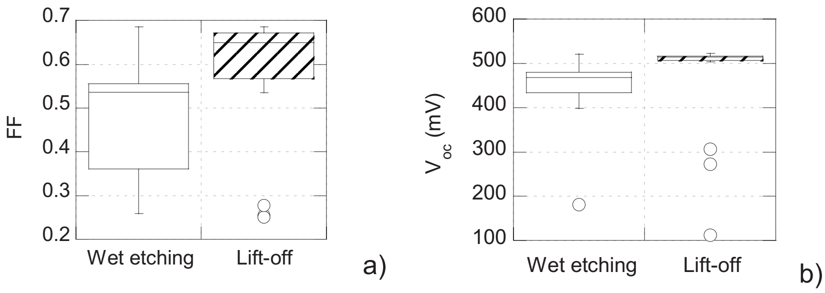

Fig.1: a) and b) fill-factor (FF) and the open-circuit voltage (V_{oc}) obtained with two different patterning techniques: wet etching (old) and lift-off (new) technique. The measurements were done on 16 single cells in both cases. The outliers (open-circle) are caused by localized shunts.

p-i-n microcrystalline silicon solar cells on LPCVD ZnO

The more reliable patterning step allowed us to focus on the optimization of the solar cells only. The optimization had to be undertaken for each layer of the devices, taking into account the influence of each layer on the growth of the subsequent layers [Val05].

- Front LPCVD ZnO: various ZnO doping and thicknesses, surface treatments
- p-layer: p-layer doping and silane concentration series
- i-layer: thicknesses and silane concentration gradients, effect of gas purifier on microcrystalline silicon solar cell
- n-layer: microcrystalline and amorphous silicon n-layers
- Back TCO: different doping and thicknesses of LPCVD ZnO
- Back reflector: white paste, silver contact

Such an optimization represents a significant amount of work. Therefore, all steps were carefully documented, with a special emphasis on the implemented steps. The goal is here to maintain standard high efficiency processes in the lab, and also to transmit this know-how in a reliable way.

Following this full process optimization, μc-Si solar cells deposited in the n-i-p configuration with front ZnO LPCVD could be prepared with efficiency up to 9%, and an efficiency of 8.4% is even achieved for ultra-thin (1μm) μc-Si devices. These are the highest efficiencies reported for solar cells deposited on LPCVD ZnO.

The electrical characteristics of the best cells are given in Table 1, the I-V and EQE curves are presented in Figs. 2 and 3.

[1] The middle line represents the median of the data. The top of the box represents the upper quartile (it contains 25% of the data higher than the median) and the bottom line the inferior quartile (25% of the data lower than the median). The difference between the top and the bottom of the box can be used as a measure of the spread of the data and is called the interquartile distance. Extreme points are represented with a dash and outliers with an open circle.

p-i-n micromorph silicon solar cells

The goals for the micromorph solar cell in 2005 were to reach a 11% stable conversion efficiency. As ground work had to be done to improve first the microcrystalline cells, only a limited effort was made to fabricate micromorph devices. By using the process improvement for the μc-Si part of the cell, a good micromorph silicon solar cell with an initial conversion efficiency of 11.6% could be fabricated, still using LPCVD ZnO as front oxide. An intermediate reflector between the top and bottom solar cell was used, enabling thereby to reduce the thickness of the amorphous solar cell to 180nm. Hence a low light induced degradation is expected. The current densities of the top and bottom solar cells are remarkably high, with values of 12.4 and 12.1 mA/cm^2, respectively.

Cell type	V_{oc} mV	FF %	I_{sc} mA/cm^2	**Efficiency (%)**
μc-Si:H 1μm	557	70.1	21.6	**8.43**
μc-Si:H 2μm	537	72.2	23.3	**9.03**
Micromorph	1315	73.2	12.1	**11.64**

Table 1. Electrical characteristics of the best p-i-n solar cells fabricated in 2005 at IMT on LPCVD ZnO coated glass. The p-i-n solar cell single junction constitutes a conversion efficiency record at IMT. The efficiency of the micromorph cell was measured after a short thermal annealing.

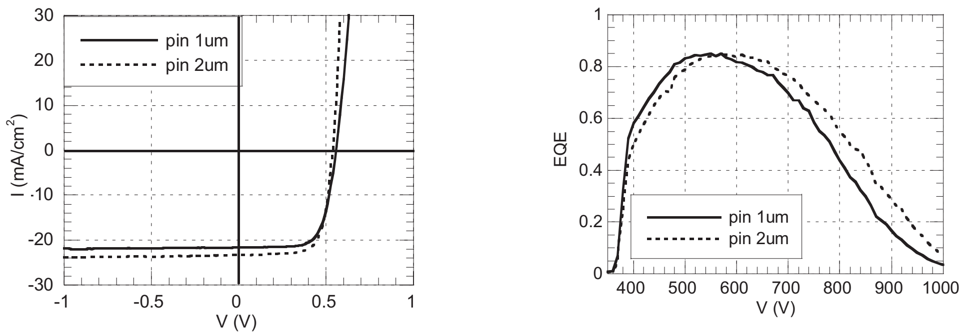

Fig. 2: I-V curves and external quantum efficiencies (EQE) of 1 and 2 microns thick p-i-n microcrystalline silicon solar cells deposited on LPCVD ZnO.

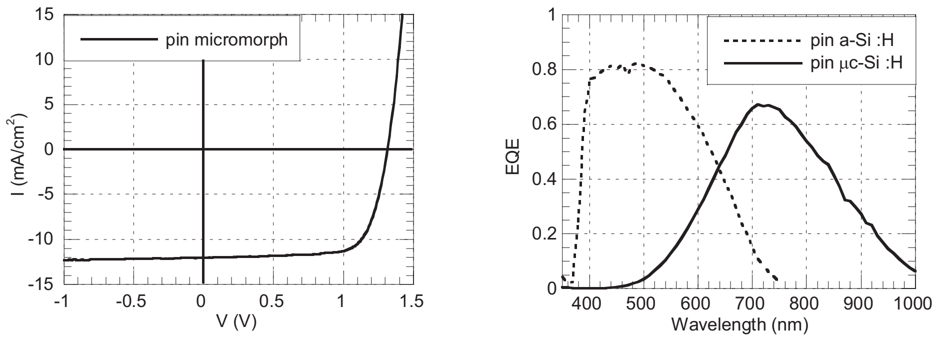

Fig. 3: I-V curve and external quantum efficiencies (EQE) of the best micromorph tandem solar cell fabricated in 2005 with a conversion efficiency of 11.6% (see Table 1).

Light-weight unbreakable substrates

IMT is transferring its pioneering results concerning a-Si :H/μc-Si :H and tandem solar cells on low cost flexible substrates. First, more homogeneous and more reliable new reflecting substrates [Ter05] are being developed in the new sputtering reactor installed in June 2005 at the IMT (Univex System from Leybold). Al-based and Ag-based reflectors deposited at room temperature are already available

on glass and nano-textured PET substrates. As-grown textured Ag on glass is currently under development (Fig. 4).
Furthermore, in order to improve the reliability of the cells, the diborane usually used as precursor gas for the deposition of the p-doped layers was replaced by the trimethyl boron gas, which has the advantage of being much more stable in time during the storage. After this modification, the p-doped layers have been re-optimised.

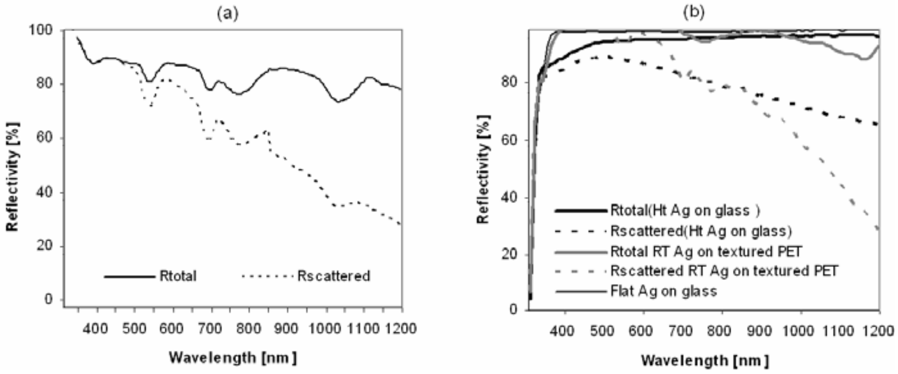

Fig. 4: (a) Total and scattered reflectivity of the Al-based back contact currently available at IMT on textured PET substrates. (b) Total and scattered reflectivity of the Ag-based back contacts currently available at IMT on glass (as-grown textured Ag deposited at high temperature and flat Ag deposited at room temperature) and on textured PET films.

a-Si:H solar cells on plastic

Single junction a-Si:H solar cells (laboratory-scale) with stabilized efficiency of 7.25% (V_{oc}=863mV, FF=63.3%, J_{sc}=13.32mA/cm^{-1}) were developed [Bail05] on textured low-cost plastic foils (PET) fabricated through a roll-to-roll process (Fig. 5a). This result was achieved using Al for the back contact and ITO as top contact (Fig. 2). The initial project goal of 7.5% stable efficiency should be reached within the next few weeks by replacing the Al and ITO layers by Ag and LPCVD-ZnO, respectively.

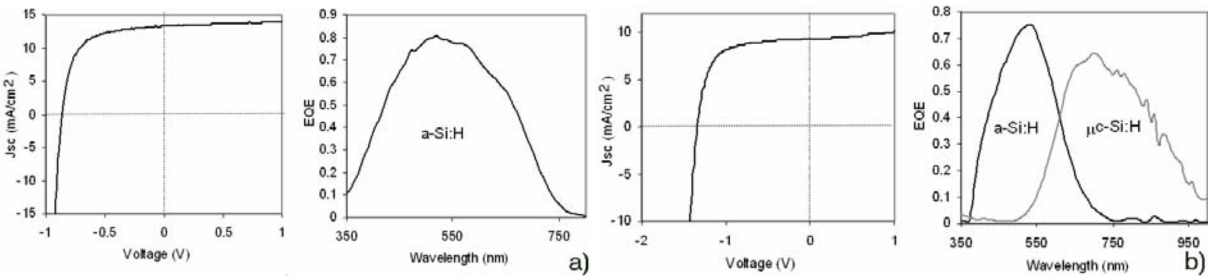

Fig. 5: a) I-V and EQE curves of the a-Si:H solar cells deposited on PET substrate. The back reflector consisted in Al and ZnO layers deposited by sputtering. ITO was used as top contact. b): IV and EQE curves of the micromorph solar cell deposited on PET substrate. The back reflector consisted in Ag and ZnO layers deposited by sputtering. LPCVD-ZnO was used as top contact.

μc-Si:H solar cells on flexible foils

Single junction μc-Si:H solar cells were deposited on flexible substrates (stainless steel plus Ag and ZnO layers deposited by sputtering). The initial project goal of 7.5% efficiency was reached (η=7.6%, V_{oc}=500mV, FF=71.5%, J_{sc}=21.4mA/cm^{-1}).

μc-Si:H/a-Si:H tandem cells on plastic substrate

Preliminary work has been done for deposition of micromorph tandem cells on PET substrates [Bail05]. The first attempt resulted in 8.3% stabilised efficiency V_{oc}=1.33V, FF=67%, J_{sc}=9.3 mA/cm^{-1} (Fig. 5b). Note that (1) the nano-texture of the scattering substrates was far from the theoretical optimum and (2) there was an important current-mismatch between the top and bottom cells.

Transparent conducting oxides

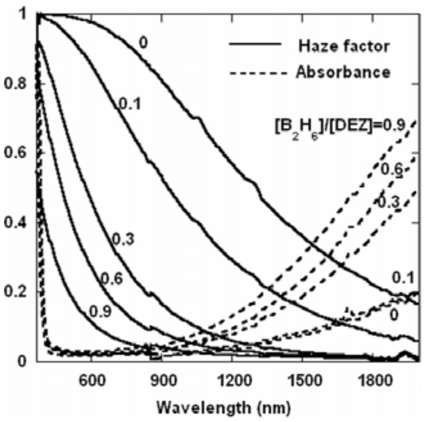

Fig. 6 : Absorbance and haze factor (i.e. diffuse / total transmittance ratio) curves for LP-CVD ZnO series deposited with various doping ratios (i.e. B_2H_6/DEZ ratio). All Layers with10 Ω_{sq}.[Stei05].

High quality TCO's are required for the fabrication of high efficiency devices. In 2005, the work has focused, on one hand, on the deposition and optimization of ITO (top TCO for cells on flexible substrates) and ZnO layers (used as front TCO, intermediate reflector or back-reflector) fabricated in the new sputtering system at IMT.
On the other hand, the work with Boron doped ZnO layers deposited by Low Pressure Chemical Vapour Deposition (LP-CVD) has been continued. These layers can be used both as front electrode and as back electrode in amorphous, μc-Si and micromorph devices [Fay05]. A special effort was made to achieve a high reproducibility in the fabrication of the layers and control procedures were implemented.
The work with LPCVD ZnO has focused, in 2005, on the preparation of layers with tailored properties (e.g. Fig. 6), such as surface roughness and light scattering capabilities [Stei05, Fay05B]. In particular, highly diffusive layers with low sheet resistance and reduced free carrier absorption in the IR part of the spectrum could be prepared.
The influence of the TCO surface morphology on the current collection of micromorph devices with intermediate reflector was systemically investigated (Dom05) and it could be shown that a high surface roughness, which increases the current collection in the bottom micromorph cell is compatible with the use of thin intermediate reflector. It could also be shown that, without careful process optimization, the fill factor and V_{oc} of p-i-n microcrystalline solar are reduced on substrate with higher roughness [Feit05Shangai]. By taking advantage of the flexibility of the LP-CVD ZnO process, and by a careful optimization of the µc-Si:H layers, µc-Si:H solar cell efficiencies of 9% were obtained, as well as micromorph cells with initial efficiency of 11.6%, as previously mentioned.

Characterization tools

Although the objective of the project is to contribute finally to the technological development necessary for lower cost photovoltaic, it is necessary to possess the right investigation tools. These tools should allow the experimenter to obtain a fast feed back on the quality of the layers, of the devices, and to perform systematic quality controls.
As planned, IMT made an active use of two techniques installed in 2004: the VIM (variable illumination measurement) technique, which in a simplified form, became a standard measurement, and FTPS (Fourrier transform photocurrent spectroscopy) which has been established in the laboratory as a standard tool for measuring the electronic quality of the i-layer incorporated into solar cells.
In addition, an infrared lock-in thermography (IRLIT) -system has been installed. This is a versatile tool that allows the visualisation of short-circuits or the detection of areas with enhanced recombination current. Thermal resolution down to a few tens of micro-Kelvin, and spatial resolution below 50 μm are achievable (Fig.7b).

With the **VIM** technique, one measures the I(V) curve of the thin-film solar cell under very high illumination down to very low illuminations, instead of measuring it only under the standard 1 sun (100 mW/cm^{-2}) illumination. In this way, both parallel and series parasitic resistances can be evaluated. The parallel resistance Rp is typically related with shunts (short-circuits) such as dust particle or structuration problems, whereas the series resistance Rs is related with contacts quality and intrinsic material resistivity.
By performing low light intensity measurements (typically at 0.4 mW/cm2), the parallel resistance plays a pre-eminent role, if its value is too low. In such a case, the Fill-Factor of the I(V) curve of the solar cell drops to very low value. On contrary, in a solar cell with a good Rp, the Fill-factor remains almost constant down to very low illumination intensities. Thus I(V) curves acquired at low illumination are now used on a regular basis to diagnose whether shunting of the device is severe or not.

The **FTPS** measurement technique allows the measurement in a highly sensitive way (over 6 decades) of the absorption coefficient of the Si-based material incorporated as the active layer of the solar cell. In the sub-bandgap region, this coefficient is in principle directly proportional to the defect density. The influence of light induced degradation on the defect density of the i-layer has been investigated [Mei05a, Mei05b]. It leads to a ten fold increase of the defect density in 90% amorphous i-layer whereas the defect density increases by a factor two in mixed amorphous-microcrystalline i-layers (deposited within the amorphous/microcrystalline transition). By successive annealing, the light-induced defects are progressively annealed out. Fig.7a. shows clearly that the decreasing absorption coefficient leads to an increasing fill-factor of the solar cell. This observed behaviour clearly indicates that ultimately (e.g. when shunting is not a determinant factor), a high i-layer material quality, with a low defect-related absorption coefficient, is determinant for the FF of the whole solar cell.

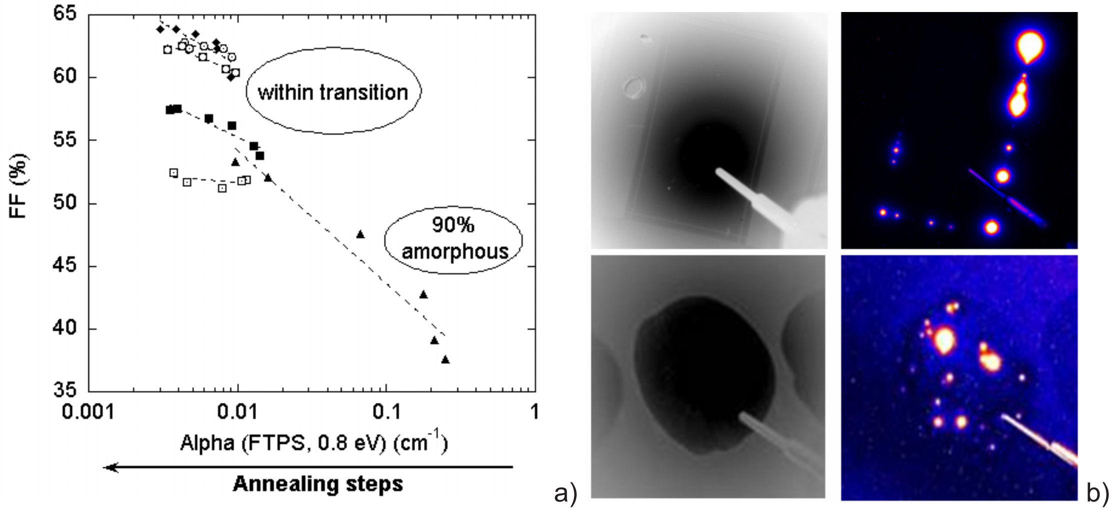

Fig. 7 a) FF of solar cells as a function of defect densities measured by FTPS, for μc-Si solar cells with different crystalline fraction b) IR images (left) and IRLIT images (right) of sample with different shunt structures. Temperature scale for the IRLIT image: 3 mKelvin..

General laboratory infrastructure

An extensive range of fabrication systems are available at the IMT PV lab. Several systems had to be upgraded in order to fill the requirements of a modern research lab. The goal is to improve process reproducibility and to be able to prepare innovative devices in an efficient manner.

- A new sputtering system for 6” substrates, with three targets, was installed. The system can be operated in RF or DC mode. All basic process for the fabrication of high quality metal (Ag, Al) and TCO (ITO, ZnO) layers have been established.
- The two chambers for LPCVD-ZnO fabrication have been completely separated and can now be run independently
- A large area deposition system (Kai-S) has been partly automated and basic process monitoring introduced

Collaboration and synergies with other projects

National collaboration with industrial and academic project partners was intensive, markedly on the industrial side:

- UNAXIS Solar, VHF-Technologies
- CRPP (EPFL), PSI, Ecole d'Ingénieurs de l'Arc Jurassien (EIAJ), Interstaatliche Fachhochschule für Technik Buchs (NTB), EMPA Thun.

The industrial projects (funded by CTI) with Unaxis-Solar and VHF-Technologies could benefit from strong synergies with this SFOE project.

Collaboration was maintained with several European research groups, and is now being reinforced in the frame of the new EU-Project Flexcellence.

Evaluation for 2005 Perspectives for 2006

2005 has been a successful transition year. A part of the infrastructure of the IMT PV-Lab was upgraded and new advanced characterization tools have been installed and are now used on regular basis. A strong effort was also put in improving the process reproducibility, by introducing better control of each fabrication step and by introducing new patterning techniques.
A better understanding of the interaction between textured TCO deposited on glass substrates and microcrystalline solar cells has allowed the overcoming of issues reported in the 2004 report. It has been possible to fabricate high efficiency p-i-n devices (9%) on glass coated with LPCVD ZnO.
Preliminary results with optimized processes yielded high initial efficiency (11.6%) for micromorph devices prepared on the same TCO material. On flexible substrates new efficiency records could be achieved both for amorphous (7.3%) and micromorph devices (8.3%) deposited on low cost plastic substrates, using processes which are in principle “industry compatible”.

In 2006-2007, the effort to modernize the laboratory infrastructure will be continued. The basis laid in 2005 will be used to further improve the performances of devices prepared on different substrates by improving and modifying specific part of the fabrication processes.
At least, the experience gained in this project, should help boost the collaboration with the industrial partners of IMT, which will be further continued in the frame of CTI and European projects.

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Annual Report 2005

High rate deposition of μc-Si:H silicon thin-film solar cell devices in industrial KAI PE-CVD reactor

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Duration of the Project (from – to)	1. March 2004 – 28. February 2006

ABSTRACT

The scope of this CTI project is twofold: the **first** task is 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 1400 cm^2: the latter corresponds to the size of industrial deposition equipment sold by UNAXIS AG. The **second** task of the present project is 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 should typically be 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, UNAXIS KAI PE-CVD 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 development of a fabrication process for microcrystalline silicon solar cells on the same industrial reactor is 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 Unaxis. A successful conclusion of the project will allow for cost-effective production of micromorph modules in the future.

The work executed in the second half of this project has focused entirely on device optimisation: the parameter space for deposition conditions has been successfully scanned and both doped and intrinsic layers can now be satisfactorily fabricated. Our sofar best devices have a conversion efficiency of 7.2% (in 2004, 5.5%), with an absorber thickness of 1 μm and a deposition rate of 0.7 nm/sec. The devices are fabricated in the KAI-S reactor at IMT using thereby a single-chamber process (i.e. the sample remains in the chamber during the whole processing cycle).

The know-how transfer from IMT to the industrial partner has 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. Unaxis 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 present no commercially available equipment for the fabrication of thin-film (TF) silicon solar modules exist on the market. All present suppliers of TF silicon solar panels run on custom-designed equipment. The main goal of the **UNAXIS Solar business unit** is to make available complete production equipment for thin-film silicon solar technology. The company UNAXIS 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 the present CTI project the experience of IMT and that of UNAXIS are 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 of 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.

With the support of the CTI, it is expected that the combined technological competences of UNAXIS and of IMT will pave the road towards the availability of a new generation of production equipment for the fabrication of high-quality and low-price thin-film silicon solar modules.

Brief description of the project / installation

The **deposition system** used for this work at IMT is an adapted version of the industrial KAI-S reactor commercialized by UNAXIS Displays. 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 UNAXIS solar performs 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 kind of thin **µc-Si:H layers** are first deposited onto glass samples. The film thickness of the deposited film is measured by profilometry; the crystalline volume fraction is 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 is 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)** are deposited onto Zinc Oxide (ZnO)-coated glass samples. The ZnO layer constitutes the front contact of the cell. The rear contacts are sputtered (ITO/Al) or prepared by LPCVD ZnO and deposited onto the silicon devices. The solar cells are then measured under both a standard AM1.5 sun simulator and in IMT's spectrally dependent Quantum Efficiency (QE) set-up.

The project is aimed at mastering the application of KAI-type PE-CVD reactors for 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 have been set during the second year 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.

Work performed and results obtained

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 t*he art layers made on the small-size laboratory PE-CVD reactors at IMT.*

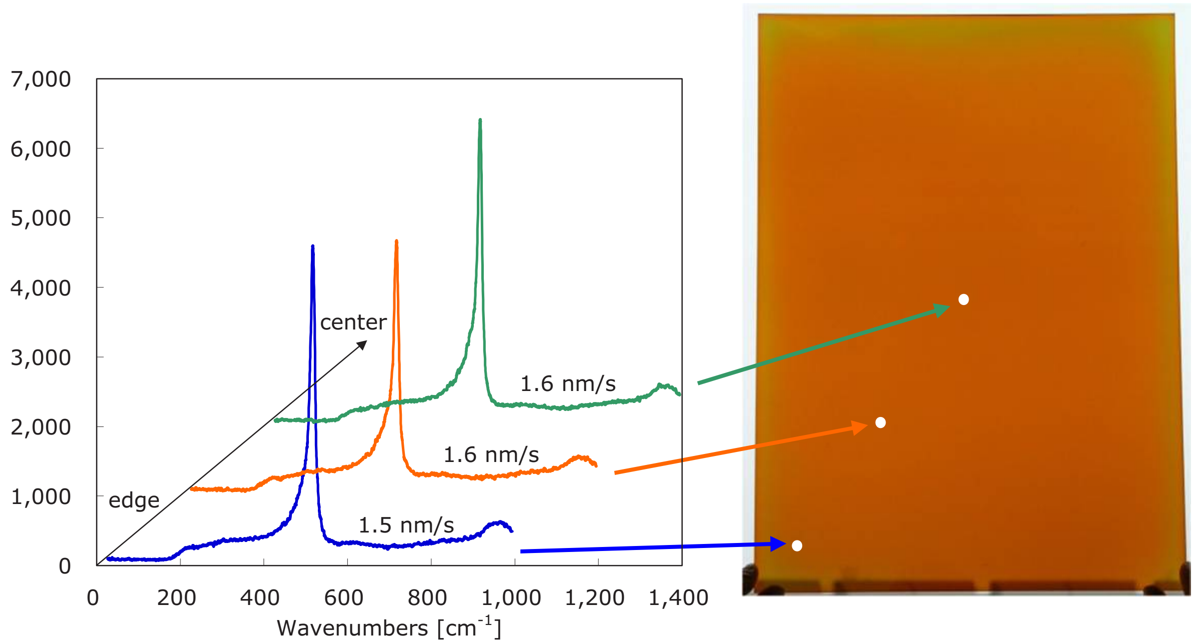

Fig. 1: Raman crystallinity of microcrystalline silicon films grown in the KAI-S reactor at IMT at deposition rates exceeding 1.4 nm/s. The Raman probe (514 nm) is taken from the center to the edge of the whole substrate area. The film has in the center a thickness of 0.96 µm.

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 UNAXIS lab in Neuchâtel and KAI-1200 at the UNAXIS 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

[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).

were undertaken in the KAI-1200. Fig. 1 reflects the best results sofar obtained 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.

The best cell conversion efficiency reported last year (2004) reached 5.5% and had actually been fabricated in the KAI reactor of UNAXIS solar. In the reporting period of this year (2005), the main focus of research at IMT was put on development of **improved µc-Si:H p-i-n devices**, thereby incorporating a new "standard" microcrystalline silicon growth process at 0.7 nm/s. During this period (2005), an increased conversion efficiency of 6.3% (on LP-CVD ZnO) for devices fully fabricated in the KAI-S reactor could be achieved. As reported in [4], 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. Because of this reason, the best conversion efficiency sofar could be obtained with solar cells fabricated on a different front TCO, i.e. on a sputtered and chemically etched ZnO: with such a front TCO IMT was able to fabricate cells reaching 7.2% efficiency with an absorber layer thickness of only 1 µm. Note that since June 2005, all cells are fabricated at a deposition rate of 0.7 nm/s in a "true[1]" single-chamber process. No layers are fabricated in another deposition system, and the attached load-lock is not used during the cell processing cycle.

The **homogeneity distribution** of the conversion efficiency was also investigated for the KAI-S reactor. For this task, several small substrates were distributed over the whole electrode area and subsequently characterised, as shown in Fig. 2.

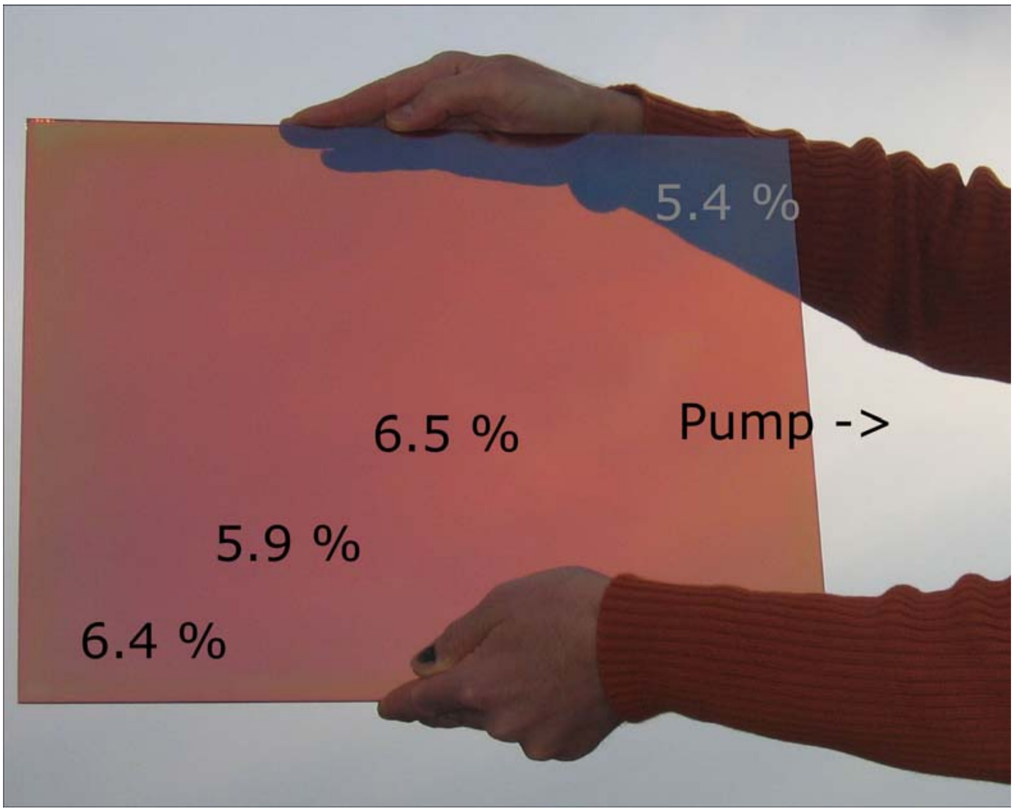

Fig. 2: Distribution of conversion efficiencies of solar cells deposited along the whole electrode (35x45 cm^2), represented here on a µc-Si:H high-rate film on glass. Cell thickness : 1 µm, deposition rate 0.7 nm/sec, deposited in the KAI-S reactor at IMT.

[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).

Know-how transfer from IMT to the industrial partner has also been undertaken in 2005: the high-rate solar-grade microcrystalline silicon absorber layer (deposition rate: 0.7 nm/sec) could be successfully implemented for micromorph solar cells. UNAXIS 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) has been undertaken in Trübbach.

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 UNAXIS. 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.

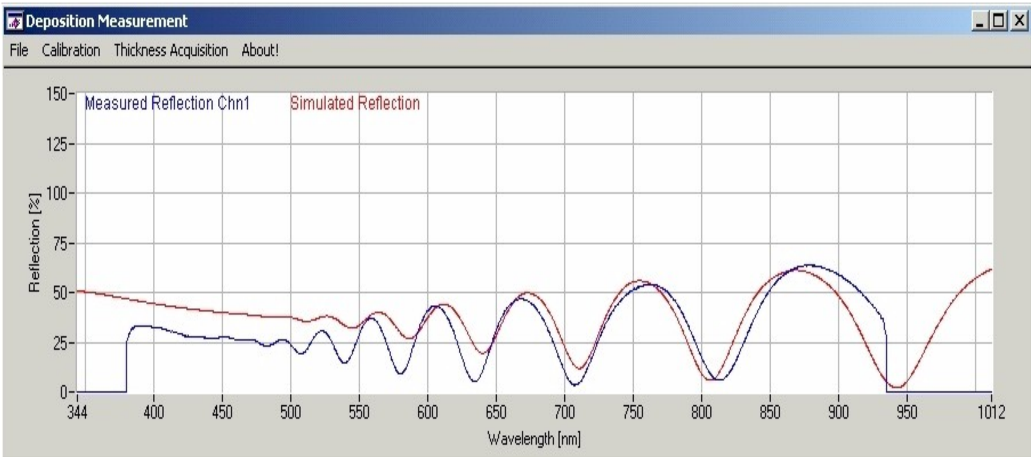

Fig 3: User Interface of the thickness measuring tool (developed by NTB), where for comparison the measured data and the fitted spectrum of an a-Si:H layer of 690 nm on glass is plotted.

More results from the UNAXIS labs, including the use of the NTB thickness monitoring tool, were presented at the 31st IEEE conference in Lake Buena Vista [1], at the 20th European Photovoltaic Solar Energy Conference in Barcelona [2,3] and also at the 15th PVSEC in Shanghai [4]. For the moment, no detailed results of the IMT part of the project have been published in journals or at international conferences, for confidentiality reasons.

National and international collaboration

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,
- *Forschungszentrum Juelich* (Germany) (B. Rech, H Siekmann), who provided the sputtered/etched ZnO-coated glasses

Evaluation of 2005 and perspectives for 2006

The utilisation of the KAI-S type PECVD reactor as now equipped at IMT has been verified for industrial photovoltaics 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. This has been achieved by some hardware modifications 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 7.2% at a deposition rate of 0.7 nm/s in a "true" single-chamber process. First high-efficiency micromorph modules could be prepared by Unaxis.

More work has to be done in order to reach the specifications initially set for the quantum efficiencies; additional optical optimisation has also to be carried out. Further steps will require the fabrication of improved microcrystalline and micromorph devices with respect to the choice of the front-TCO. A particular emphasis will be set on the homogeneity of the µc-Si:H devices; this is one of the last issues for the remaining two months of this project in order to reach the milestones initially fixed by us. This work will prepare the way for the low-cost fabrication, at an Industrial level, of state of the art “micromorph” tandem modules.

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Annual Report 2005

A new large area VHF reactor for high rate deposition of microcrystalline silicon for solar cells

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Project- / Contract Number	KTI 6947.1
Duration of the Project (from – to)	1.5.2004 - 30.04.2006

ABSTRACT

A novel very high frequency (VHF) plasma source shall be 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, is solved by using adequately shaped electrodes. The proof of principle of this new reactor has up till now only been made in non-reactive plasmas. In the present project, the novel RF reactor design shall be used for the first time in applications, in particular for solar cell production. The aim is 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 is 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 is necessary and will therefore be 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 will be 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 aim is 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 SPTec at Neuchatel and Truebbach. The CRPP has studied the theoretical and experimental aspects of plasma uniformity in large-area VHF reactors, and is currently investigating the plasma parameters for micro-crystalline silicon deposition. The Unaxis 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. Micro-crystalline silicon deposition at high pressures and small gap shows that unacceptably-large quantities of silicon powder are produced. On the other hand, experiments at moderate pressures (2 mbar) with 15 to 18 mm gap show good uniformity with very little powder formation. Novel experiments using infrared absorption spectroscopy in the exhaust line have been coupled with Raman crystallinity measurements to validate and calibrate an analytical model of plasma chemistry. This work shows that the silane dilution and its depletion in the plasma are the two necessary parameters to determine the optimum conditions for deposition of the solar cell i-layer. Unaxis is meanwhile pursuing the industrial development of micromorph solar cells.

National collaboration

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

Evaluation of 2005 and perspectives for 2006

The complete solution for electromagnetic non-uniformity in a plasma reactor has been derived, and a reactor construction has been established for uniform thin film plasma deposition. Experimentally and by analytical modelling, the two parameters for micro-crystalline silicon deposition have been shown to be the silane dilution and its depletion in the plasma. This approach is being investigated for optimisation of plasma conditions for solar cell production. During 2006, the aim is to define the optimum electrode gap and process parameters for microcrystalline and amorphous silicon deposition with uniformity suitable for large-scale solar cell production with minimal powder formation.

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Annual Report 2005

Numerical Modelling for large area plasma enhanced chemical vapour deposition (PECVD) reactor development

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Duration of the Project (from – to)	1.4.2003 - 1.04.2005

ABSTRACT

Since the substrate size used in the flat panel industry is rapidly increasing, the use of numerical simulation for the development of the PECVD reactors will help the industrial partner UNAXIS Displays to reduce their development cost and to speed-up the reactor upscaling and design, leading to earlier market penetration, higher market share and therefore the guarantee of long-time survival of the activity of UNAXIS in the AMLCD machine business.

A numerical model for Plasma Enhanced Chemical Vapour Deposition (PECVD) processes in large area rectangular reactors has been developped. This model is able to predict the uniformities of the film thickness and composition over the substrate area as a function of the process conditions and reactor geometry. The numerical results have been validated for a-SiN:H PECVD with experiments performed on the existing industrial KAI type reactors of UNAXIS Displays. This numerical model, developped by the CRPP, can now be used to improve the geometrical design and process conditions of the next larger reactor generation in order to reduce the film thickness and composition non-uniformities.

Introduction / Project goals

Since the substrate size used in the flat panel industry is rapidly increasing, the use of numerical simulation for the development of the PECVD reactors will help the industrial partner UNAXIS Displays to reduce their development cost and to speed-up the reactor upscaling and design, leading to earlier market penetration, higher market share and therefore the guarantee of the activity of UNAXIS in the AMLCD machine business.

A numerical model for Plasma Enhanced Chemical Vapour Deposition (PECVD) processes in large area rectangular reactors will be developed. The aim of this model is to predict the uniformities of the film thickness and composition over the substrate area as a function of the process conditions and reactor geometry. The model will first be validated by comparison with experiments performed on the existing industrial KAI type reactors of UNAXIS, and then will be used to improve the geometrical design and process conditions of the next larger reactor generation in order to reduce the film thickness and composition non-uniformities.

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 Displays at Palaiseau (France) and Truebbach. The CRPP has developped a computational tool based on a commercial software (CFDRC ACE® by ESI group) to better understand the fundamental physics of the a-SiN:H PECVD for TFT production. Simulations are carried out in a fully three dimensional environment to account for electromagnetic and edge effects. In large area reactors, these effects are responsible for thin film deposition non-uniformity compromising the final product performance. Unaxis Displays has performed the necessary experiments in a KAI 800 reactor in order to validate the results of the numerical model. During this project, the efforts have been directed towards the a-SiN:H thin film PECVD, because this layer plays a critical role in the TFT design and its specifications in terms of uniformity and composition were one of the more difficult aspects for the reactor upscaling.

Work performed and results obtained

A detailed model of PECVD in a rectangular geometry will require the simultaneous solution of Maxwell's equations, mass continuity, momentum and transport equations of neutral and charged species. CFD-ACE+ from ESI group offers the possibility of dealing with such a complex problem in a fully three-dimensional space. Nevertheless, electromagnetic effects (non-uniformity due to standing waves and edge effects) are not correctly accounted because the built-in plasma module doesn't solve the appropriate system of equations for the physics of large-area reactors. By the aid of an external program, FlexPde (partial differential equation solver from PDE Solution Inc.), gas injection distribution and electromagnetic effects are simulated and coupled to the CFD-ACE solver by a home-made dynamic library. Time evolution of plasma is then not solved self-consistently, but simulation outcomes are able to reproduce the trends of main deposition rate profiles observed experimentally by UNAXIS Displays and provide an insight investigation of thin film quality (silicon to nitride ratio). A big effort has been made to shorten the simulation time needed for a three-dimensional calculation to one day in order to match industrial requirements.

National collaboration

The CRPP and Unaxis Displays Palaiseau (France) and Truebbach were in close contact for feedback on industrial specifications, process conditions, and reactor design and modelling.

Evaluation of 2005 and perspectives for 2006

This project has been ended on 1.4.2005. The numerical modelling tool has been validated and delivered to UNAXIS Displays. However, very recently, UNAXIS Corporate Group has decided to discontinue the flat panel display activities of UNAXIS Displays Technologies Division and to stop all R&D development.

On the other hand, a first interest was shown from UNAXIS Solar Division about a possible exploitation of the numerical tool for PECVD reactors in thin film photovoltaic solar cell production. This interest is due to the fact that, as for flat panel display, the performance for solar cell PECVD reactors suffers from the same non-uniformity problems. Thus the numerical tool could be adapted to simulate amorphous and micro-crystalline silicon deposition and the expertise accumulated during the project could be transferred from Displays Division to Solar Division with low cost and time.

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Annual Report 2005

Stability of advanced LP-CVD ZnO within encapsulated thin film silicon solar cells

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Project- / Contract Number	KTI 7253.2
Duration of the Project (from – to)	01.11.2004 – 31.10.2006 (2 years)

ABSTRACT

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

During the year 2005, the degradation mechanisms of ZnO material have been studied in details and some means to improve the stability of ZnO have been tested. Some of these treatments have been found to improve in a significant manner this stability.

In parallel, encapsulation tests have been done, which lead to PV modules that stay stable when submitted to a humid environment. In particular amorphous Si modules with size from 10x10 cm^2 to 1.4 m^2 successfully passed the so-called damp-heat test (exposure to 85% humidity at 85°C during 1000 hours), with degradation below 1%.

The year 2006 will be dedicated to continue to improve the ZnO stability, in order to be able to simplify the encapsulation step.

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 [1]. 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 proposes 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 efficiency for high performance devices in the laminated state should decrease by more than 5% after the damp heat test (1000h @ 85 degC & 85% R.H.).

Brief description of the project

Two paths are 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 already tested.

- **Investigation of various encapsulation materials and techniques:** solar devices and ZnO layers alone have been and will be exposed to damp-heat tests encapsulated with various materials, which were previously tested with respect with their permeation to water and others gas.

Results obtained after one year

The industrial partner of IMT, Unaxis Solar, published this year results on stability tests done on encapsulated solar modules that use CVD ZnO as back contact (see Fig 1) [2, 3]. Indeed, it has been demonstrated that, with the help of an adequate encapsulation, protected solar modules can pass successfully the damp-heat test.

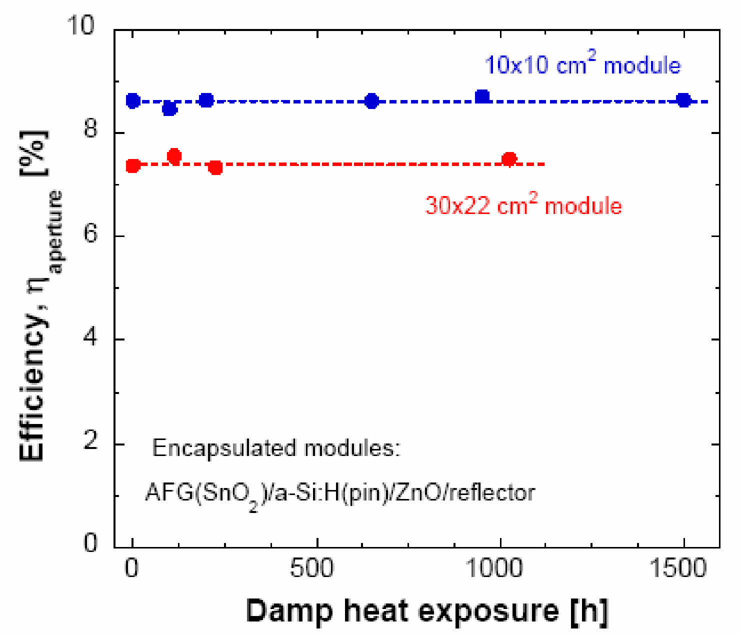

Fig 1 Evolution of the efficiency of encapsulated solar modules submitted to damp-heat test. These modules use LP-CVD ZnO as back contact.

Encapsulated 1.4 m^2 a-Si:H modules using LP-CVD ZnO as back contact were also produced by Unaxis (see Fig 2). These modules were sent to the German TÜV Rheinland for independent DH investigations.

Fig 2 AFG a-Si:H p-i-n module of 1.4 m^2 area on the outdoor test bench of NTB (Neues Technikum Buchs).

Fig. 3 reveals that these large-area modules passed successfully the damp heat test of 1000 h. There is no significant decay in the module efficiencies observed. The changes are less than 1 % and confirm the cell and encapsulation technique to be well adapted for outdoor application. These results confirm that LPCVD ZnO has, with a proper adequate encapsulation, a long-term outdoor reliability. Further tests with optimized module design and encapsulation materials are still ongoing. As silicon films are excellent humidity barriers the results in Fig 3 imply that modules made on front LPCVD ZnO should as well pass the damp-heat test, since more delicate to moisture is the less protected ZnO back contact of these superstrate modules.

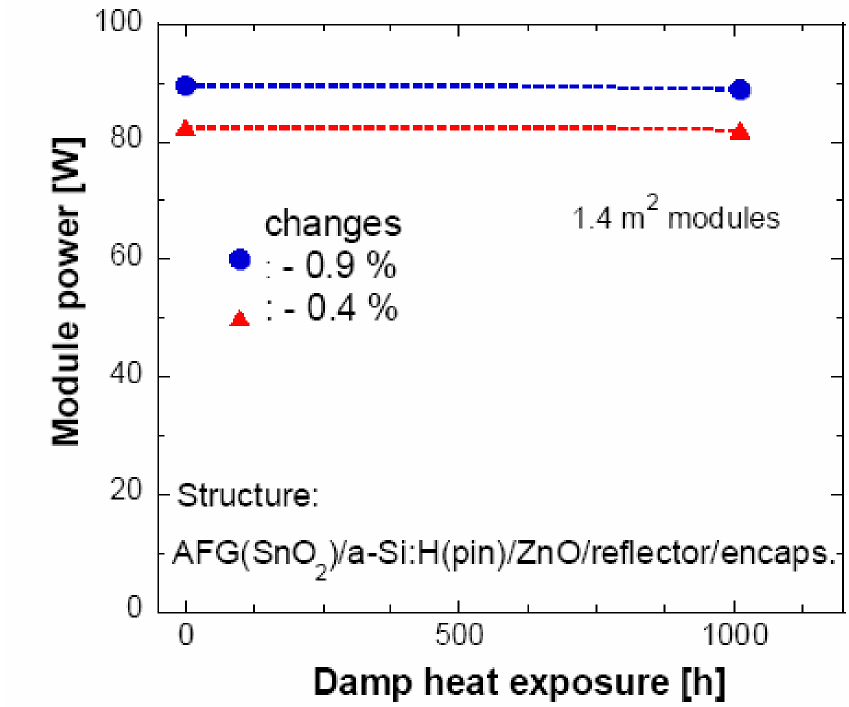

Fig 3 Damp heat experiments of 1.4 m^2 a-Si:H modules performed and characterized by TÜV Rheinland (Germany). Both modules show a good stability and a change of less than 1 % after 1000 h of damp heat exposure.

National and international collaboration

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

Year 2005 evaluation and perspectives for 2006

As we mentioned it in the previous paragraph, encapsulated modules using CVD ZnO as back contact have successfully passed the damp-heat test. Therefore, the main goal of this project has been already reached. But the actual solution found for the encapsulation could be further simplified, and therefore could become cheaper, if the stability of ZnO material was improved further. IMT will therefore continue to investigate new ways of improving the ZnO stability.

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Spectral photocurrent measurement system of thin film silicon solar cells and modules

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Project- / Contract Number	KTI 7112.2 / EPRP-IW
Duration of the Project (from – to)	September 2004 – September 2006

ABSTRACT

The goal of our industrial project partner UNAXIS SOLAR is to become the leading equipment supplier for thin film silicon solar cells. 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 tools. Today, there is no commercial Spectral Response Measurement System (SRMS) for thin film cells and modules available.

The goal of the present project is to develop an accurate, reliable and fast scan SRMS to analyse 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 with the main focus to develop a mass production line.

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. First mapping results of the spectral photocurrent on a test module were successfully demonstrated.

Introduction and project objectives

Characterization is an important issue in the development process of photovoltaic modules. The spectral response (SR) characteristics of a single a-Si:H cell show the quality of semiconductor device as well as the quality of the light-trapping. In thin film micromorph (a-Si:H/μc-Si:H) tandem cells, the individual SR characteristics of the a-Si:H top and the μc-Si:H bottom cell provide information on the matching of the short-circuit-currents with respect to AM1.5 illumination. The overall performance of a large-area thin film monolithic series connected module strongly depends on the uniformity of the spectral photocurrent. Up to now, there is no commercial equipment available to characterise the uniformity of the spectral photocurrent of thin film modules. Our motivation is to develop such a mapping tool for the needs of the PV thin film industry [1].

Short description of the project

A reliable automated photo current measurement system with functionality fitted to the industrial user, Unaxis Solar, together with user-friendly software, is needed. The task/goal of this project is to build up the setup of the hard- and software of the spectral response measurement on single cell scales as well as on module scale. For that purpose, an intensive communication between the scientists and process engineers at Unaxis Solar and the project partners at NTB is essential.

The overall goal of this project is to develop the metrology to build a **S**pectral **R**esponse **M**easurement **S**ystem **SRMS** for the characterization of thin film silicon solar cells, as well as, of a large-area thin film PV modules. In particular there will be constructed two types of SRMS. The first one appointed to optimize test cells (order of 1 cm^2 area size) and the second one to optimize modules (order of 1 m^2). To define the specific scientific and technical goals one has to distinguish between the four main parts of the project.

- **Cell SRMS** on single and tandem cell configurations
- **Module SRMS** to find the lateral homogeneity of the spectral photocurrent
- **Verification** of SR measured data by comparing with the measurement results of the full spectra short-circuit-current of solar cells and modules by mainly indoor measurements
- **Integration** of SRMS in a module production line should be evaluated.

Today there exist no commercial SRMS on the market to measure thin film tandem modules.

At the last international Photovoltaic conference in Paris, June 2004, none of the 250 PV-companies offered a commercial spectral response measurement system either on cell or on module level.[2] International experts in the field of PV module test and qualification agreed with the finding that there exists no commercial SRMS.[3] But they pointed out that in future a spectral response measurement of a thin film module is a must to guarantee high accuracy of the measured and guarantied module power with small tolerances. At one of the most experienced European solar PV module test laboratory the JRC in Ispra, spectral response measurement is a standard measurement procedure for today’s crystalline silicon modules power test qualification. The JRC Ispra group uses a specially designed unique large area spectra response measurement system which is not suited to measure thin film tandem modules without fundamental modifications. The responsible scientists at JRC expressed their interest in our SRMS project focused on thin film cells and modules. [3] There already exists collaboration between NTB and the JRC on the topic of SR and other fields of photovoltaic.

The innovation of the planed SRMS is given by a fast and accurate spectra scan.

The quality of the SRMS is given by the accuracy and the measurement duration. The SRMS is a fundamental and frequently used analysis tool in each PV solar cell lab. By analyzing the work flow in a PV solar cell lab one will identify the duration to measure the SR as the bottle neck in speed up the cycles.

The technical goals for the SRMS on the cell level are at a measurement duration between 1 (10 spectra points) and 5 minutes (at 50 spectra points) for a full spectra scan at a reproducibility of 1%.

ADDITIONAL FEATURES:

1. Tandem cells SR-characteristics will be measured automatically with colored bias light.
2. SR-characteristics at different operating points in the cells IV-curve will be measured (standard condition: short circuit or reverse voltage)
3. An **additional innovation factor** of the SRMS is the integrated **IV- curve tester**. The absolute accuracy of the measured open circuit voltage and the fill factor is very low compared to a commercial standard solar simulator and IV-tester in the cost range of typical 200 TFr and above. A low quality light source (LED) is used. But the result of a fast (about 1 minute) automatic IV-test in addition to the accurate spectra photocurrent scan will give a first rough estimate of the over all IV cell parameters. Thereby the mechanical and electrical connections have not to be changed.

INNOVATION by using the SRMS

Why the results of the spectral photocurrent measurement of modules are needed?
The conclusions drawn out from the potential of the spectral photocurrent measurements are summarized and attributed to the different application areas in the future evolution steps:

Development process to
1. Improve single a-Si test cells (layers, interfaces, see chapter 2)
2. Improve tandem test cells (a-Si/µc-Si or a-Si/a-Si)
3. Improve single a-Si modules (automatic lateral scan mode)
4. Improve tandem modules (automatic lateral scan mode)

If this project will successfully end up with an automated fast and accurate SR measurement tool appropriate for industrial needs future option beyond that project may be possible. The first one may be the integration into a module production process as a quality test instrument. This can also be an option for standard or high efficiency crystalline silicon cells. The second option may by the use of the measurement tools to answer the important question if 1Wp of a thin film tandem module will generate more electricity than 1Wp of a standard crystalline silicon technology at different location with different solar irradiance spectra’s.

Production process – Inspection at the end test in the production line

1. Measure the lateral variation of PV modules the spectral photocurrent (extended SR tests applied to out of specification modules; statistical routine test applied to the good part – of the different classes)
2. Increasing the measurement accuracy of the final power test in the module production line. With this additional information the uncertainty of the measured STC short circuit current under the solar simulator will be reduced. Thus this reduction of the over all measurement uncertainty, which lead to smaller, guaranteed module power tolerances of the production line.

Post production process – Performance of the module in

1. Calculate the short circuit current at different spectra, at different sites and different air mass values (day time dependence)
2. A tandem cell will have a higher dependence on sun spectra variation over the whole year than a single cell. (If a tandem configuration is optimized to reach the highest STC efficiency at the AM1.5 spectra, this must not be the optimum configuration to reach maximum solar electricity output over the whole year at a certain site.

Work and results

Technical and economical status of SRMS on cell level

Two cell SRMS have been installed, the system A at the R&D lab of Unaxis SPTec in Neuchâtel and the system B at the Unaxis Solar lab in Trübbach. The systems are built in a very compact way and the handling in terms of installation of the samples and operation of the measurement software are designed to the industrial users needs. (Fig. 1)

The long-term stability of the whole SRMS system is very promising. Control measurements over month show a surprising good stability. On well-defined devices control measurements reveal over month deviations of the measured results below 1 %.(see Fig. 2) This is certainly attributed to the improved design of the whole system and the choice of the high-quality components involved. This fact is of very high practical impact in a thin film PV lab: During daily use one can rely on stable SR measurement equipment without having doubts of a drifting and unstable SR apparatus. The cell SRMS systems are frequently used every day by several users. The developed SRMS cell systems is approved with respect to stability and represents an important contribution for the optimisation of thin film silicon cells of Unaxis Solar.

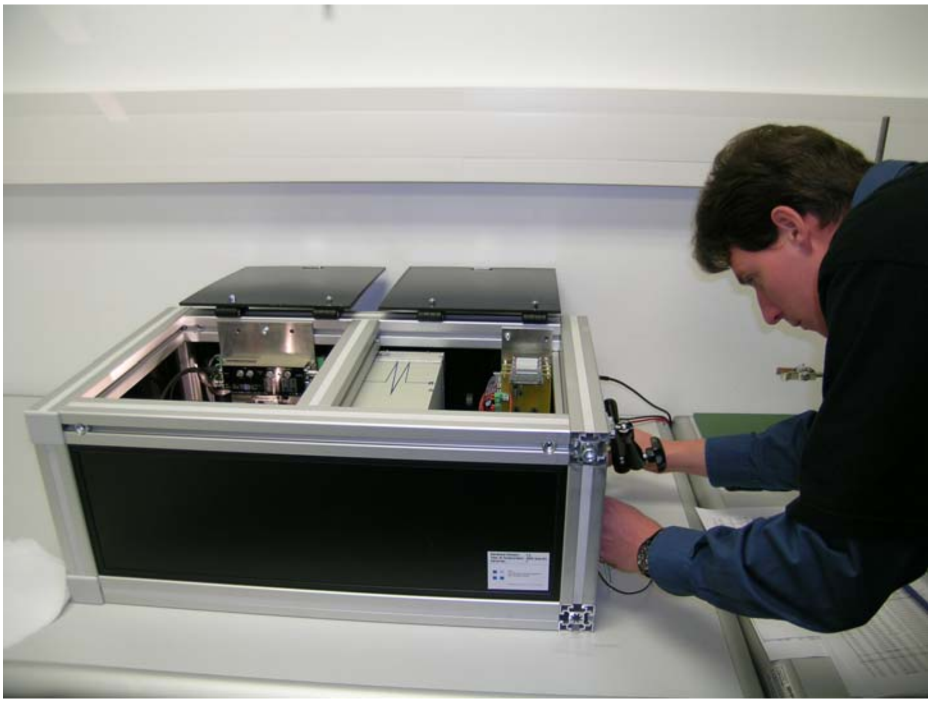

Fig. 1: Compact and well-designed SRMS A at Neuchâtel.

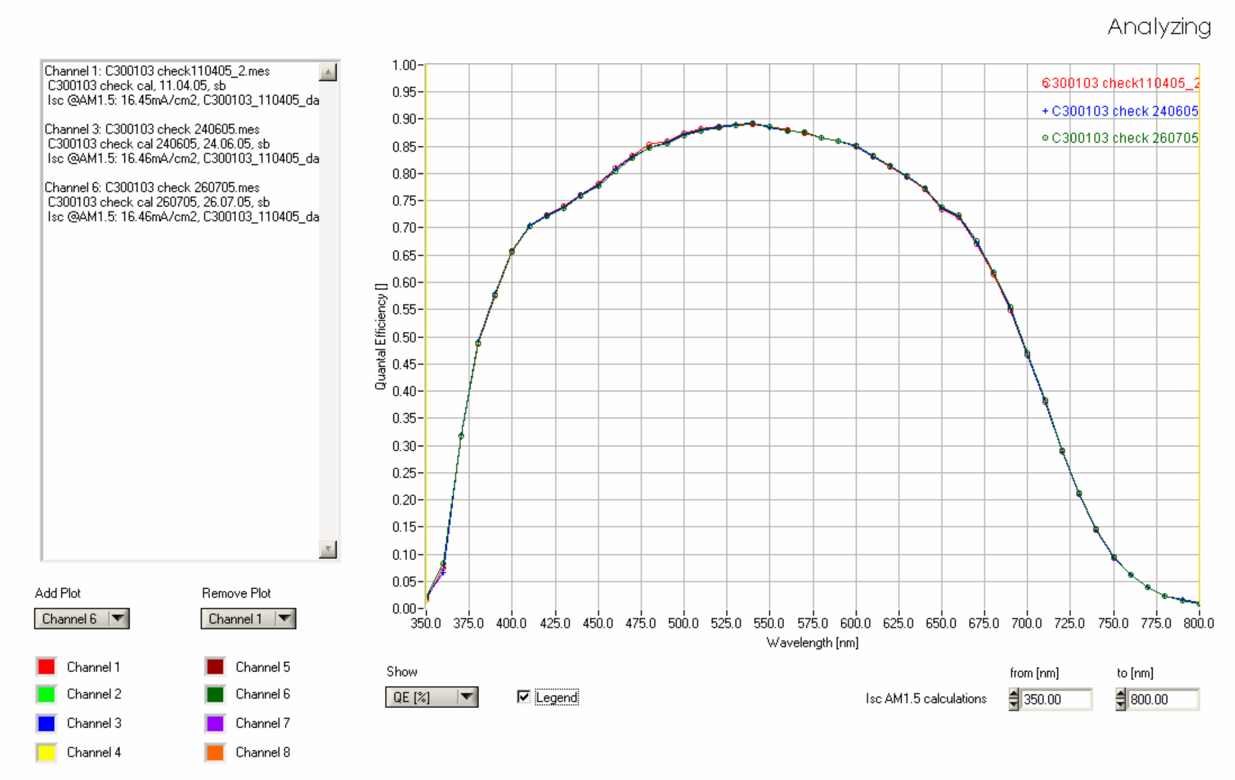

Fig 2: Evidence of SR apparatuses stability: Control measurements of a calibration device by the SRMS system A. The red curve represents the control QE-data of the device immediately after calibration on April 11, 2005. The following control with measurements done on 24th June, 2005 (blue curve) and of 26th July 2005 (green curve) show perfect stability of the QE system. Note that the system is always based on the calibration done on April 11, 2005.

Technical status of SRMS on module scale

In the SR characteristics the contribution of the several sub-layers to the overall photocurrent can be evaluated. Thus, in case of an a-Si:H p-i-n solar cell the impact of the p, i, n layer, as well as the quality of the light-trapping is seen in the different SR spectral regions.(Fig. 3) For example the uniformity of the p-layer of a large-area a-Si:H p-i-n module can be found in the short wavelength SR region. In addition, the quality of the laser patterning and pinholes shunts can be localized.

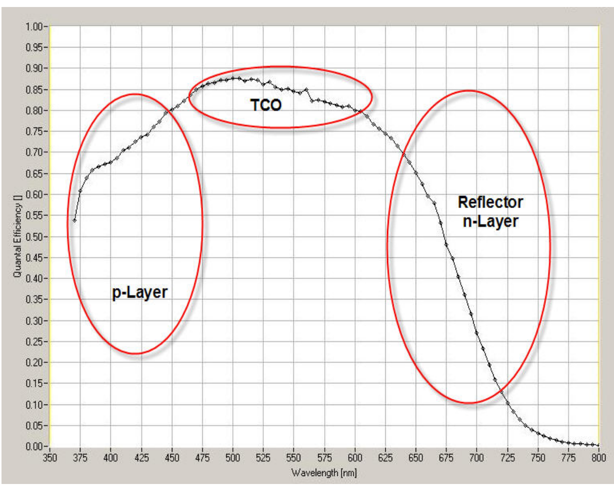

Fig 3: Quantum efficiency (QE) of an a-Si:H cell, sub layers are characterized by red areas

The developed Spectral Response Measurement System (SRMS) consists of a halogen lamp, an optical chopper, a monochromator (350 - 1100 nm) and an optical glass fiber guiding the light beam to the module area under test. (Fig. 4) There the generated photocurrent is pre-amplified and measured by lock-in amplifier technique. The optical fiber is split to illuminate the cr-silicon reference photodiode and to the test device. This system allows characterizing a-Si:H and µc-Si:H single-junction as well as tandem cells. The system includes automatic control of backlight illumination (blue, red, white). During the mapping the glass fiber is moved across the segments while the module is moved in the perpendicular direction. This setup is able to measure thin film modules up to a size of 1250x1100mm. The measurement grid can be individually chosen. The entire system is computer controlled.

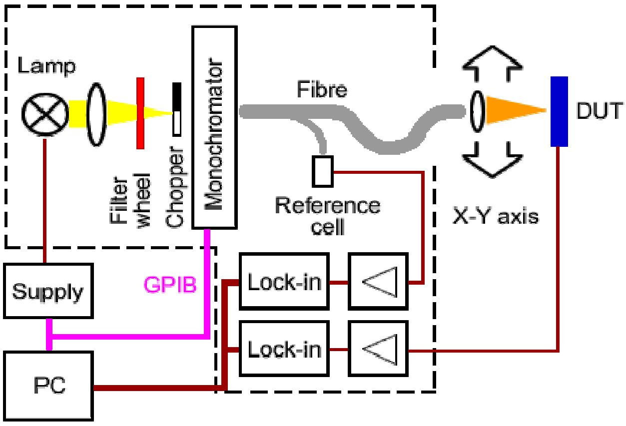

Fig. 4: Functional principle of the Spectral Response Measurement System (SRMS)

Fig. 5 Spectral Response Measurement System loaded with a 1.4m^2 monolithic series connected a-Si:H p-i-n module

The SRMS was successfully used to map the spectral photocurrent of large-area (up to 1.4 m^2) a-Si:H p-i-n modules. It was found that high quality modules show a small variation of SR values across the mapped module area. In modules with reduced performance local defects are identified by strongly reduced SR values.

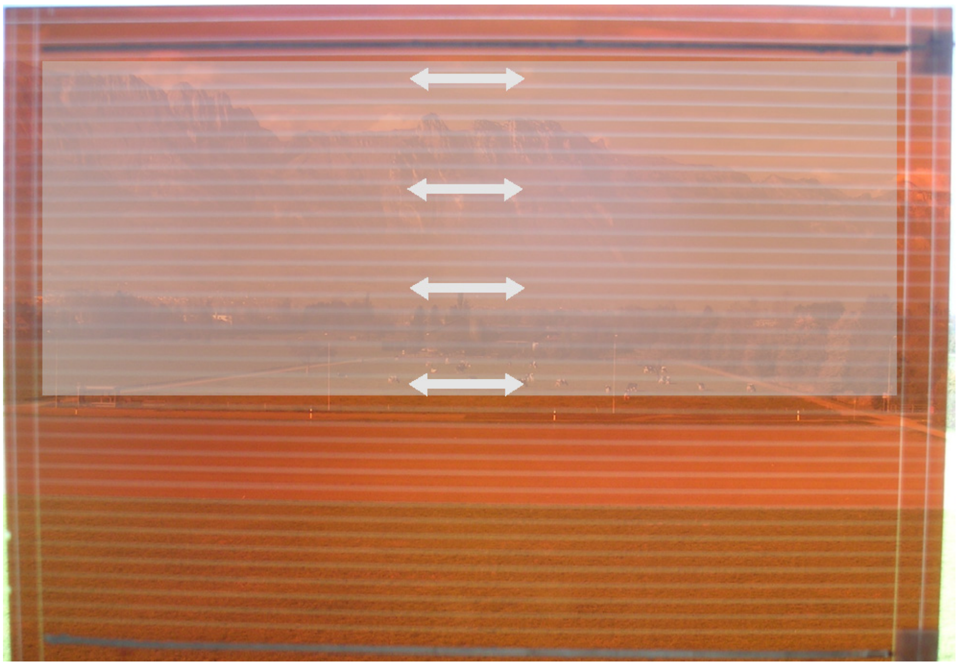

Fig. 6: Photograph of an a-Si:H p-i-n module (300x220mm), the marked white area indicates the scanned section with the results shown in Fig. 7

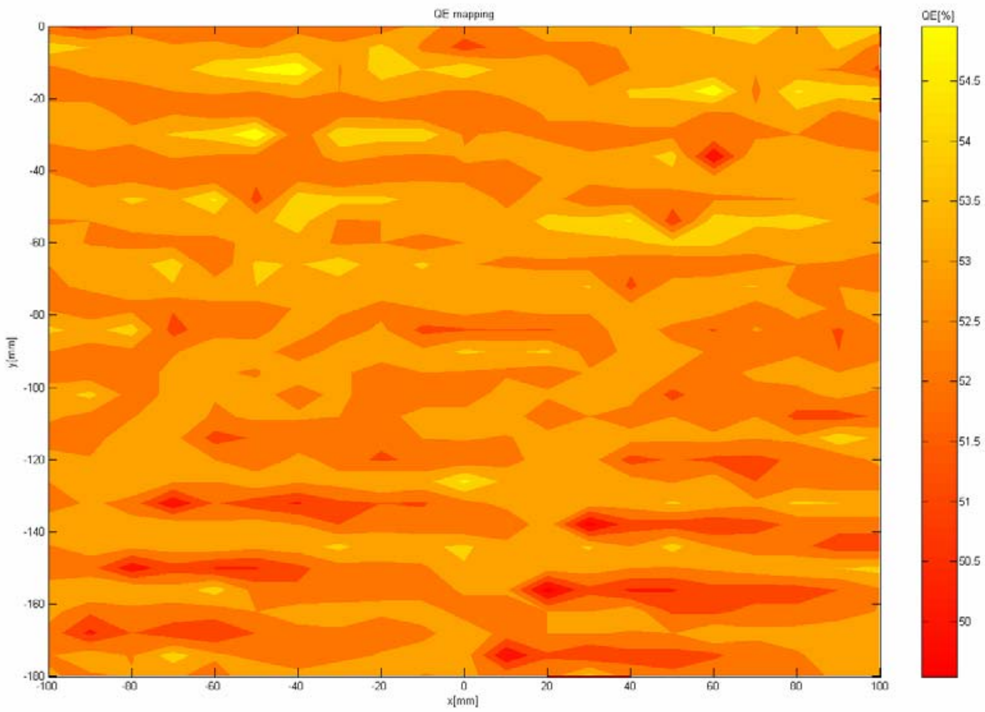

Fig. 7 QE (quantum efficiency, spectral photocurrent) mapping results on an UNAXIS a-Si:H prototype module(1.4m^2) shown in the sub-area of 200x180mm^2. The deviation of the measured QE uniformity is within +/- 2.5% at a wavelength of 550nm (based on 360 individual measurement positions in the scanned area)

These first results are very promising and have to be applied to different types of modules with different types of loss mechanism. The experience in identifying the origin of the losses will help to improve the overall thin film module performance. The presented SRMS tool may also be used for advancing other thin film technologies in R&D as well as even for quality checks in the industrial thin film production line.

National and international collaboration

The main topic of the present collaboration of the NTB with the solar test and installation group at the European JRC Joint Research Center in Ispra is to further on develop the measurements techniques of spectral response measurements on thin film single and tandem cells. Part of that work, focused on the comparison of indoor and outdoor IV measurement results on a-Si:H single junction mini-modules will be presented in a joint publication at the next European Conference. [2]

The head of the NTB electrical measurement laboratory is active again as a member of the scientific committee to organize the program of the next European PV conference in Dresden.

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Annual Report 2005

Optical nano-gratings and continuous processing for improved performance flexible solar cells

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Project- / Contract Number	CTI 7013.1
Duration of the Project (from – to)	01 01 2004 – 01 07 2005

ABSTRACT

The Swiss company VHF-Technologies S.A. is currently developing a roll-to-roll continuous production line for thin film amorphous silicon (a-Si:H) solar cells on flexible substrates. The goals of the reported project were to enhance the quality/price ratio of photovoltaic modules produced by VHF-Technologies as well as to open-up the promising market for flexible photovoltaic elements.

With the goal of enhancing the performance of the photovoltaic modules, the possibility to increase the photo-generated current by using nano-structured gratings promoting light trapping into the flexible solar cells was exploited. Simultaneously, the series connections and current collection were improved in the completed solar modules. In order to reduce the fabrication cost, more cost-effective substrates (PET or PEN instead of polyimide), faster structuring methods and better-adapted VHF electrodes were investigated.

Different nano-structured gratings, produced by OVD-Kinegram A.G. through a roll to roll process, were tested as substrate for solar cells. The most remarkable result, in term of light-trapping, is an increase of the photo-generated current density (J_{sc}) of 15%, as compared to the J_{sc} of the best cell on the reference flat substrate. At the moment, laboratory-scale a-Si:H solar cells with 7.3% stable efficiencies have been obtained at IMT on a back reflector fabricated at VHF-Technologies (Al-based reflector coated on textured PET foil). All the experiments were realized with a fabrication process compatible with the one running at VHF-Technologies S.A.

Furthermore, VHF-Technologies showed that PET and PEN substrates with gratings, as supplied by OVD-Kinegram A.G., are compatible with their fabrication process on the production line. The series resistance and the “dead surface” of the modules were reduced, a full roll-to-roll process for interconnection was implemented and a new VHF-electrode with an improved design was installed in the reactor at VHF-Technologies. In that way, higher reliability of the process, higher environmental stability, higher yield and higher efficiencies were obtained. Overall, the performance in the production of the 28cm x 60cm standard module product was increased from 5 Watt (2.9%) at the beginning of the project to 7 Watt (4.1%) at the end of the project.

Besides, a new stable and thoroughly tested code was developed at PSI in order to calculate the dimensions of the gratings for optimum light-trapping into cells (essentially arbitrary 1-dimensional grating structures).

Introduction / Project goals

The development of solar electricity production has the potential to contribute significantly to the energy generation in the next decades. Reasonable scenarios target at a 4% share of electricity production by 2030 worldwide and up to 30% a few decades later [1].

To reach these ambitious objectives:

- The costs of the modules must decrease from around 3€/Wp to below 0.5€/Wp,
- The photovoltaic modules must be easy to integrate on buildings,
- Their fabrication must be environmentally friendly.

Considering these points, thin film silicon modules prepared in a roll-to-roll process have a very high potential. Indeed, they are fabricated with a small quantity of relatively cheap raw materials, with inexpensive methods, which (1) allow the use of flexible, lightweight cheap substrates and (2) enable clear improvements for architectural design and building integration (Fig. 1).

Fig. 1: (a) Flexible PV modules produced by the company VHF-Technologies, (b) (c) (d) Examples of photovoltaic elements for building integration manufactured by VHF-Technologies

The company VHF-Technologies is currently developing a continuous roll-to-roll production line for flexible thin-film silicon photovoltaic modules. The present project aimed at increasing the efficiency/price ratio of the modules already manufactured by the company.

Description of the project

In order to simultaneously decrease the production costs of photovoltaic modules and obtain higher performances, the project partners proposed to increase the photo-generated current by using nano-structured gratings, which promote light trapping, into flexible solar cells deposited on low cost plastic substrates (Poly-Ethylen-Terephtalate PET or Poly-Ethylen-Naphthalat PEN).

For this purpose, several different nano-textured substrates were fabricated on glass and PET by IMT (on laboratory scale) and OVD-Kinegram A.G (large scale area and roll-to-roll process).
All these substrates were incorporated into solar cells and the photo-generated currents were compared to those of co-deposited cells on flat substrates.

In parallel, EIAJ and VHF-Technologies collaborated in order to (1) redevelop the solar module series connection process so that the series connections (series resistance) and the current collection (interconnection area) could be improved in the completed solar modules, (2) design and install a new larger VHF coating electrode on the VHF-PECVD roll-to-roll reactor of VHF-Technologies. This new electrode led to increased throughput and system uptime as well as to the improvement of the quality of the silicon layers.

Finally, the PSI collaborated with the IMT in order to develop a new calculation code for the determination of the most suitable grating dimensions for light-trapping into a-Si:H solar cells.

Results

During this project, IMT could show that the fabrication process used by VHF-Technologies has a large potential for further improvement of the solar cell efficiency deposited on plastic substrates.
Indeed, single amorphous silicon (a-Si:H) solar cells (laboratory-scale) with stabilized efficiency of 7.3% (V_{oc}=863mV, FF=63.3%, J_{sc}=13.32mA/cm^{-1}) were developed on textured low-cost plastic foils fabricated by OVD-Kinegram A.G. (roll-to-roll process). This result was reached on the new "second generation" textured film provided by OVD-Kinegram A.G, taking into account the present process limitations of VHF-Technologies i.e. using Al-based back contacts fabricated on their large-scale production system and ITO as top contact.
Fig.2 illustrates the fact that, the "second generation" textured substrate developed during the project provides an increase in the current density of 15% (14.4mA/cm^2) as compared to the best cell on the reference flat substrate (12.5mA/cm^2) [2].

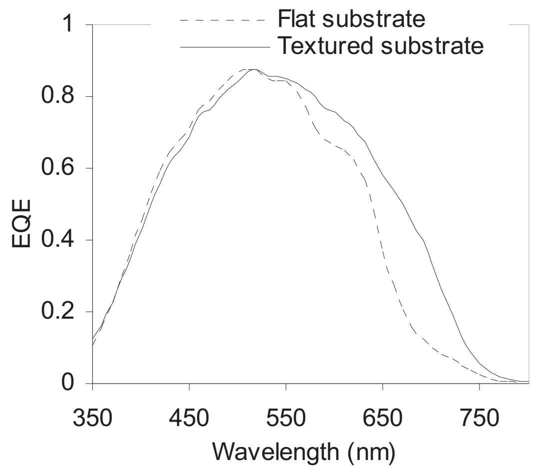

Fig. 2: Comparison of the External Quantum Efficiency (EQE) of the standard a-Si:H solar cells deposited at the IMT on flat substrate and on the new "second generation" textured film

At the same time, VHF-Technologies could demonstrate the basic compatibility with its solar cell fabrication process of the nano-textured rolls supplied by OVD-Kinegram A.G.. With a basic aluminium back contact, an increase of the photocurrent of +5% could be demonstrated with a "first-generation" textured film.
Regarding the results obtained by the IMT on the advanced "second-generation" textured substrates, VHF-Technologies has planned further R&D to overcome the remaining hurdles and introduce the textured substrate technology into the roll-to roll production line. The initial project goal of 5% stable efficiency on industrial modules seems to be reachable within a further period of 6 to 12 months.

The solar module series connection process was completely redeveloped by EIAJ and VHF-Technologies, and a new series connection production line, comprising roll-to-roll screen printing and roll-to-roll laser welding, was installed and taken into operation by summer 2005 (Fig. 3). The following improvements could by realized:

- The old series connection process, a batch process, was replaced by a fully continuous roll-to-roll process,
- The "dead-area" loss could be reduced from 22 % to 13 %,
- By introducing the screen printed silver finger-grid, the solar module fill factor was increased from formerly 53-54% to 58-60%,
- The production yield was increased by the automated continuous operation, and product reliability was enhanced by the higher reliability of the laser-welding process, as compared to the initial mechanical scratching step.

Fig. 3: New roll-to-roll production line at VHF-Technologies

Overall, the performance in the production of the 28 cm x 60 cm standard product of VHF was increased from 5 Watts (2.9 % module efficiency) at the beginning of the project to 7 Watt (4.1 % module efficiency) by the end of the project.

In parallel, a new VHF coating electrode was designed and installed on the VHF-PECVD roll-to-roll reactor of VHF-Technologies. Thereby, the electrode surface was increased by 20%, increasing the throughput correspondingly. The quality of the silicon layer was improved, and the new design allowed a better system uptime. The new electrode is since then used in the standard production process of VHF-Technologies.

Based on theoretical approach (exact calculation based on Maxwell equations) from PSI, R. Morf developed a new stable and thoroughly tested code in order to calculate the suitable dimensions of the gratings for light-trapping into cells. According to the calculations, optimal blazed structure should lead to more than 30% enhancement of the photo-generated current, for cells incorporating ITO as top contact layer. This grating must still be accurately replicated to be tried out experimentally.

Finally, in December 2004, a co-operation contract was signed between VHF-Technologies S.A. and Eternit A.G. (Niederurnen) with the target to co-develop a photovoltaic fibre-cement roof shingle technology. A demonstrator roof with 100 Watts power rating will be fabricated and installed in Niederurnen.

Collaborations

The project could benefit from the expertise of the partners in the different sectors:

- Light trapping and fabrication of laboratory scale solar cells (Institute of Microtechnology, IMT),
- Fabrication of large scale area modules by means of roll-to-roll process, interconnection (Ecole d'Ingénieurs de l'Arc Jurassien EIAJ, VHF-Technologies S.A.)
- Fabrication of large scale area nano-structured plastic substrate by means of roll-to-roll process (OVD-Kinegram A.G.)
- Calculation and simulation of the light trapping into cells (Paul Scherrer Institute, PSI).

OVD-Kinegram could supply large area nano-textured plastic foils which are totally compatible with the fabrication process used at VHF-Technologies. OVD could develop special gratings based on the best results obtained at IMT on various solar cells.

IMT and PSI had complementary roles since the IMT mastered the experimental side of laboratory scale substrate production and PSI could bring its experience in the field of optical calculation [3-5].

Finally, EIAJ worked in close collaboration with VHF-Technologies for the development of more performing inter-connection processes and solar modules in a continuous roll-to-roll process.

Evaluation for 2005 perspectives for 2006

During this project, a new "second generation" textured PET film could be developed and produced by means of a continuous roll-to-roll process. Using this substrate, the IMT obtained an increase in the current density of 15% (14.4mA/cm^2) as compared to the best cell on the reference flat substrate (12.5mA/cm^2) and a stabilised efficiency of 7.3%.
At the same time, VHF-Technologies could demonstrate the basic compatibility of this new substrate with its solar cell fabrication process. Given these results, the initial project goal of 5% stable efficiency on industrial modules seems to be reachable within a further period of 6 to 12 months. Therefore, VHF-Technologies has planned further R&D to introduce the textured substrate technology into the roll-to roll production line.

During the project, VHF-Technologies strongly improved its manufacturing process in collaboration with EIAJ. The performance in the production of the 28 cm x 60 cm standard product of VHF-Technologies was increased from 5 Watts (2.9 % module efficiency) at the beginning of the project to 7 Watt (4.1 % module efficiency) by the end of the project.

Finally, promising photo-generated current gains were calculated by R. Morf from the PSI. The calculated texture must still be accurately replicated and tested into solar cells.

Further work at IMT and VHF-technologies on flexible substrates will be partly accomplished in the frame of the European project Flexcellence entitled *"Roll-to-roll technology for the production of high-efficiency low cost thin film silicon photovoltaic modules"*. IMT is coordinator of the project, about which additional information can be found on www.unine.ch/flex.

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Annual Report 2005

Flexible CIGS solar cells and mini-modules (FLEXCIM)

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Duration of the Project (from – to)	01.03.2004 – 30.04.2006

ABSTRACT

Thin film $Cu(In,Ga)Se_2$, called CIGS, solar cells are known for high efficiency, long term stable performance and potential for low cost solar electricity generation. CIGS solar cells on metal and polymer foils offer several advantages: They are flexible, lightweight and can be manufactured with roll-to-roll deposition processes. The roll-to-roll production is potentially low cost, 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 metal foils of 5 x 5 cm^2 size by using vacuum evaporated CIGS layers and applying a patented process, developed by ETHZ, for controlled and reliable incorporation of Na in CIGS. This low temperature CIGS deposition process offers several advantages for development of high efficiency solar cells on different substrates. In the report of 2004 we reported the development of 14.1% flexible solar cell on polyimide foil. This efficiency measured under AM1.5 illumination at ISE-FhG, Freiburg, Germany is a highest 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. We have grown CIGS layers at different substrate temperatures and investigated the properties of evaporated CIGS layers by different methods (SEM, SIMS, EDX). 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.

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 with self designed and constructed mechanisms for substrate heater, in-line movement of heated substrates, linear thermal evaporation sources. Testing of evaporation sources and other mechanisms has started. Development of large area flexible solar cells and mini-modules has also started, and as a proof of concept flexible mini-modules to run small ventilator-fans have been developed.

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.

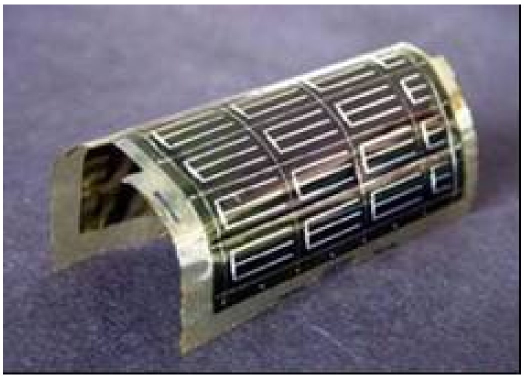
ETHZ group has been involved in the development of high efficiency flexible CIGS solar cells with low deposition temperature processes and incorporating controlled amount of Na in CIGS for efficiency enhancement. In this project the work is focused on the improvement of cell efficiency and process reproducibility on polyimide foils, and also to test the potential of ETHZ 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 $MoSe_2$. The R&D work on this subject of $MoSe_2$ growth and cell development on $MoSe_2$/ITO coated glass substrates was presented in the progress report of the year 2004.

Work and results

Flexible solar cells on polyimide foils

The choice of an appropriate substrate is an important issue for the development of flexible and lightweight solar modules. It is well known that the efficiency of the CIGS solar cell depends on deposition temperature and Na addition in CIGS. High efficiency (15-19%) solar cells have been grown at substrate temperatures exceeding 550 °C, while lower efficiencies (8-14%) are obtained for the cells grown at 400 - 450 °C. An optimum concentration of Na is required for high efficiency solar cells. The absence of Na in CIGS lowers down the efficiency by up to 40%. Impurities diffusion from metal foil can severely degrade the cell efficiency, especially from steel foils. Therefore, a stack of diffusion barrier layer is needed to prevent impurities from metal foils. Monolithic module development on metal foil is not easy because of conducting surface, while polymers are insulators and more suitable for monolithically interconnected modules.



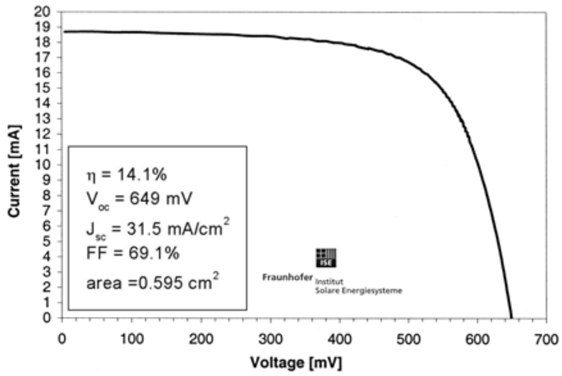
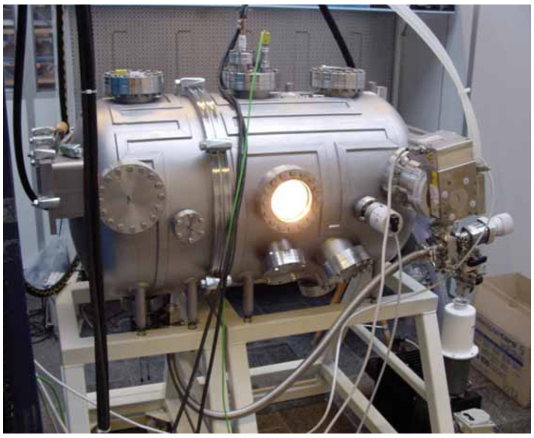


Figure 1: Flexible CIGS solar cells on a 5 x 5 cm^2 polyimide foil (left) and current-voltage characteristic of the 14.1% efficiency cell measured under simulated AM1.5 standard test conditions at ISE-Fhg Freiburg, Germany (right). This value achieved in December 2004 still remains the highest efficiency record for any kind of solar cell grown on polymer foil.

As described in the reports of year 2004, commercially available polyimide (UPILEX ™) and steel metal foils were used to grow solar cells on 5 x 5 cm^2 substrates, and no diffusion barrier layer was applied on steel foils. Layers of ZnO:Al/ZnO/CdS/CIGS/Mo were grown as described in earlier reports; but briefly, Mo back contact was deposited by dc sputtering, CIGS absorber layer was grown by evaporation of elemental Cu, In, Ga and Se and using the “3-stage” process, CdS buffer layer was grown by a chemical bath deposition method, ZnO:Al/ZnO were grown by rf magnetron sputtering and and Ni-Al contact grids for better current collection were deposited by electron beam evaporation method. Substrate temperature during CIGS deposition was below 450 C (this is a reference value, actual substrate temperature might differ). A recently invented method by ETHZ group for controlled and reliable incorporation of Na in CIGS with a post-deposition treatment was applied. 10-12% efficiency solar cells were routinely obtained on steel, while on polyimide foils highest efficiency of 14.1% (Voc = 649 mV, Jsc = 31.5 mA.cm-2, FF= 69.1%, total area = 0.595 cm2, no antireflection coating) was measured under simulated AM1.5 standard test conditions at ISE-Fhg Freiburg, Germany (figure 1). This result presented in the 2004 yearly report still remains the highest efficiency record for any kind of solar cell grown on polymer foils.

Large area deposition and mini-module development

As a first step towards industrial production of thin film CIGS solar cells and modules, up-scaling of all the processing steps to 30x30 cm^2 substrates should be demonstrated in research labs. In order to study critical problems of large area deposition we have started scaling-up of all deposition processes to 30x30 cm^2 size substrates. Because of lack of investment fund for purchase of standard sputtering equipment we have initiated this development with second-hand equipment for Mo and ZnO:Al/ZnO sputtering. We have been able to deposit layers on 30x30 cm^2 size substrates, but 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 2). An automated in-line movement mechanism of heated substrate in vacuum has been installed and tested to a satisfactory level. Furthermore, 30 cm long evaporation sources for Cu, In, Ga elements have been designed and constructed. Experiments to evaluate thickness and composition uniformity have started. Figure 2 shows the first results of composition distribution of CIGS layer and chemical bath deposited buffer layer on 30x30 cm^2 size substrate; further experiments are required to improve the thickness and composition uniformities.



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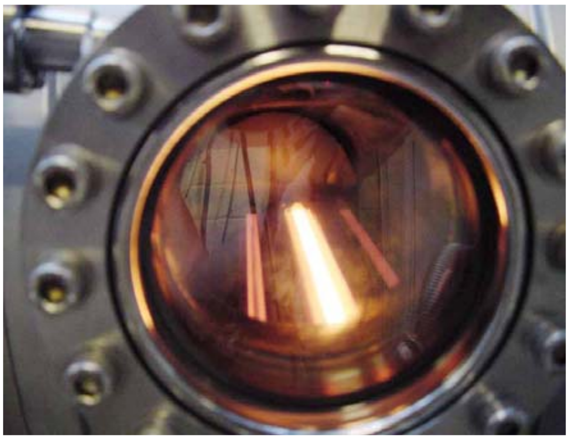

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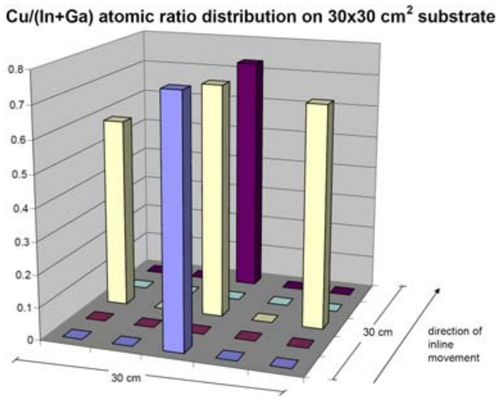

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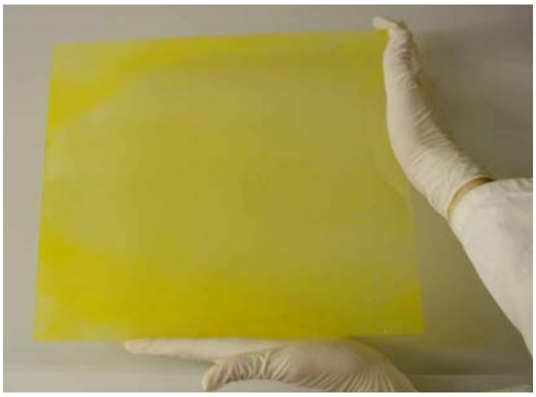

d)

Figure 2: (a) Picture in-house developed large area CIGS deposition system; (b) picture of 30 cm long glowing evaporation sources; (c) preliminary results of Cu/(In+Ga) composition ratio distribution on 30x30 cm^2 area substrtae; (d) chemical bath deposited buffer layer on 30x30 cm^2 glass substrate. for the co-evaporation of CIGS.

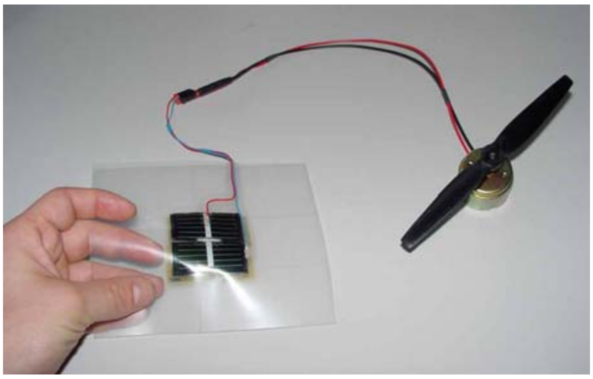

Figure 3: Pictures of flexible CIGS solar cell layers on a roll (left) and flexible mini-module to run a ventilator-fan.

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.

We have grown CIGS solar cells on commercially available Al foils as well as coated Al foils, those provided by Akzo Nobel, which they use for a-Si solar cells. On the rear of the substrate a SnO_2:F layer has been deposited at 450°C by Akzo Nobel. The substrate size in all these experiments was 5 x 5 cm^2. The Mo back contact was directly deposited by dc sputtering without application of any insulating or buffer layer. We have used different thicknesses for the Mo layer (0.5 – 2 µm) to investigate the barrier and thermo-physical mismatch buffer properties of the back contact. CIGS absorber layers were grown by evaporation of elemental Cu, In, Ga and Se and using the "3-stage" process. During the 1st stage of absorber growth the substrate temperature was kept at 400°C, while during 2nd and 3rd stages the substrate temperature (in the following called $T_{sub,max}$) was kept at 400°C or increased up to 500°C. There was no addition of Na before, during or after the growth of the absorber layer. The solar cells were finished by deposition of a CdS buffer layer by chemical bath deposition, rf sputtering of i-ZnO/ZnO:Al front contacts (300nm thick) and electron beam evaporation of Ni-Al contact grids for better current collection. No anti-reflection (AR) coating was applied. Current density - voltage (J-V) characteristics of the solar cells were measured under simulated AM1.5 conditions at room temperature.

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.

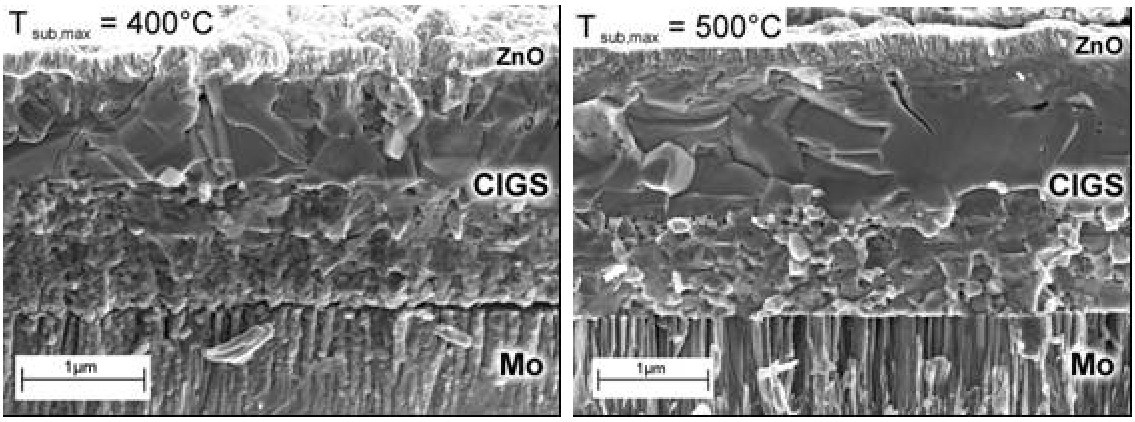

Figure 4: SEM cross-section images of solar cells on Al foils where CIGS layers were grown at a 400 °C (left) and 500 °C (right), the mentioned temperature is a reference value and not the exact substrate temperature.

The growth temperature has the most important impact on the structure and the quality of the absorber. 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 4, 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 3stage 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.

For an absorber grown at $T_{sub,max}$ = 500°C we can observe two different microstructure (figure 4 right), which is typical for the 3-stage process at low temperature. At the top we can find large grains with size up to a few µm. At the bottom the grain size is much smaller. This indicates a lower Ga content at top than at the Ga-rich bottom. The small crack near the surface in a big grain is due to stress relaxation during cool-down step in the layer. In this case, unlike in figure 4-left, the crack is not a result of sample preparation as can be seen at the intact ZnO layer. Also interesting are the small holes in different crystal grains, especially at the bottom. Those are most probably created by the recrystallization of the grains.

The secondary ion mass spectrometry (SIMS) depth profile (figure 5) confirms the composition changes observed in the SEM images. The Ga-signal shows clearly a Ga dip, while an In-peak appears near the absorber surface. This results in a band-gap grading in the absorber layer. It should be clarified that the Cu dip is a matrix effect as cross-checked with several samples of different types. The band-gap grading (or composition profiles) depends on CIGS deposition temperature and the *results are consistent with previous results on glass and polymer substrates.*

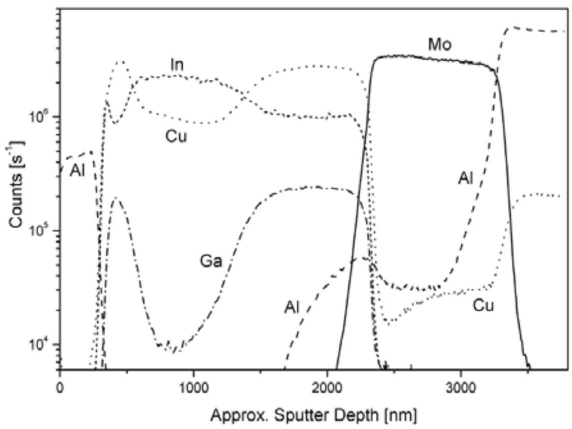

Figure 5: SIMS depth profile of CIGS/Mo layers in solar cells grown on Al foils at 500°C. Diffusion of Al through the Mo back contact and contamination of CIGS is observed. The Ga-dip/In-peak is due to the 3-stage process and low In-Ga inter-diffusion at low temperature.

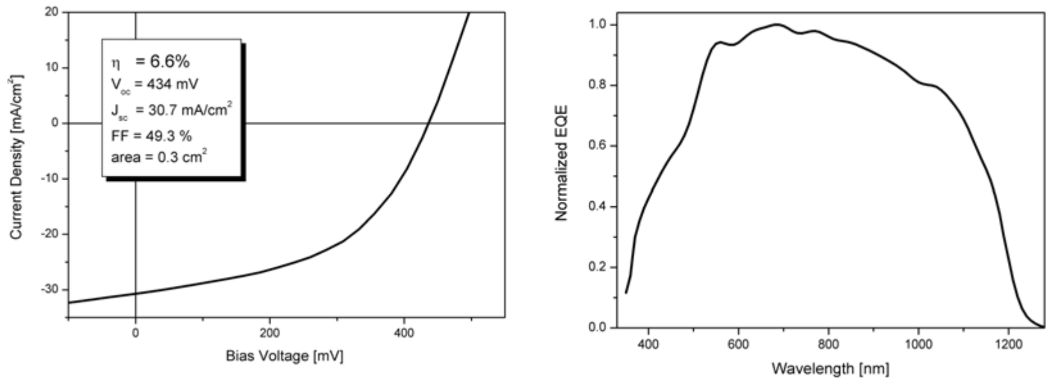

Figure 6: Current-voltage characteristic (left) and quantum efficiency (right) of a CIGS solar cell on Al foil. Neither Na was incorporated in CIGS absorber nor any AR coating was applied. This 6.6% efficiency is the highest value of efficiency reported to date for CIGS cell on Al foil. Addition of Na in CIGS will further increase the cell efficiency.

SIMS measurements show an aluminum contamination of the absorber. Al diffuses from the substrate through the Mo back contact into the absorber. At the same time Cu seems to diffuse in the opposite way from the absorber to the substrate. To prevent that contamination, the application of an intermediate barrier layer or a lower deposition temperature is needed. At $T_{sub,max}$ = 450°C no Al contamination of CIGS was observed (not shown here). It should be mentioned that the Al-signal at the surface comes from the Al-doted ZnO front contact and has no relation to the substrate.

Figure 6 (left) shows the current-voltage characteristics of our best solar cell achieved so far. A conversion efficiency of 6.6 % (V_{oc} = 434 mV, J_{sc} = 30.7 mA/cm^2, FF = 49.3 %, total area = 0.3 cm^2 ; no AR coating) was measured under AM1.5 standard test conditions. 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. It is known that addition of Na can significantly increase the efficiency by additionally up to 70% of the Na free value.

The external quantum efficiency (EQE) of the solar cell is shown in figure 6. The low EQE between 450 nm and 550 nm wavelength comes from the photon absorption loss in the CdS buffer layer. Absorption at wavelength until approximately 1250 nm confirms the presence of a band-gap grading of Ga and grains with low Ga content.

National and international collaboration

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

Evaluation 2005 and outlook 2006

Flexible CIGS solar cells on polymer and metal foils were developed with a novel process developed at ETHZ. The 14.1% efficiency achieved by us and certified by ISE-FhG, Freiburg, Germany in December 2004 still remains the highest record efficiency for any kind of flexible solar cell grown on polymer foils. We have developed for the first time CIGS solar cells on Al-foil and investigated the compatibility issues of Al substrate solar cell component layers. Because of mismatch in thermo-physical properties deposition conditions need careful optimization to avoid micro-crack; further work is needed in this direction. 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. For further increase in cell efficiency controlled addition of Na in CIGS is necessary and the influence of CBD process on CIGS surface modification requires more studies. Development of CIGS solar cells on Al foil is challenging but our results have shown encouraging results and identified some key steps to further increase the cell efficiencies.

Large area CIGS deposition equipment has been assembled in-house. An automated in-line movement mechanism of heated substrate in vacuum has been installed and tested to a satisfactory level. Furthermore, 30 cm long evaporation sources for Cu, In, Ga elements have been designed and constructed. Experiments to evaluate thickness and composition uniformity on 30x30 cm^2 size substrates started; further experiments are required to improve the thickness and composition uniformities. Unfortunately, this project comes to an end in March 2006.

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.

Annual Report 2005

New buffer layers for efficient chalcopyrite solar cells (NEBULES)

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Duration of the Project (from – to)	01.12.2002 – 31.12.2005

ABSTRACT

The contribution of the ETHZ group in this collaborative project of the European Union is focussed on the structural and electronic characterisation of Cu(In,Ga)Se_2 (CIGS) solar cells developed with different types of buffer layers.
Structural, inter-diffusion and chemical analyses of interfaces between CIGS and In_xS_y buffer layers deposited by various techniques have been performed and the effects of buffer deposition method have been investigated. For the In_2S_3 buffers deposited by atomic-layer deposition (ALD) and sputtering the optimum deposition temperatures of about 210-230 °C have been found. Efficiencies of the corresponding solar cells increase with increasing temperature below and decrease with increasing temperature above this temperature range. Energy-dispersive x-ray spectrometry (EDX) suggests inter-diffusion of Cu, Ga and In across the In_xS_y/CIGS interfaces. The Cu depletion and In enrichment found on the CIGS side of these interfaces indicate the presence of an intermediate Cu-depleted Cu-(In,Ga)-Se layer between CIGS and In_xS_y. The width of this layer increases with increasing temperature, as the Cu depletion and In enrichment are more enhanced at elevated temperature. Such an intermediate, Cu-depleted Cu-(In,Ga)-Se layer may considerably improve the band alignment between CIGS and In_xS_y and thus the solar-cell performance. For substrate temperatures of about 340 °C, the deposition of In_xS_y on CIGS by sputtering has led to the formation of $CuIn_5S_8$. Its intrinsically large densities of vacancies and defects of this layer may affect recombination of the generated charges, and thus reduce considerably the efficiency of the solar cell. Since $CuIn_5S_8$ formation has been revealed for interfaces between CIGS and In_xS_y deposited by various techniques for temperatures above about 250°C, this formation may be an explanation for the deteriorated performances of the corresponding solar cells at elevated temperatures.
In addition, structural and chemical properties have been studied between CIGS and ALD-Zn(O,S) buffers deposited with varying ratios of H_2O and H_2S sequences (as O and S sources), and on different CIGS absorbers. Best solar-cell efficiencies have been obtained for Zn(O,S) layers with a H_2S/H_2O sequence ratio of 10% (“Zn(O,S)10%”). Elemental distribution profiles obtained by means of EDX exhibit a local maximum of the S signal near the Zn(O,S)/CIGS interface, whereas the O signal shows a local maximum near the Zn(O,S)/front contact interface for Zn(O,S)10% samples. For Zn(O,S)20% or Zn(O,S)5% samples, such local maxima have not been found. This may indicate a different compositional gradient and thus different band alignments to CIGS for Zn(O,S) layers with different O/S ratios.

Introduction and project objectives

In high efficiency chalcopyrite solar cells a buffer layer of CdS is sandwiched between the *p*-type $Cu(In,Ga)Se_2$ (CIGS) absorber and the *n*-type ZnO-window layers. This *n*-type buffer layer is generally grown with a chemical bath deposition method. The role of the buffer layer is not yet clear: it may protect the CIGS surface from ion damage during the ZnO sputtering; it may reduce the shunting paths and even cause type-inversion at the absorber surface. Photons of low wavelength (350-550 nm) can be absorbed in the buffer layer, thereby reducing the photo-current if buffer layer is thick. This EU collaborative project is devoted to the development of chalcopyrite solar cells with novel buffer layers. The objective of the ETHZ group is on the characterisation of the surface and interface properties of CIGS absorber layers and solar cells developed with different buffer layers, and to provide pathways for efficiency improvement.

Short description of the project

Surface properties of the CIGS absorber layer and buffer-CIGS interface have strong influence on the solar cell efficiency. The CIGS surface can go through modifications prior or during the buffer layer deposition. The chemical composition and structural relationships at the interface affect electronic transport across the heterojunction. Therefore, micro- or nanoscopic characterisation is important. This can help to understand why chemical bath deposited CdS buffer layers yield higher efficiencies than vacuum evaporated buffer layers.

One of the reasons for the research of buffer-layer materials as alternatives to CdS is to minimise the absorption loss in the buffer layer. Therefore, wide band gap (> 2.4 eV) semiconductors are investigated in order to substitute CdS layer in CIGS solar cells. Recently, in collaboration of ZSW, Stuttgart and ENSC, Paris, 16.4% efficiency CIGS solar cells were developed with an In_2S_3 buffer layer deposited by atomic layer deposition (ALD). Also, ZSW presented efficiencies of up to 13.3% for CIGS solar cells with sputtered indium sulfide buffers. Structural and chemical properties of the CIGS/ALD-In_2S_3 and CIGS/sputtered In_2S_3 interfaces are investigated in detail within the scope of the present project, especially in view of the effects of various conditions during the buffer-layer deposition. In collaboration with ZSW Stuttgart, we have investigated the structural and chemical properties of these In_2S_3 buffer layers and In_2S_3–CIGS interfaces grown under various conditions.

In addition, CIGS solar cells with ALD-Zn(O,S) buffer layers grown at ÅSC, Uppsala University, Sweden, have shown efficiencies of over 16%. In collaboration with this laboratory, we have investigated structural and chemical properties also of these Zn(O,S) buffer layers and Zn(O,S)-CIGS interfaces.

Work and results

CIGS solar cells with sputtered indium sulfide buffer layers

The CIGS layers were grown by co-evaporation of Cu, In, Ga, Se on Mo coated glass substrates. After the deposition of buffer layers, solar cells were completed by depositing rf magnetron sputtered i-ZnO and ZnO:Al layers. Finally, Ni-Al grids were evaporated for electrical contacting.
Sputtered In_xS_y layers were deposited in a von Ardenne CS 730S laboratory magnetron sputtering system with a base pressure of $2x10^{-7}$ mbar. The In_xS_y was sputtered from a ceramic In_2S_3 (3N) target with a diameter of 200 mm and a target-to-substrate distance of 74 mm. The In_xS_y layers were deposited at a rate of about 20 nm/min and at a power density of 1 W/cm^2 using Ar (5N) as sputter gas. The pressure during the sputtering process was kept at $1x10^{-2}$ mbar. The sputtering chamber provides three positions for the sample: a load-lock position for mounting and removing the sample, an annealing position where the sample is placed in front of a heater and the sputtering position.

In the sputtering chamber, the substrates can be annealed in vacuum, prior to as well as after the sputtering process (*pre-annealing* and *post-annealing*). Best results have been achieved for pre-annealed samples. Therefore, for all samples studied, the CIGS/Mo/SLG substrates were pre-annealed prior to the buffer layer deposition, and the substrate temperature was measured during the sputtering process. Fig. 1 shows the substrate temperature as well as the according position of the sample in the sputtering chamber in dependence of the duration. The average substrate temperatures during the sputtering were 60°C, 230°C and 340°C; therefore, in the present publication, the respective samples are referred to as 60°C, 230°C and 340°C samples.
Cross-sectional specimens were investigated by means of bright-field (BF-TEM) and high-resolution TEM (HR-TEM), and also by means of selected-area electron diffraction (SAED) and energy-dispersive x-ray spectrometry (EDX) using an FEI TECNAI F30 transmission electron microscope operated at 300 keV.

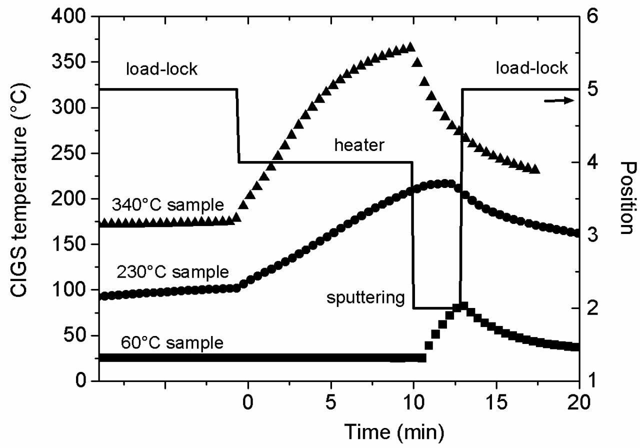

Figure 1: Substrate temperatures and positions of the samples in the sputtering chamber in dependence of the duration. The samples were termed after the average substrate temperature during the sputtering, 60, 230, and 340 °C.

The photovoltaic properties of all solar cells studied are summarized in Table I. The efficiencies in dependence of the substrate temperature show a maximum at about 230 °C and a very low efficiency for the 340 °C sample (as also revealed by earlier optimization experiments). In addition, the quantum-efficiency curves (Fig. 2) indicate a reduced carrier collection for the 340 °C sample, compared with those of the 60 °C and 230 °C samples. These behaviors are similar to according results from solar cells with In_2S_3 buffer layers deposited by ALD (see 2004 report). There, the solar-cell performance improves with increasing substrate temperature, up to a value of about 230 °C; from this temperature on, the efficiencies decrease with increasing substrate temperature. These behaviors are similar for both, cells with sputtered In_xS_y and ALD-In_2S_3 buffer layers.

Table I: Photovoltaic properties of the solar cells investigated. These values are averages obtained from three cells.

Sample	V_{oc} (mV)	j_{sc} (mA/cm^2)	*FF* (%)	η (%)
60°C	473 ± 38	26.3 ± 0.5	55.4 ± 0.4	6.9 ± 0.6
230°C	615 ± 41	26.4 ± 0.3	68 ± 2	11 ± 1
340°C	412 ± 31	18 ± 4	25 ± 7	1.9 ± 0.6

As revealed by the BF-TEM images in Fig. 3, the In_xS_y layers of the samples investigated all seem to cover the CIGS contiguously. However, all three samples show inhomogeneous In_xS_y layer thicknesses, varying between 25 and 100 nm. For the 340 °C sample, a layered structure is found in the buffer (Fig. 3). This structure is formed by a high density of planar defects in the buffer layer, directly at the interface to CIGS, as shown by the HR-TEM image in Fig. 4. The interplanar distances in this buffer do not correspond to the crystal structures of any In_xS_y phase, thus, a question mark was added after the notation "In_xS_y". Such a defect-containing layer was also found at an interface between ALD-In_2S_3 deposited at 240 °C and CIGS (see earlier reports), however, appearing only as intermediate layer between the tetragonal CIGS and β-In_2S_3 structures.

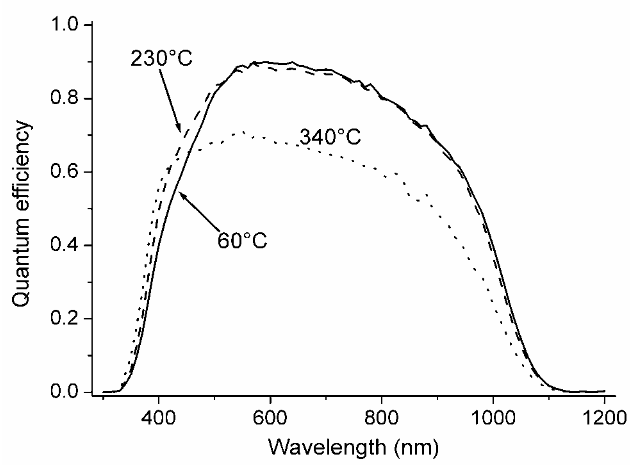

Figure 2: External quantum efficiencies of the 60, 230 and 340 °C samples. Reduced carrier collection was found for the 340 °C sample, compared with the 60 and 230 °C samples.

For the 60 °C and the 230 °C samples, such defects were not found in the buffer layers (Fig. 4). In contrast to the 340 °C sample, very small grain sizes of about 5 nm can be estimated from the HR-TEM images of the 60 and 230 °C samples (Fig. 4). While the In_xS_y/CIGS interfaces of the 60 °C and the 340 °C samples appear abrupt, the corresponding interface of the 230 °C sample seems to be rather diffuse. By means of SAED acquired on the In_xS_y/CIGS interfaces (Fig. 5), a tetragonal β-In_2S_3 crystal structure was revealed for the 230 °C sample (the pattern of the 60 °C sample, not shown here, is very similar to that of the 230 °C sample).For the buffer layer produced at 340 °C, the SAED pattern in Fig. 5 shows a $CuIn_5S_8$ phase instead of In_xS_y. $CuIn_5S_8$ formation has also been found at interfaces between CIGS and In_xS_y buffers evaporated from In_2S_3 powder at 300°C. The spinel-type crystal structure of $CuIn_5S_8$ contains a large number of vacancies, which, together with the planar defects in the buffer layer (see Fig. 4), may affect recombination near the *p-n* junction of the solar cell considerably.

Linear elemental distribution profiles, extracted from EDX elemental mappings on CIGS/ In_xS_y interfaces, are shown in Fig. 6 for the 60, 230, and 340 °C samples. The dashed lines indicate the positions of the CIGS/buffer interfaces, given by the crossover of the Se and the S signals; these two elements did not show any significant change in any of the samples investigated, thus, Se and S are considered to interdiffuse only to a negligible extent. For the 60 °C and the 230 °C samples, the linear profiles reveal Cu and Ga diffusion from CIGS into In_xS_y. On the In_xS_y side of the CIGS/In_xS_y interfaces, the Cu and Ga signals decrease much more gradually than the Se signal. The extent of their diffusion increases with increasing deposition temperature.

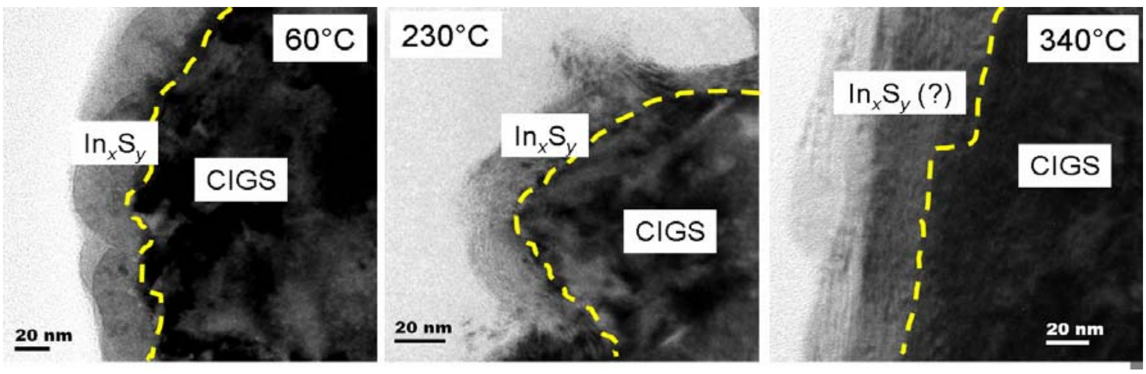

Figure 3: Bright-field transmission electron micrographs of the interfaces of CIGS with In_xS_y layers grown at 60, 230, and 340 °C. All three samples show inhomogeneous In_xS_y layer thicknesses, varying between 25 and 100 nm. For the 340 °C sample, a layered structure is found.

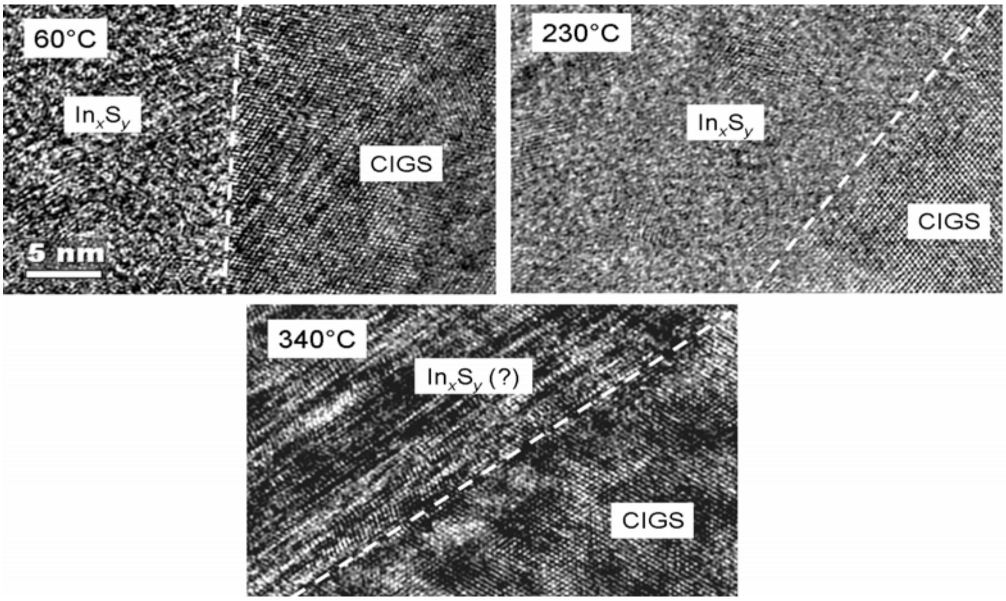

Figure 4: High-resolution transmission electron micrographs of the interfaces of CIGS with In_xS_y layers grown at 60, 230, and 340 °C. A large density of planar defects is revealed in the buffer layer of the 340 °C sample, directly at the interface to CIGS.

In addition to the Cu and Ga diffusion, an obvious depletion of Cu and an enrichment of In are visible on the CIGS side of the interface, especially in the case of the 230 °C and 340 °C samples. Apparently, depletion and enrichment of the elements are also enhanced with increasing deposition temperature of the In_xS_y layer. A similar result has been obtained at ALD-In_2S_3/CIGS interfaces (see 2004 report).

Assuming a Cu:In ratio of 1 on the (not depleted) CIGS side of the interface and a In:S ratio of 2:3 on the buffer side of the interface, the Cu concentration in the buffer can be estimated to about 7 at.% for the 60 °C and to about 13 at.% for the 230 °C sample, neglecting the Ga diffusion. For the 340 °C sample, a much larger Cu depletion than for the 60 °C and 230 °C samples was found (Fig. 6).

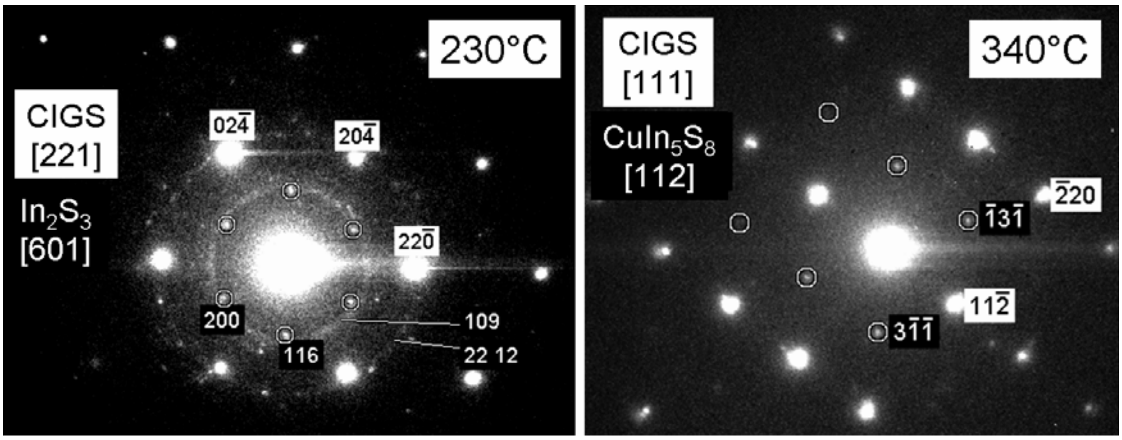

Figure 5: Selected-area electron diffraction patterns from the interfaces of CIGS with In_xS_y layers grown at 230 and 340 °C. A tetragonal β-In_2S_3 crystal structure was revealed for the 230 °C sample. For the 340 °C sample, cubic $CuIn_5S_8$ formed instead of In_xS_y. The reflections from the $CuIn_5S_8$ layer are barely visible, thus, there were outlined by circles.

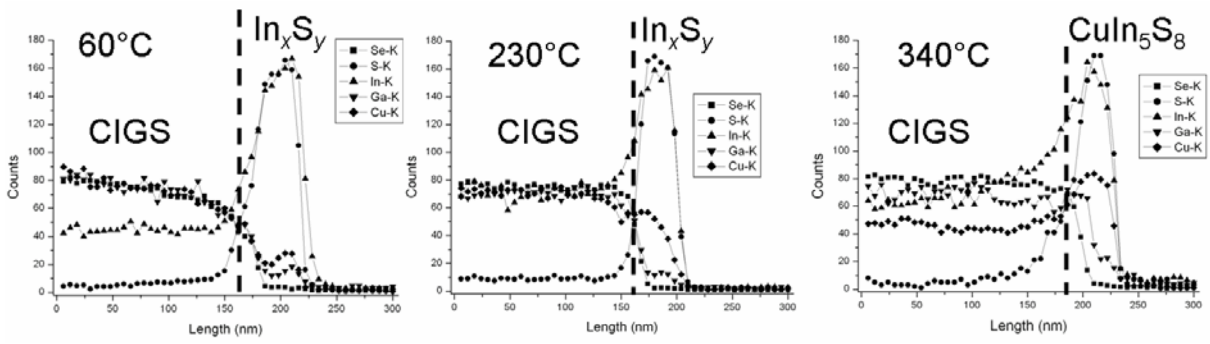

Figure 6: Linear elemental distribution profiles across CIGS/In_xS_y interfaces. Cu and Ga diffusion from CIGS into In_xS_y are revealed, as well as Cu depletion on the CIGS side of the interface for the 230 and 340 °C samples. Only for the 340°C sample, also enhanced In enrichment on the CIGS side of the interface was found. All effects increase with increasing In_xS_y deposition temperature.

Unfortunately, it is not clear how large the Cu-depleted layer on the CIGS side of the interface is. Apparently, the width of this depleted layer is larger than about 200 nm. It has to be taken into account that Cu may not only diffuse from CIGS into the buffer layer, but may also deplete on the CIGS side at the CIGS/buffer interface and enrich at the interface to the Mo back contact. This conclusion is supported by the fact that the number of depleted Cu atoms on the CIGS side of the interface (as far as to be estimated from Fig. 6) is much larger than the number of Cu atoms diffused into the buffer layer.

It is also remarkable that for the 340 °C sample, the Cu concentration in the buffer layer seems to be larger than its concentration on the CIGS side of the interface (Fig. 6). Probably, such a strong Cu diffusion is not only driven by the substrate temperature; furthermore, also gradients of chemical potentials or strains indicated by the planar defects shown by Fig. 4 are possible causes.

Local maxima of the Cu-K linear elemental distribution profiles inside the In_xS_y layer are visible in all samples studied (Fig. 6). These maxima are not artifacts of the measurements, but can be interpreted in the following way: Cu diffuses from the CIGS into the In_xS_y layer, occupying vacancies and In sites, and In diffuses into the CIGS layer, occupying Cu vacancies. Generally, Cu ions show a much higher mobility than In ions, thus, it can be assumed that Cu diffuses more rapidly into In_xS_y than In into CIGS, which would lead to a Cu depletion on the CIGS side of the interface and to an enrichment of Cu on the In_xS_y side of the interface, forming a local maximum. Similar local maxima of the Cu-K linear elemental distribution profiles inside the indium sulfide layer have been found also at ALD-In_2S_3/CIGS interfaces (see 2004 report). Considering also the occupation of Cu vacancies by In ions, these assumptions would imply the inversion of the near-interface region of CIGS from *p*-type to *n*-type.

From the present results, the following speculative interpretation of sputtered In_xS_y/CIGS interfaces with respect to the In_xS_y deposition temperature was developed. With increasing deposition temperature, Cu, Ga, and In interdiffusion becomes more enhanced, which leads to a Cu-depleted and In-enriched near-interface region of CIGS. There, an inversion from *p*-type to *n*-type is probable. This region becomes broader with increasing deposition temperature, which seems to have a beneficial effect on the junction formation. Thus, the cell performance improves up to temperatures of about 230 °C. This behavior is similar to that assumed for ALD-In_2S_3/CIGS interfaces. For higher temperatures, $CuIn_5S_8$ forms instead of In_xS_y.

The role of the band alignment between CIGS and $CuIn_5S_8$ is not yet clear, however, the intrinsic vacancies of $CuIn_5S_8$ and the defects in the buffer shown in Fig. 4 may enhance recombination at the *p*-*n* heterojunction of the solar cell. It is already known from studies on $CuInS_2$ based solar cells that the electronic properties of the heterojunction deteriorate as soon as the $CuIn_5S_8$ phase segregates in the films. Thus, it may be assumed that a $CuIn_5S_8$ interfacial layer could be the reason for a severe deterioration of the heterojunction properties.

CIGS solar cells with ALD-Zn(O,S) buffer layers

All samples studied were provided by the Thin-Film Solar Cell Group of the Ångström Solar Center, Uppsala University, Sweden. Zn(O,S) films were deposited in a Microchemistry F-120 reactor using the sources H2O, H2S and diethylzinc (DEZ). The temperature in the deposition zone was 120 °C. The pulsing sequences were DEZ/N_2, purge/H_2O or H_2S/N_2 purge, with pulsing times of 200/400/200/400 ms. For the Zn(O,S) films, sequences with H_2O and H_2S were alternated. E.g., a film with 20% H_2S pulses was obtained by running 4 sequences with H_2O and one with H_2S repeatedly. In the following, the notation "Zn(O,S)20%" will be used for such a film. In the frame of this study, Zn(O,S)5%, Zn(O,S)10%, and Zn(O,S)20% samples have been investigated by means of HR-TEM and EDX. The photovoltaic properties of the solar cells investigated are listed in Table 2.

Table 2: Photovoltaic properties of the solar cells investigated (the CBD-CdS reference cells have not been studied). These values are averages obtained from 7-8 cells. The cells CIGS type 1 contain Zn(O,S) and CBD-CdS buffer layers deposited on the same CIGS substrate.

Sample	CIGS type	η (%)	V_{oc} (mV)	*FF* (%)	J_{sc} (mA/cm^2)
Zn(O,S)5%	1	4.6	417	38	28.8
Zn(O,S)10%	1	9.7	513	62.3	30.2
Zn(O,S)20%	1	0.1	266	20.2	2.1
CBD-CdS (ref)	1	9.6	595	57	28
Zn(O,S)10%	2	16.2	637	73	34.4

High-resolution transmission electron micrographs of interfaces between Zn(O,S) and CIGS layers are shown in Fig. 7. It appears that for the samples with CIGS type 1, these interfaces are quite abrupt, whereas for the sample with CIGS type 2, the interface is rather diffuse. This result was verified along several micrometers of these Zn(O,S)/CIGS interfaces. It seems as if the interface formation strongly depends on the CIGS substrate and rather not on the sulfur concentration in the buffer layer.

Also, there are orientation relationships visible between atomic layers of CIGS and Zn(O,S) for the 5% and the 10% (CIGS type 1) samples (also verified by electron diffraction, not shown here), which is not present in the 20% sample or the sample with CIGS type 2. Orientation relationships between the *p*-type and the *n*-type layer of a heterojunction indicate good lattice match and thus reduced recombination losses (structural defects may act as recombination centers).

As revealed by EDX elemental distribution profiles, only for the Zn(O,S)10% samples, a local maximum of the S signal at the CIGS/Zn(O,S) interface and an enhanced O signal at the Zn(O,S)/epoxy interface is found (shown for the sample on CIGS type 2 in Fig. 8). No local maxima in the Zn(O,S) layers are found for the 5% and 20% samples. Taking into account different band-gap energies for ZnO and ZnS, a compositional gradient across the Zn(O,S) layer may indicate a gradient in the energy-band distribution. Since highest solar-cell efficiencies have been achieved for the 10% samples, such a compositional gradient may be beneficial to the energy-band alignment between CIGS and Zn(O,S) and thus improve the photovoltaic performance of the solar cells.

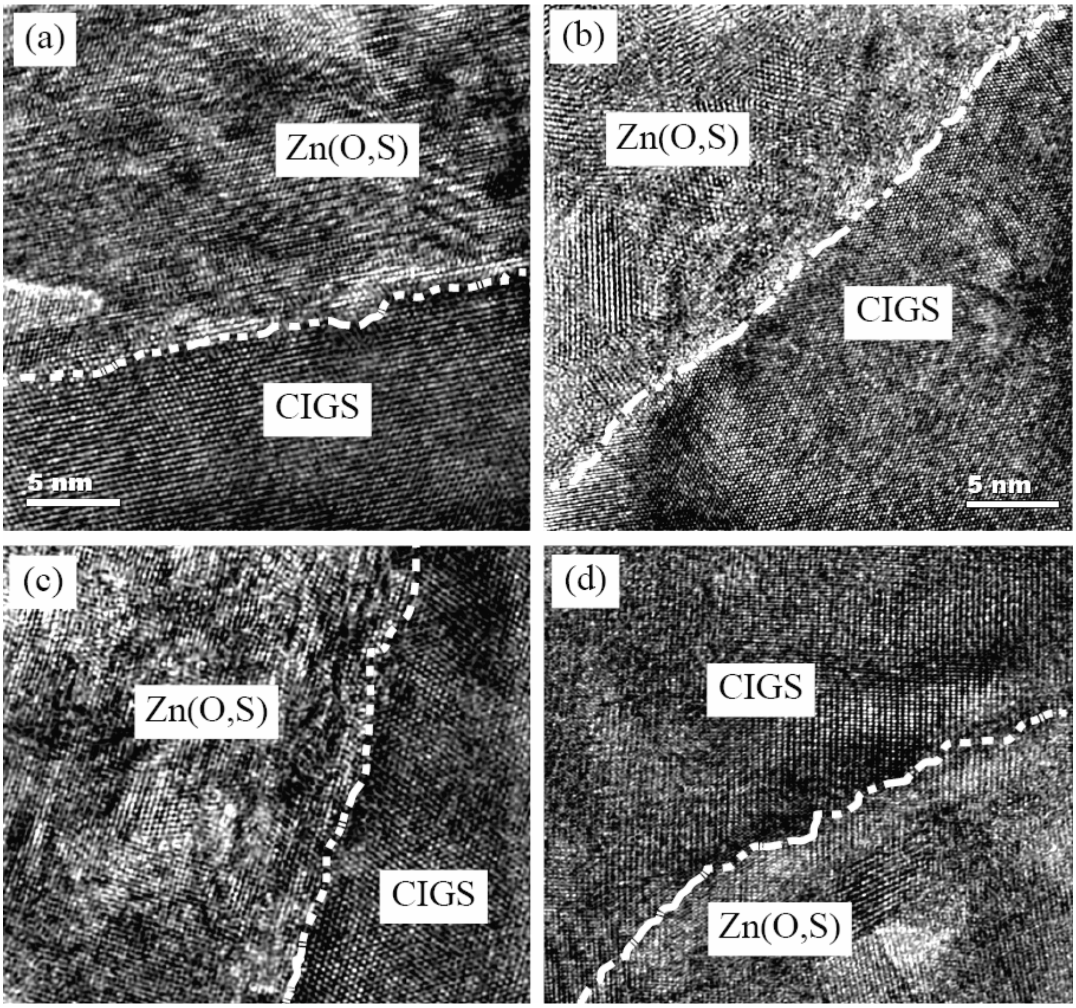

Figure 7: High-resolution transmission electron micrographs of interfaces between CIGS type 1 and Zn(O,S)5% (a), Zn(O,S)20% (b), Zn(O,S)10% (c), and between CIGS type 2 and Zn(O,S)10% (d).

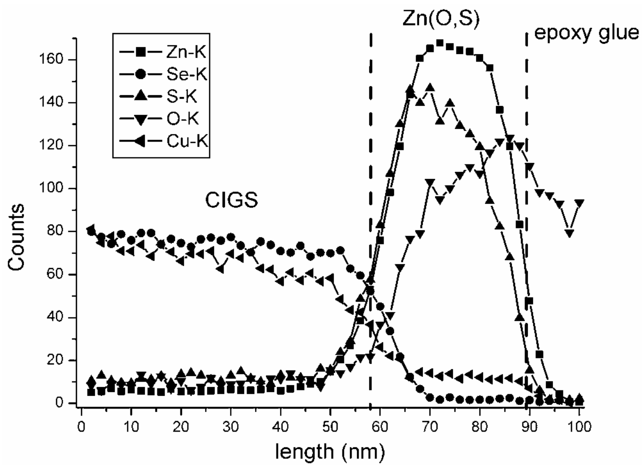

Figure 8: Elemental distribution profiles across the interface between CIGS type 2 and Zn(O,S)10%, obtained by energy-dispersive x-ray spectrometry.

National and international collaboration

The partners of the NEBULES project are: HMI-Berlin (D), ZSW-Stuttgart (D), Würth-Solar (D), Uppsala University (S), Nantes University (F), CNRS (F), ETHZ (CH). Collaborations with the group of Prof. G. Kostorz (IAP, ETHZ).

Evaluation 2005

Work was performed as planned in the proposal. Interfaces between CIGS and sputtered In_xS_y layers, provided by ZSW, have been studied under variation of the substrate temperature during the In_xS_y growth. The microstructural and chemical properties of these interfaces can be directly compared to the properties of CIGS/ALD-In_2S_3 interfaces. Cu and Ga were found to diffuse from CIGS into In_xS_y, whereas In diffuses from In_xS_y into CIGS. In addition, Cu depletion and In enrichment was found on the CIGS side of the In_xS_y/CIGS interface. All effects seem to increase with increasing substrate temperature. This may indicate the formation a Cu depleted and In enriched layer between CIGS and buffer, which may improve their band alignment considerably for temperatures up to about 230 °C. For a temperature of 340 °C, $CuIn_5S_8$ formed instead of In_xS_y. The intrinsic vacancies of the $CuIn_5S_8$ layer and its defects may affect recombination at the *p-n* heterojunction of the solar cell and thus explain the very poor solar-cell performance for cells with In_xS_y sputtered at 340 °C.
Since very low efficiencies have been found for solar cells with In_xS_y buffer deposited at temperatures higher than ~250 °C by various techniques (ALD, evaporation, sputtering, spray ion-layer gas reaction), and since $CuIn_5S_8$ formation has been confirmed for several of these cells (e.g., evaporation from In_2S_3, sputtering), this formation appears to be a general phenomenon to be found when depositing an In_xS_y buffer layer on CIGS above ~250 °C by any technique.

In cooperation with the Uppsala University, CIGS/ALD-Zn(O,S) interfaces have been investigated (Zn(O,S)5%, Zn(O,S)10%, and Zn(O,S)20%). The Zn(O,S) layers cover the CIGS absorber contiguously. Whether the CIGS/Zn(O,S) interface is abrupt or diffuse seems to depend rather on the CIGS absorber and not on the Zn(O,S) composition. Slight Cu diffusion from CIGS into Zn(O,S) has been revealed for all samples studied. Only for the Zn(O,S)10% samples, an enhanced S signal was found at the CIGS/Zn(O,S) and an enhanced O signal at the Zn(O,S)/epoxy interface. This result needs further study. However, since the stoichiometry of these samples leads to the highest efficiencies, such a ”separation of phases” may be beneficial to the energy-band alignment between CIGS and Zn(O,S) and thus improve the photovoltaic performance of the solar cells.

Altogether, the results presented in the reports 2003-2005 provide a good overview of promising candidates for buffer layer materials in high-efficient CIGS solar cells and the structural and chemical properties of their interfaces to CIGS under variation of various process parameters. Thus, it was possible to enhance the knowledge about processes at interfaces and therefore to help to improve the performance of the corresponding solar cells. The project ends in December 2005.

Acknowledgement: The authors would like to thank Prof. G. Kostorz, and Dr. D. Mukherji, IAP, ETH Zürich for constant support and fruitful discussions.

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Annual Report 2005

Dye-sensitised Nanocrystalline Solar Cells

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Project- / Contract Number	Project EPFL
Duration of the Project (from – to)	January – December 2005

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 widely 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. A schematic of the optical excitation and charge transfer sequence is presented in Fig.2.

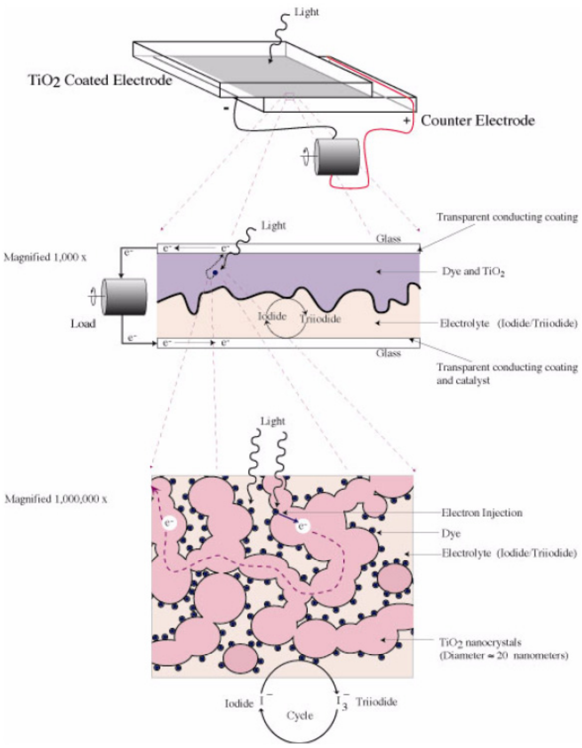


Fig.1: Structure of dye-sensitised photoelectrochemical cell on different scales.

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

(Centre): electrodes and electrolyte, micron scale.

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

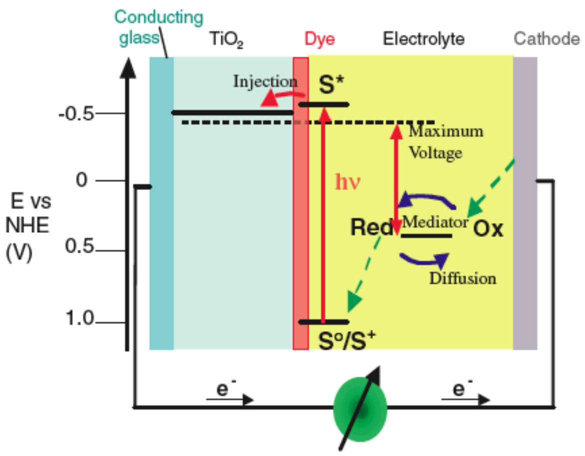


Fig.2: Principle of operation of the dye-sensitised nanocrystalline solar cell. Photoexcitation of the sensitizer (S) is followed by electron injection into the conduction band of an oxide semiconductor film. The dye molecule is regenerated by the redox system, which itself is regenerated at the counter 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.

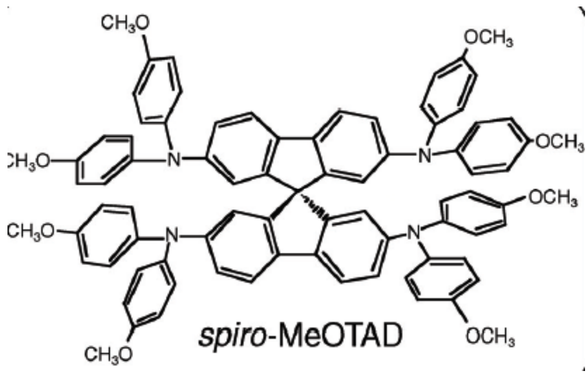


Fig. 3: structure of spirobifluorene hole-conducting p-type organic semiconductor. The fluorene structures are perpendicular, conjoined through a carbon site common to both.

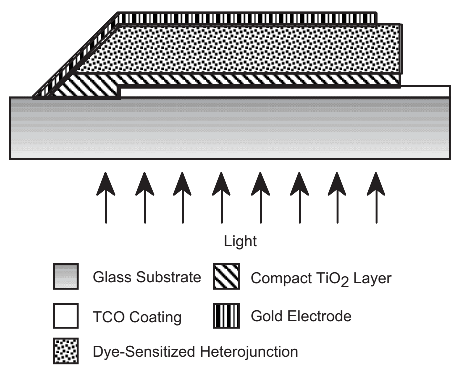


Fig. 4: Schematic of the dye sensitized heterojunction PV cell.

The application of a dye-sensitised component within a tandem cell for photoelectrolysis has also been investigated. The sensitised cell itself, of course does not provide the potential difference of about 1.23 volts necessary for electrolysis of water; a complementary photoelectrochemical cell is required 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. In the present case the second photoanode is an oxide semiconductor, iron or tungsten being favoured. A schematic of the energetics of this system is shown in Fig.5.

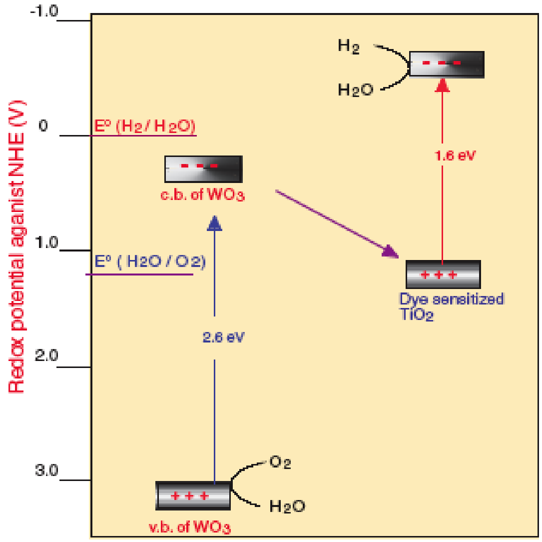


Fig.5: schematic of energy levels and electrical series connection of a tandem arrangement for solar photoelectrolysis. As stated in the text, the two photosystems are also in optical series.

Ongoing Work and Results 2005

The quality of the semiconductor mesoporous film is evidently crucial for the efficiency of the resultant cells. The inorganic films are made of a network of wide-bandgap oxide nanocrystallites, producing a junction with a large contact area. The surface extension for a film composed of 15–20 nm.-sized particles is about 100 times the area it occupies for each micron of thickness. A roughness factor, defined as the ratio of the real surface area to the projected area, of at least 1000 is required to ensure efficient solar light harvesting by the currently employed sensitizers. The TiO_2 film is deposited, usually by screen printing, from a colloidal suspension providing a reproducible and controlled porous high-surface-area texture. Typically, the specific surface area of the films is 80–200 m2/g TiO_2. While commercially available titania powders produced by a pyrolysis route from a chloride precursor have been successfully employed, the present optimized material is the result of a hydrothermal technique, as described by Brooks et al. (3) A specific advantage of this procedure is the ease of control of the particle size and hence of the nanostructure and porosity of the resultant semiconductor substrate. The synthesis involves the hydrolysis of the titanium alkoxide precursor, producing an amorphous precipitate, followed by the dispersion of the particles in acid or alkaline water to produce a sol, which is then subjected to hydrothermal Ostwald ripening in an autoclave. The resulting TiO_2 particles consist of anatase or a mixture of anatase and rutile, depending on reaction conditions. Fig. 6 shows a scanning electron microscope picture of a mesoscopic TiO_2 film. The film thickness is typically 5–20μ and the TiO_2 mass is 1–4 mg/cm^2. Analysis of the layer morphology shows the porosity to be 50–65%. The prevailing structures of the anatase nanoparticles are square-bipyramidal, pseudocubic, and bricklike.

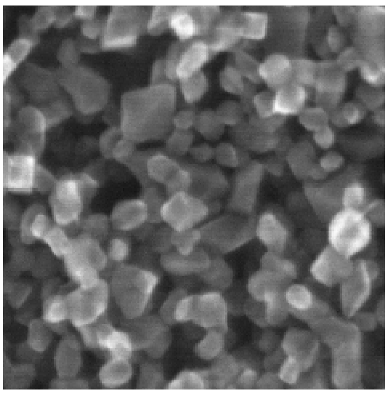


Fig. 6: SEM image of photovoltaic-quality titania mesoporous film

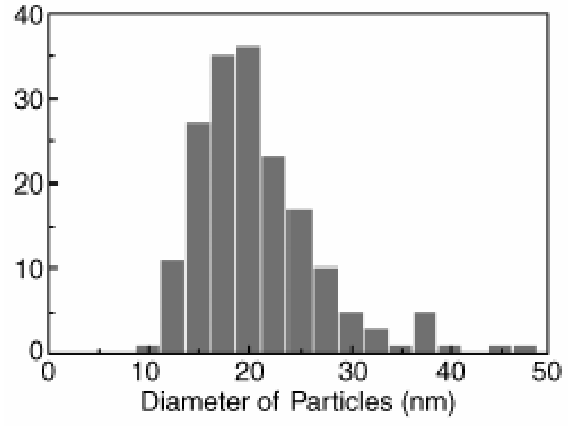
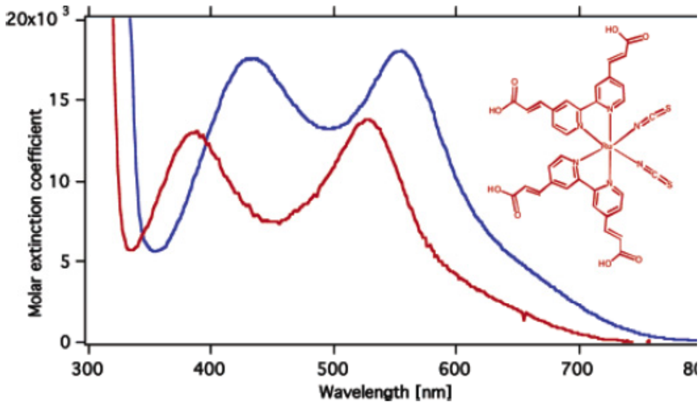


Fig.7: Histogram showing the frequency of occurrence of a given particle size for a mesoscopic TiO_2 film prepared at 230° C, which has demonstrated optimal photo-voltaic performance.

According to high-resolution transmission electron microscope (HRTEM) measurements, the (101) face is mostly exposed, followed by the (100) and (001) surface orientations. The formation of the (101) face is favored by its low surface energy. The size distribution of the particles is presented in Fig. 7 above. The median particle size is some 20 nm. The oxides particles are employed in their intrinsic insulating state. There is no need to dope them because the injection of one single electron from the surface adsorbed sensitizer into a TiO_2 nanoparticle switches the particle from an insulating to a conducting state.

On dye development the attention has been on molecular engineering to improve stability particularly at higher temperatures. There has also been attention to the substitution of hydrophobic chains on the dye molecule, so that traces of water in the ionic liquid electrolytes are not deleterious for cell performance. The optical absorption spectrum and molecular structure of the first of the "K-series" dyes is shown in fig. 8. 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 (4).



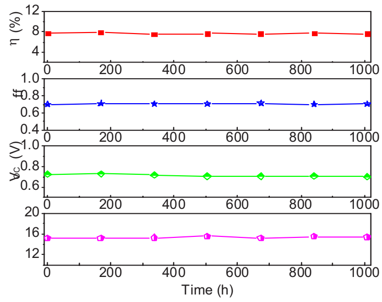


Fig.8: Molecular structure and optical properties of the dye K8.

Fig.9: cell stability over 1000hr, AM1.5, after thermal aging at 80 °C

Electrolyte performance has also been enhanced in the course of the year past (5). The particular objective is the stability of cells over a long lifetime 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 an impressive 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 thinlayer 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.9). 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 (6).

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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Annual Report 2005

Voltage Enhancement of Dye Solar Cells at Elevated Operating Temperatures

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Project- / Contract Number	7019.1
Duration of the Project (from – to)	24 months: 2004 - 2006

ABSTRACT

The present action with the industrial partner, Greatcell Solar SA (GSA) follows on the 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 present action aimed during the year at increased stability, particularly at elevated operating temperatures, with enhanced efficiency. 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 2005 particular attention was given to molecular engineering of suitable dyes which by their physicochemical effects enhance stability at a higher output voltage. Attention was also given to 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.

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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. 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. Molecular engineering of dyes for performance enhancement has continued. Lifetime tests at elevated temperatures are ongoing.

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, Barcelona, 2005 (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. The present project, recognising this, aims at the niche market of indoor comsumer low-power devices, by the development.

Ongoing Work and Results 2005

The goals of this project are the 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.

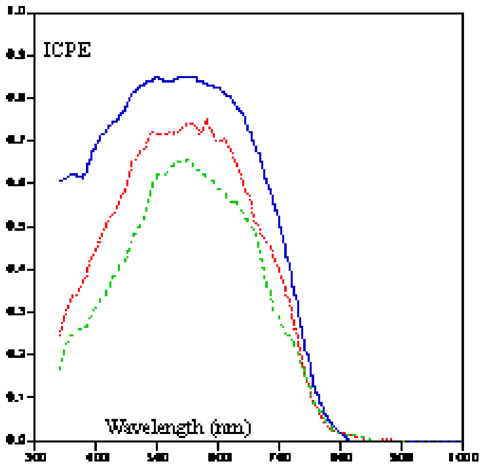

Fig. 1: spectral response, given as incident photon conversion efficiency against wavelength, of a dye-sensitised cell (——)in comparison with a new (·········) or used (----- 6 hrs., 800 W/m^2) amorphous silicon cell.

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

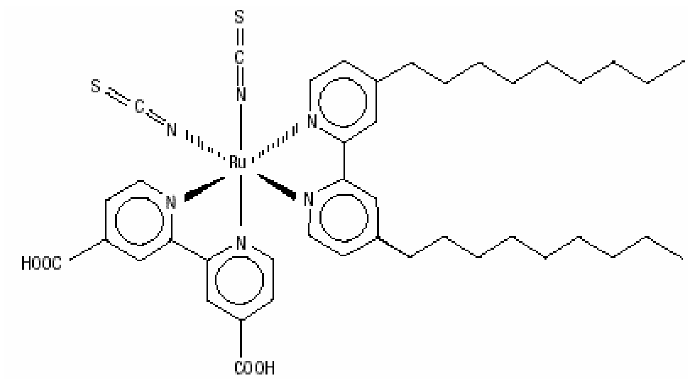

Fig. 2: structure of dye Z907 (3)

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.

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. In Fig. 3 the absorption spectrum of the prototype of this series, referenced as K8, is shown with that of the original chemisorptive dye N3 as a comparison. The extension of the absorption spectrum towards the red is evident, as is the higher molar extinction coefficient and the good match to the visible spectrum. Further development led to the dye K19 (5) with structure as in Fig. 4, and further molecules in the K-series are under test and evaluation.

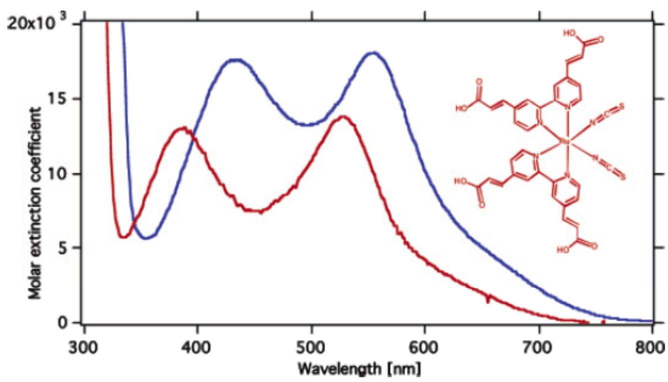

Fig.3: Structure of K8 (inset) and comparison of VIS-UV absorption spectrum with that of the prototype dye N3.

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 up-scaled to meet the needs of the company.

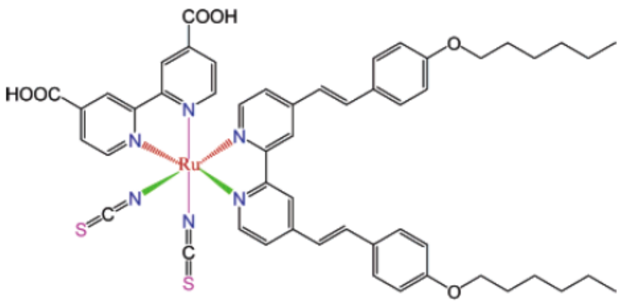

Fig.4: molecular structure of the K-19 sensitiser.

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, and is the subject of a separate report. 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/KZI (Commission for Technology and Innovation).

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Annual Report 2005

MOLYCELL - Molecular Orientation, Low bandgap and new hYbrid device concepts for the improvement of flexible organic solar CELLs

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Project- / Contract Number	SES6-CT-2003-502783
Duration of the Project (from – to)	01.01.2004 – 30.06.2006

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. There are still some crucial obstacles to overcome before a large-scale production of plastic-based solar cells can be considered. However this remains the clear aim of the industrial partners in the MOLYCELL consortium. The feasibility of this approach will be proven with a new generation of organic PV having better efficiency (≥ 5% on $1cm^2$ glass substrate and ≥ 4% on $1cm^2$ flexible substrate), longer lifetime and a production cost far below those of competing technologies based on silicon. To reach this goal, the following issues are 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 still inadequate charge transport properties.
2. Development of two device concepts to improve efficiencies: all-organic solar cells and nanocrystal/organic hybrid solar cells.

All-organic solar cells

Devices will be based on donor-acceptor bulk heterojunctions self-assembled by blending of two organic materials serving respectively as electron donor and as electron acceptor under the form of an homogeneous blend and sandwiching the resulting structure between two electrodes. One of these electrodes is transparent and the other is usually an opaque metal electrode. Two concepts will be developed to improve efficiencies: a) an innovative junction concept based on the orientation of polar molecules and b) a multi-junction bulk donor-acceptor heterojunction concept.

Nanocrystal/organic hybrid solar cells

Devices may also be based upon solid-state heterojunctions between nanocrystalline metal oxides and molecular/polymeric hole conductors. Two strategies will be addressed for light absorption: the sensitisation of the heterojunction with molecular dyes, and the use of polymeric hole conductors with the additional functionality of visible light absorption.

In order to achieve these targets, the consortium brings 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 will be also available if necessary within the consortium.

The achievement of these objectives will establish the potential of this technology to achieve a paradigm shift in PV production costs, to below 1 € / Wp.

Technical Summary

LPI contributes to four work packages within the overall consortium for the MOLYCELL project. The specific contribution of the EPFL laboratory is in the area of dye-sensitised heterojunctions to mesoporous semiconductor substrates, in particular to titania. This structure is an evolution of the dye-sensitised photovoltaic devices reported on elsewhere. 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. 1. The structure of the solid-state dye-sensitised heterojunction cell appears as Fig. 2. Preparation procedures for the mesoporous titania substrates, supported on glass with an intermediate transparent contacting layer of doped tin oxide, are already well established within the Lausanne laboratory from experience in the development of the analogous electrochemical device, the "Grätzel cell".

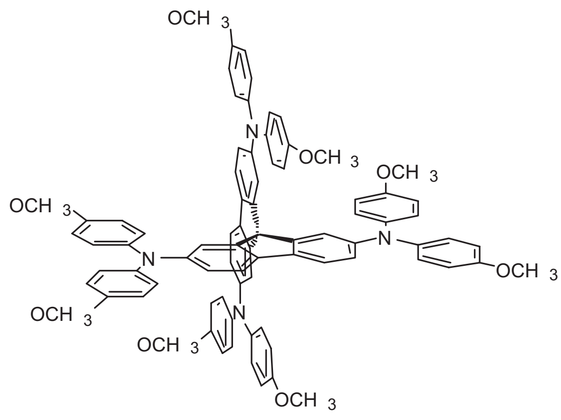


Figure 1: structure of spirobifluorene hole-conducting p-type organic semiconductor. The flourene structures are perpendicular, conjoined through a common carbon site.

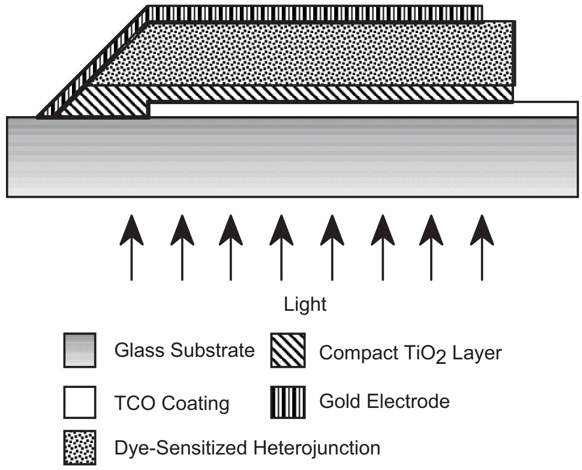


Figure 2: Schematic of the dye sensitized heterojunction PV cell.

Ongoing Work and Results 2005

A structure of work packages (WP) has been agreed for the cooperation in effort and management of the consortium, providing for the optimisation of employment of competences and facilities, and has been implemented during the past year, as in Fig. 3. In MOLYCELL project, EPFL is involved in WP2, WP3, and WP5. EPFL is also sharing information with ECN on cell stability issues coming under WP6. EPFL is the activity leader for WP5.

From EPFL, the following actions are in hand:

1.1 Fabrication of mesoporous, nanocrystalline metal oxide films on TCO coated plastic substrates following methodologies established for redox electrolyte based dye sensitised solar cells. These films will comprise benchmark films for this work package.

1.2 Optimisation of film fabrication for solid state nanocrystalline / organic solar cells, including the fabrication of homogeneous, sub-micron films suitable for use with light absorbing organic hole conductors. Materials and electrical characterisation of such films.

1.3 Development of a low temperature fabrication methodology for dense TiO_2 blocking layers (hole blocking layer) deposited as an underlayer to mesoporous films fabricated in tasks 1.1 and 1.2. Evaluation of the hole blocking function of such underlayers.

1.4 Development of alternative methodologies for the fabrication of mesoporous, nanocrystalline metal oxide films on TCO coated plastic substrates, including alternative metal oxides and template fabrication of orientated metal oxide nanostructures. Materials and electrical characterisation of such films.

Activities under WP2

Under WP2, EPFL was looking for reliable and reproducible TiO_2 film fabrication methods, suitably adapted to making hybrid flexible solar cells. The hitherto available low temperature procedures to make nanocrystalline TiO_2 films on flexible substrates proved to affect the solar cell efficiency considerably. EPFL is currently discussing with Konarka, USA, about the possibility of obtaining for trials some of their TiO_2 pastes, which could be processed at low temperatures. Some samples are expected in 2006.

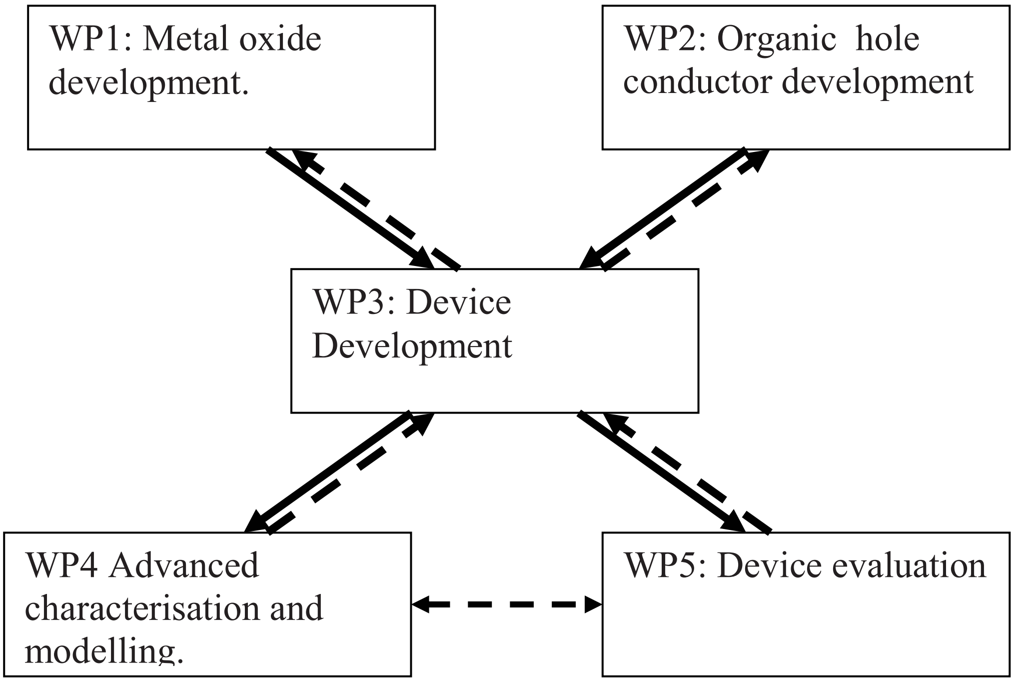


Figure 3: workpackage structure for project coordination and management.

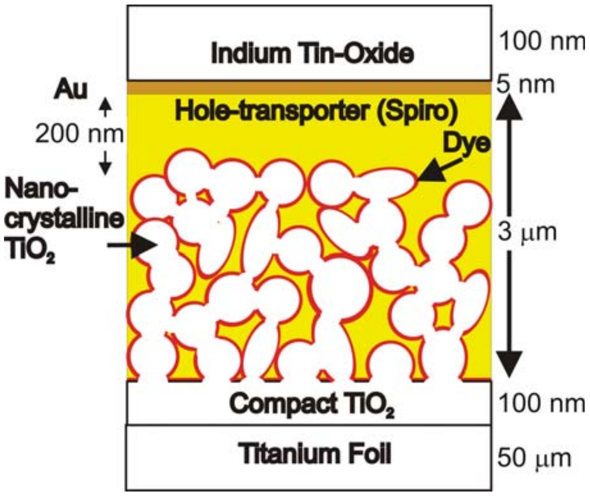


Figure 4: a) The scheme of a solid-state dye-sensitized solar cell fabricated on a titanium foil substrate.

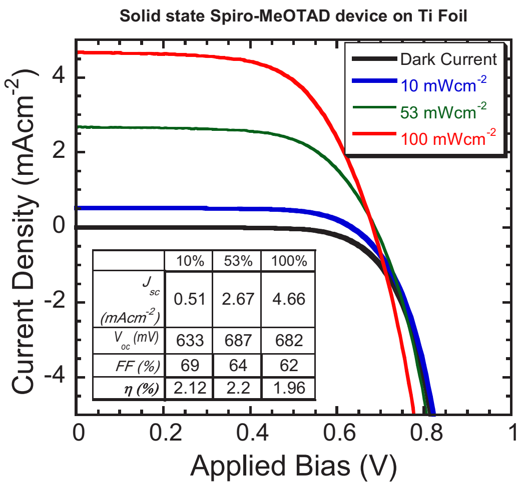


Figure 4: b) The current voltage characteristics under simulated AM 1.5 solar conditions for a device fabricated as per the scheme shown in (a).

Meanwhile, EPFL made an effort to make flexible dye sensitized solar cells containing hole-conductors on titanium metal foil. Such an inverted device structure can be denoted as: Ti-foil/nc-TiO_2/dye/OMeTAD/Au (5 nm)/ITO (sputtered). The advantage of this approach is that nc-TiO_2 can be sintered at high temperatures. The disadvantage is that illumination of light takes place from the hole conductor side, causing a decrease in light harvesting.

Very recently fabrication of these flexible solid-state dye-sensitized solar cells on titanium foil was started. A metal-oxide sputtering route is followed. The experimental conditions and other important sputtering system parameters are yet to be optimized. The main focus will be to develop an effective method for making transparent top contacts and to optimize the device geometry for an "inverted" structure. The initial results are highly promising when using a normal active layer structure with a composite gold/sputtered indium-tin-oxide semi-transparent top contact. Power conversion efficiencies in the range of approximately 2 % have been achieved and further improvements are expected. A scheme of the device structure is shown in Figure 4a and the i/V characteristics of such a cell under simulated solar conditions in Figure 4b.

Activities under WP 3

The contact barrier presented at the electron collection electrode governs the performance of the solid-state dye-sensitized solar cell. The barrier height at this anode interface is dramatically reduced under ultraviolet (UV) illumination, which is attributed to generation of surface states resulting in "pinning" of the Fermi level in the semiconductor. The barrier height is controlled by the doping level of the inorganic semiconductor, which results in significant improvements in the device performance. Figure 5 shows the current voltage characteristics of dye-sensitized solar cells fabricated with compact underlayers, which were sprayed under argon (bad contact) or oxygen (good, improved contact) carrier gas.

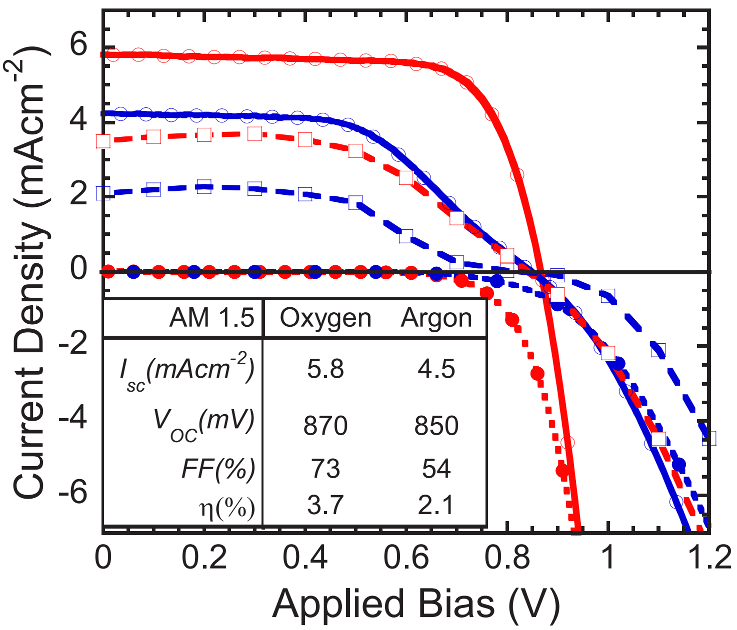
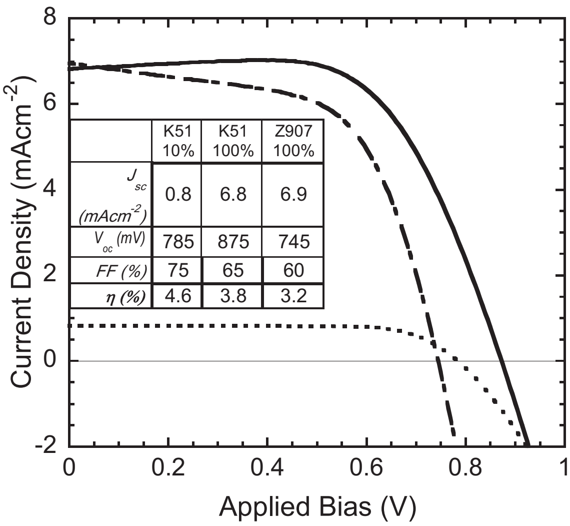


Figure 5: Current-voltage curves for solid-state dye sensitized solar cells incorporating an "oxygen-sprayed" compact layer (red curves) and an "argon-sprayed" compact layer (blue curves), in the dark (doted lines, solid circles), under monochromatic 514 nm incident illumination with an intensity of 25 $mWcm^{-2}$ (dot-dashed lines, open squares) and under simulated AM 1.5 solar conditions at 100 $mWcm^{-2}$ (solid lines, open circles).

Activities under WP 5

The solid state dye sensitized solar cell (DSC) is one of the most promising organic based device concepts demonstrating solar power conversion efficiencies in excess of 4%. The basic strategy of this “hybrid” system is such that light is absorbed in a dye, forming an excited electronic state or “exciton”. Electron-transfer takes place from the excited dye molecule to an inorganic semiconductor where it is transported to and collected at an electrode. Subsequent hole-transfer from the oxidized dye to a hole transporting organic molecule or polymer takes place, where the hole is transported to and collected at the counter-electrode. The fundamental advantage of this system over two component systems is that the electron and hole transporting components are spatially separated by the dye molecules, thereby inhibiting carrier recombination and allowing efficient charge collection through micron-sized material. Furthermore, the efficiency of such devices significantly improves with various additives in the hole transporting material, the most efficient devices incorporating specific quantities of ionic salts and electrochemical dopants. This “cocktail” of additives has been fine tuned and optimized for the current system. However, the precise function of each component is not of yet fully understood. Here, a new charge transfer sensitizer is reported, endowed with an ion complexing moiety formed by oxyethelyne side groups. Lithium coordination to the backbone of this dye is found to induce a striking improvement of photovoltage and cell performance, with voltages of nearly 900 mV regularly achieved and efficiencies improved from 3.2 % to 3.8 % (under 100 mWcm^{-2} simulated AM 1.5 solar conditions) for the lithium coordinating sensitizer as compared with a non-coordinating analogy. An efficiency of 4.6 % is achieved under 10 mWcm^{-2} simulated AM 1.5 illumination. Figure 6 shows the i/V curves for such devices under simulated solar conditions. Our supramolecular approach to the self-assembly of functional components opens new avenues to control charge separation and recombination at the interface, and gives a more comprehensive understanding of the mechanisms occurring within this class of solar cells.



	K51 10%	K51 100%	Z907 100%
J_{sc} (mAcm^{-2})	0.8	6.8	6.9
V_{oc} (mV)	785	875	745
FF (%)	75	65	60
η (%)	4.6	3.8	3.2

Figure 6: Current voltage characteristics under simulated AM 1.5 solar conditions (100 mWcm^{-2}) for a full device containing K51 sensitizing dye (solid line) and Z907 sensitizing dye (dot-dashed line). Also shown is the K51 device illuminated by 10 mWcm^{-2} simulated sun light. The standard device performance parameters, as calculated from the *JV* data, are displayed in the inserted table.

In order to improve the system further, dyes incorporating side chains with a range of length and functionality were tested. Figure 7a shows the sensitizers investigated. Solar cells incorporating an improved spatially extended sensitizer exhibit record efficiencies of up to 4.2 % under standard simulated solar conditions (Figure 7b).

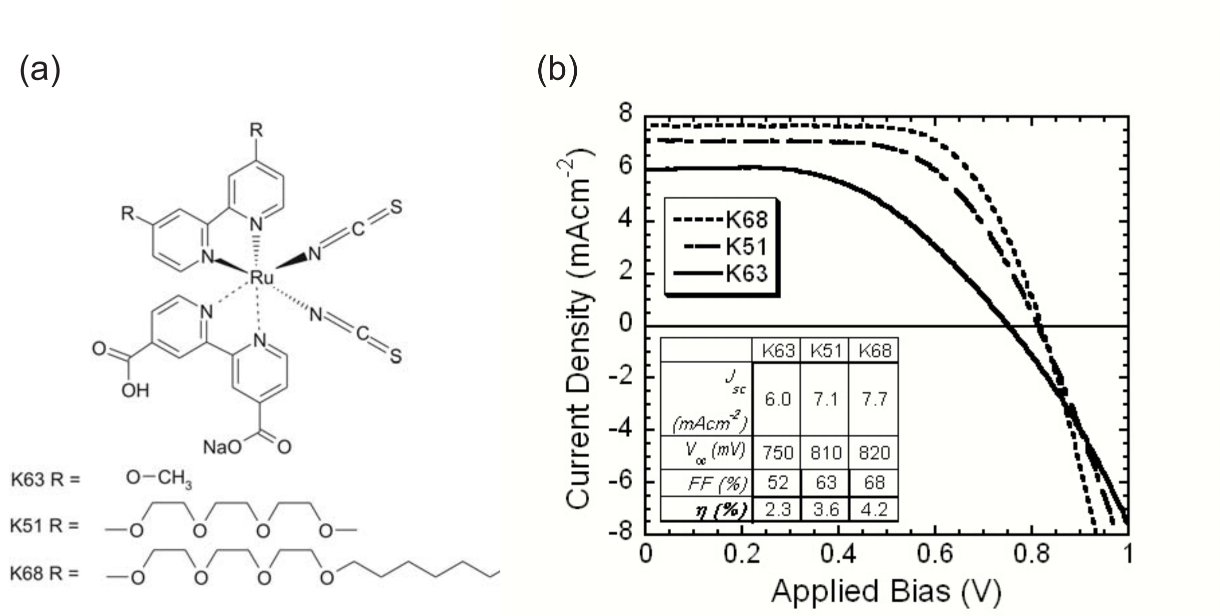


Figure 7: a) The sensitizer molecules used in this study; b) current-voltage characteristics under simulated AM 1.5 solar conditions at 100 mWcm^{-2} for solid-state dye-sensitized solar cells incorporating K63 sensitizer (solid line), K51 sensitizer (dot-dashed line) and K68 sensitizer (dotted line). The inserted table shows the device performance values.

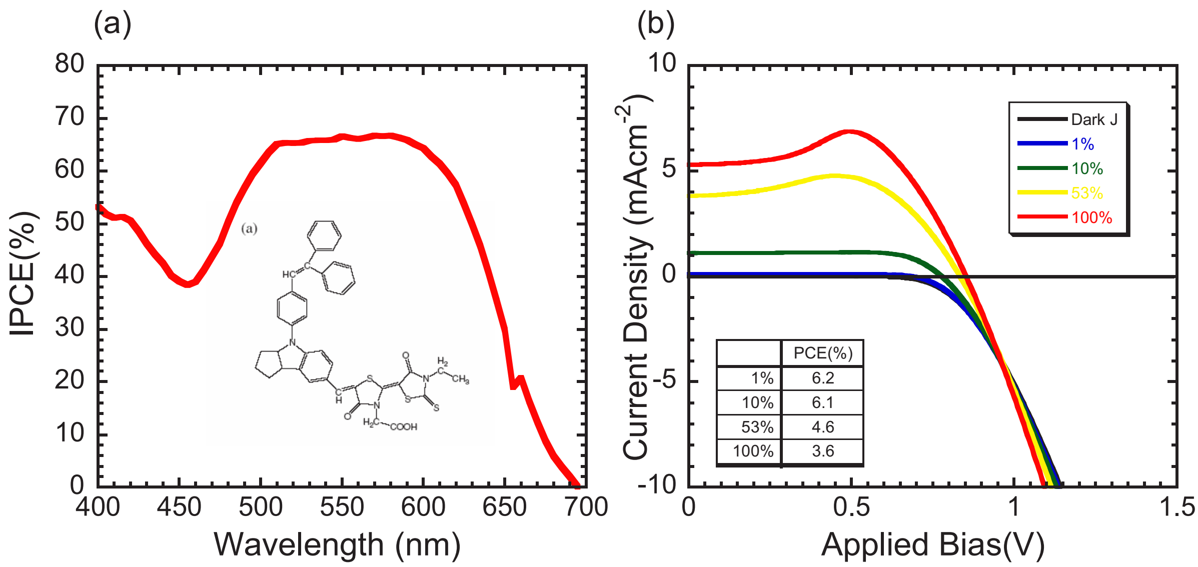


Figure 8: a) Incident photon-to-electron conversion efficiency spectrum for a solid-state dye-sensitized solar cell incorporating an indoline based organic dye: the inserted figure is the chemical structure of the dye. b) Current-voltage characteristics of a similar device to that measured in (a) under simulated solar AM 1.5 illumination over a range of illumination intensities.

Highly efficient organic indoline based dye in the solid state dye sensitized solar cell

This organic dye has a much higher optical absorption coefficient than the Ru-dyes (e.g. 55800 l mol^{-1} cm^{-1} for the organic dye at 491 nm; 13900 l mol^{-1} cm^{-1} at 541nm for N3 Ru dye). This leads to a strong absorption of the incoming light. Therefore an organic indoline based dye "D149" was used in a solid-state dye-sensitized solar cell. The incident photon-to-electron conversion efficiency (Figure 8a) is surprisingly high, reaching almost 70% over a large region of the solar spectrum. This is unprecedented for the solid-state cell. The high quantum efficiency is reflected by the large short-circuit current density at low light levels with power conversion efficiencies in excess of 6 % reached under simulated AM 1.5 solar illumination of 1 and 10 $mWcm^{-2}$. However, as the light intensity approaches "full sun" conditions (100 $mWcm^{-2}$), the short-circuit current ceases to increase linearly and efficiencies between 3.5 and 4.2 % are achieved at 100 $mWcm^{-2}$. We are currently investigating the reason for this non-linearity in photocurrent. When we resolve this issue we should be able to achieve efficiencies in excess of 6 % at full sun illumination. I-V curves are shown in figure 8 (b).

Summary

EPFL has shown considerable progress in the second year of the MOLYCELL project. Many new materials and several cell geometries have been screened for their performance in solid-state solar cells. These new materials include new TiO_2 preparations, inorganic and organic dyes, and hole-conductors. The most notable new cell geometry is the inverted flexible cell constructed on Ti foil substrates. The role of contact barriers at the electron collection electrode in a solid-sate DSC has been investigated. The role of carrier gas when spraying underlayers is also investigated and conditions for obtaining improved contacts have been identified. This again shows that the challenge to make stable dye sensitised solar cells rests more with the engineering and manufacturing issues. An ion-coordinating sensitizer has been used for preparing solid-state DSC for the first time.

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, Germany, Netherlands and Sweden is programmed in the MOLYCELL multinational specific targeted research/innovation project (STREP) of the 6th. Framework Programme of the European Union

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Photovoltaic Textile

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Project- / Contract Number	KTI Nr. 7228.1 NMPP-NM
Duration of the Project (from – to)	01.11.2004 – 31.03.2006

ABSTRACT

The goal of this project is to produce a working prototype of a photovoltaic textile based on third generation photovoltaic technology. Konarka Technologies, Inc, the parent company of Konarka Technologies AG, demonstrated a proof of concept photovoltaic fiber device in 2002, based on dye sensitized photovotaics. This project will focus on 1) improving the photovoltaic, physical and mechanical performance of such photovoltaic fiber devices, 2) combining them in the form of a woven textile, and 3) determining methods of interconnecting the fibers to achieve a useful device. The goal at the end of the project is to produce a working prototype PV textile sample with an efficiency of greater than 4%

Solar energy

Solar cells were first developed for space applications, such as telecommunications satellites and vehicles for planetary exploration. Nowadays, however, solar power may be found much closer to home. The amount of solar radiation that reaches the earth's surface, an average of approximately 5 kilowatt-hours per square meter per day, is close to 20 000 times greater than our total annual energy consumption. Typical solar panels can already convert this to 700 watt-hours of electricity. The challenge is now to make exploitation of this almost unlimited energy source sufficiently cheap and convenient for it to replace traditional power generation based on fossil fuels.

The rapid growth of the solar power industry over the last 10 years has been driven by a combination of consumer education and environmental and economic concerns. Solar power is still relatively expensive, current technical innovations are reducing its cost by around 5% every year, and a total decrease of 35% is forecast between 2004 and 2010. The field of applications of technologies for which solar power is a viable proposition therefore continues to expand rapidly. Domestic applications first focused on isolated dwellings or installations for which traditional energy sources were impractical or un-economic, but solar power has since come to supplement or replace these even in urban environments, and is also widely used in water pumping and treatment systems, communications, and agriculture. At present, most solar power generation comes from centralized installations, such as Mont-Soleil in Switzerland, that provide electricity for collective housing or residential areas. Elsewhere in Switzerland, the city of Lausanne has greatly encouraged development in this area, with many construction projects incorporating photovoltaic (PV) systems. The EPFL is widely involved in these projects thanks to the experience and research potential of its institutes, including LESO, LPI and the LTC.

The LTC is specifically involved in the study of new ways of implementing PV technologies through the use of novel materials. The targeted field of application is consumer goods, which is expected to develop substantially over the next few years. The development of portable devices (telephones, computers, navigational instruments, security devices, etc.) and the increasing importance of our leisure culture (tents, sportswear, sports equipment etc.) will require technologies that are increasingly autonomous and economic in terms of energy consumption, providing a clear opportunity for PV-based technologies. Currently the most popular of these are derived from monocrystalline and multicrystalline silicon semicronductors (85 % of the market), and amorphous silicon thin films (more than 10 % of the market). However, there is increasing interest in the use of electrochemical PV devices and dye-sensitised cells (DSC), which make use of the concept of artificial photosynthesis, developed by Professor M. Graetzel of the EPFL.

Among the main issues that need to be addressed in developing PV technology are the cost, weight and fragility of large solar panels. Konarka has been involved in the commercial production of flexible PV devices (Figure 1) that consist of thin films on polymer substrates, with significant advantages over conventional technology in terms of cost and weight, and that are suitable for an expanded range of applications. Moreover Konarka approach is compatible with cost effective production techniques such as roll to roll coating and lamination. The DSC technology employed by Konarka may also be adapted to other geometries, including fibres, opening up exciting new possibilities for the production of flexible PV textile materials.

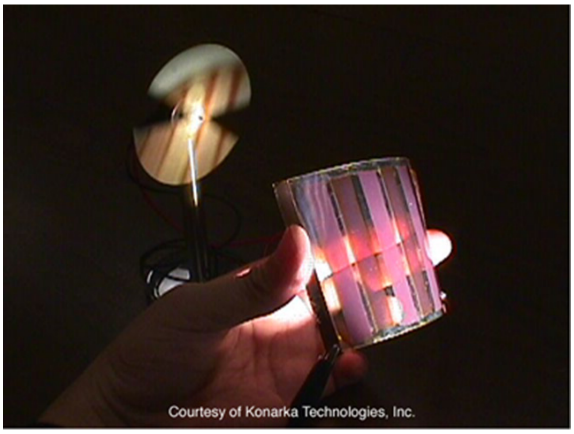


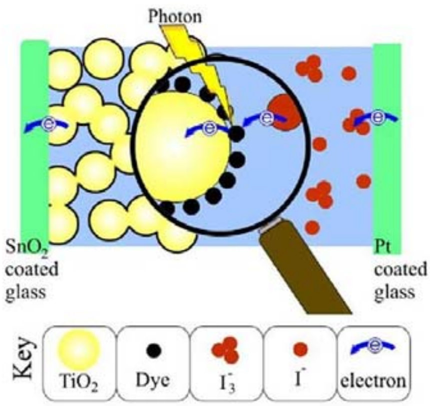
Figure 1: A flexible PV cell produced by Konarka Technology

Solar textiles - principles and advantages

Traditional solar panels take the form of flat plates that are relatively heavy (more than 10 kg/m^2) and relatively expensive (5 CHF/Wpeak). More recent technologies are aimed at obtaining light (less than 2 kg/m^2), cheap (1 CHF/Wpeak) free-form components (flexible sheets, textiles). Research effort in the LTC is focussed on PV textiles woven from fibres based on the DSC concept (Figure 3), produced in Lowell (MA, USA) by Konarka.

DSC fibres

A DSC fibre cell is composed of two electrodes, a counter-electrode and a working electrode. This latter is a titanium wire coated with thin nanoporous TiO_2 film, impregnated with a photo-sensitive dye (Figures 2 and 3). The light excites the dye molecules, which inject electrons into the valence band of the TiO_2. These are then able to enter the circuit via the conducting substrate. The dye recovers its initial state by acquiring an electron from the electrolyte (an I_3^-/I^- redox system). The electrolyte is then regenerated by the reduction at the counter-electrode.



$$\text{Dye} + \text{light} \rightarrow \text{Dye}^*$$
$$\text{Dye}^* + TiO_2 \rightarrow e^- (TiO_2) + \text{Dye}^+$$
$$e^- (TiO_2) + \text{C.E.} \rightarrow TiO_2 + e^- (\text{C.E.}) + \text{energy}$$
$$\tfrac{1}{2} I_3^- + e^- (\text{C.E.}) \rightarrow 3/2\ I^- + \text{C.E.}$$

CE = counter electrode

Figure 2: The principle of a DSC cell

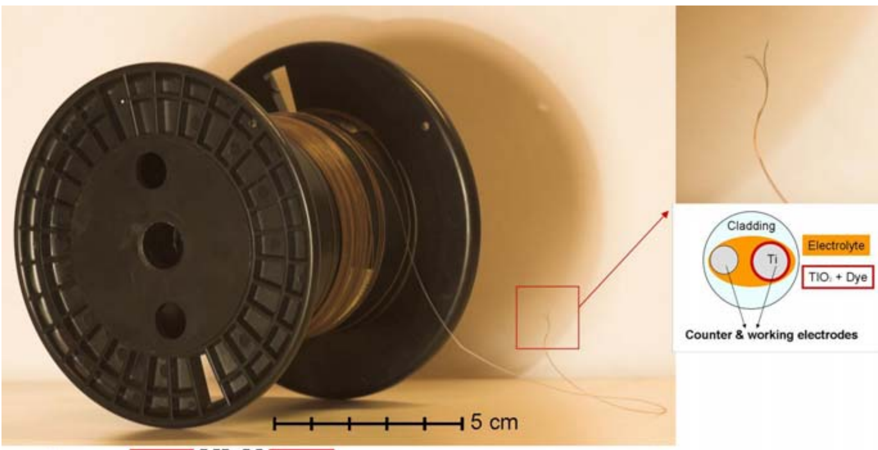


Figure 3: A DSC PV fibre produced by Konarka.

Applications and Advantages

This 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 (Figure 4), which optimizes surface exposure of the functional fibre.

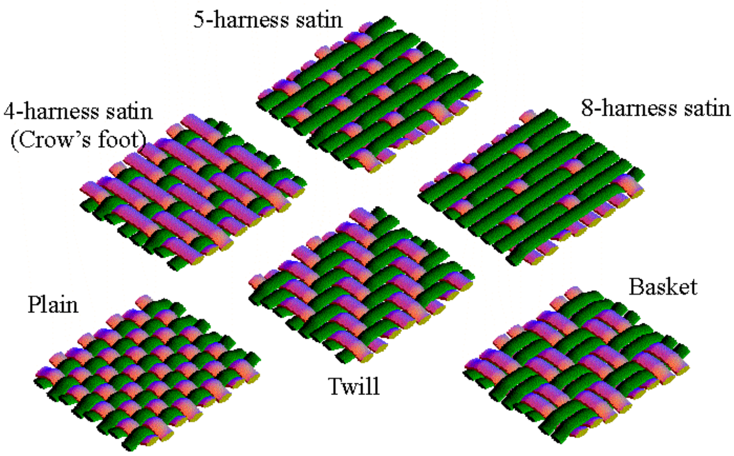


Figure 4: Different types of woven textile structure

Activities in the LTC

The overall aim of research at the Composite and Polymer Technology Laboratory (LTC) is to establish the scientific basis for the next generation of materials and processes in the fast-growing fields of polymer and composite technology. This involves novel approaches to tailoring material systems and process cycles, development of new materials with controlled rheology, solidification kinetics and surface characteristics, process simulation and costing, and quantitative durability analysis for optimal life cycle strategies. To this end, the activities of the ~35 senior researchers, engineers and doctoral students currently working in the LTC are organized around eight interdisciplinary core competences:

- Materials tailoring
- Surface and interface engineering
- Impregnation and consolidation
- Material and process integration
- Internal stresses and dimensional stability
- Life Cycle Engineering
- Equipment and test method development
- Implementation of new materials technologies.

Work in the area of solar cells involves correlating the mechanical properties and structural integrity of the functional coating of the working electrodes of DSC fibres with their PV performance, and the development and characterization of prototype PV textiles, using manufacturing techniques compatible with a high degree of PV efficiency in the final part. This work builds on the LTC's extensive experience in the development and analysis of nanosized ceramic coatings on polymer and metallic substrates, which has had a major impact on the laboratory's profile and reputation in the scientific community. The LTC disposes of a comprehensive range of state-of-the-art characterization and processing equipment, including specialized installations for the testing of nanometric multilayered structures.

Summary of results

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. The PV efficiency of a lab-scale fiber is averaging 5.5%. Two different textile prototypes, namely encapsulated non-woven with reflective backside, and satin, were produced.

Acknowledgements

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Annual Report 2005

Photoelektrochemische und Photovoltaische Umwandlung und Speicherung von Sonnenenergie

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Project- / Contract Number	76645 / 36846
Duration of the Project (from – to)	January 2003 – December 2005

ABSTRACT

Thin silver chloride layers evolve oxygen under UV/Vis illumination in aqueous solution under appropriate conditions. AgCl deposited on a conducting support photocatalyzes the oxidation of water to O_2 in the presence of a small excess of silver ions in solution. The light sensitivity in the visible part of the spectrum is due to self-sensitization caused by the formation of silver species during the photoreaction. Anodic polarization reoxidizes the reduced silver species. Experiments were carried out with gold colloids sedimented on AgCl layers. We observed that small traces of Au colloids greatly influenced the photoelectrochemical activity. AgCl photoanodes as well as gold colloid modified AgCl photoanodes were combined with an amorphous silicon solar cell in a setup for photoelectrochemical water splitting. Illumination of the AgCl photoanode and the amorphous Si solar cell led to photoelectrochemical water splitting to O_2 and H_2. For AgCl photoanodes modified with gold colloids an increased photocurrent, and consequently a higher O_2 and H_2 production were observed. To increase the active surface area of the AgCl photoanode new synthesis procedures are being developed. Microporous materials as support for the AgCl layer (Zeolite A and L), as well as mesoporous materials as matrix (TiO_2 nanotubes, mesoporous WO_3, and Al_2O_3 membranes) are being used.

No experimental evidence has been published so far to prove 1-dimensional electronic excitation energy transport. One-dimensionality is sometimes understood as a transport along a line or at least along a path. Quasi 1-dimensionality in 3-dimensional space of an object with e.g. cylinder morphology means that the net transport resulting from the individual transfer steps occurs along the cylindrical axis. (1) We have found that quasi 1-dim. Förster transport occurs in dye-loaded zeolite L crystals. (2) An important step towards adding further functionality to dye-zeolite systems and to achieve a higher level of organization is the controlled assembly of zeolite crystals into oriented structures. For zeolite L this implies the alignment of the unidirectional channels over a large number of crystals. We have found a way to prepare oriented monolayers of zeolite L crystals on a substrate and have been able to modify them such that energy transfer from molecules inside the channels to a stopcock attached at the top of the crystals takes place. (3) We have found a general route for preparing fully transparent devices based on dye-loaded zeolite L materials. This is important for the preparation of highly efficient and stable solar cells and fluorescent solar concentrators. (4) A US patent we applied for in Nov. 2000 has been granted on Aug. 23, 2005.

Projektziele

Die Projektziele sind im Gesuch wie folgt formuliert:

Photoelektrochemische Wasserspaltung mit sensibilisiertem Ag/AgCl als Photoanode und einer Halbleiter Photokatode

und

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.

Kurzbeschrieb des Projekts

Photoelektrochemische Wasserspaltung

AgCl Schichten, die auf einem Glassupport elektrochemisch hergestellt werden, können in Gegenwart von Ag^+ als Photokatalysator für die Oxidation von Wasser in Sauerstoff benutzt werden. Dabei entstehen Silbercluster auf der AgCl Schicht, die durch Anlegen einer Polarisationsspannung quantitativ wieder zu Ag^+ oxidiert werden. Diese Silbercluster sind auch für die Eigensensibilisierung verantwortlich, die es dem System erlaubt auch Licht im sichtbarem Wellenlängenbereich zu absorbieren. Für die photoelektrochemische Spaltung von Wasser in H_2 und O_2 wird Silberchlorid als Photoanode mit einer Solarzelle aus amorphem Silizium kombiniert. Es wird daran gearbeitet die Effizienz der Photoanode durch Sensibilisierung und andere Herstellungsverfahren zu erhöhen.

Dünnschicht-Antennen-Solarzelle

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.

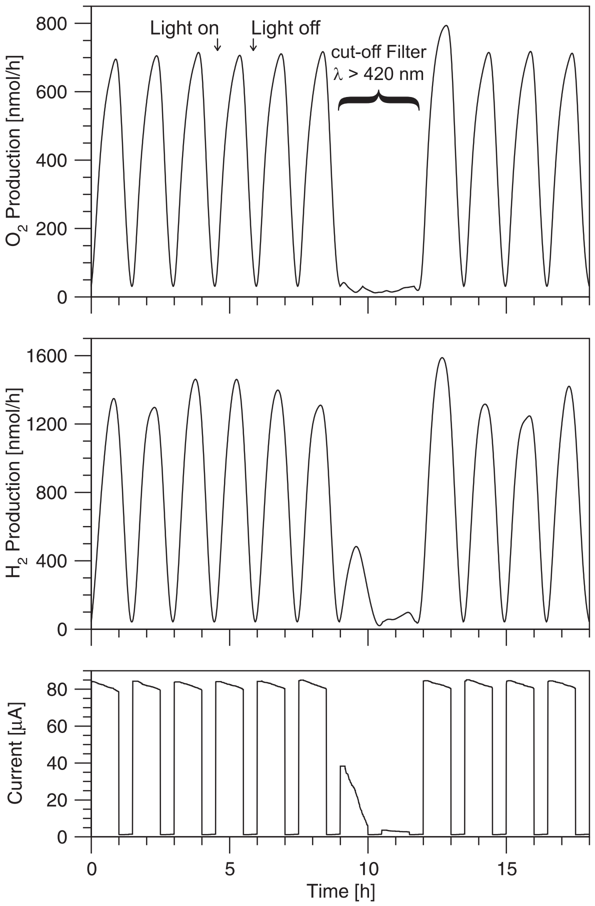
Durchgeführte Arbeiten und erreichte Ergebnisse

Photoelektrochemische Wasserspaltung

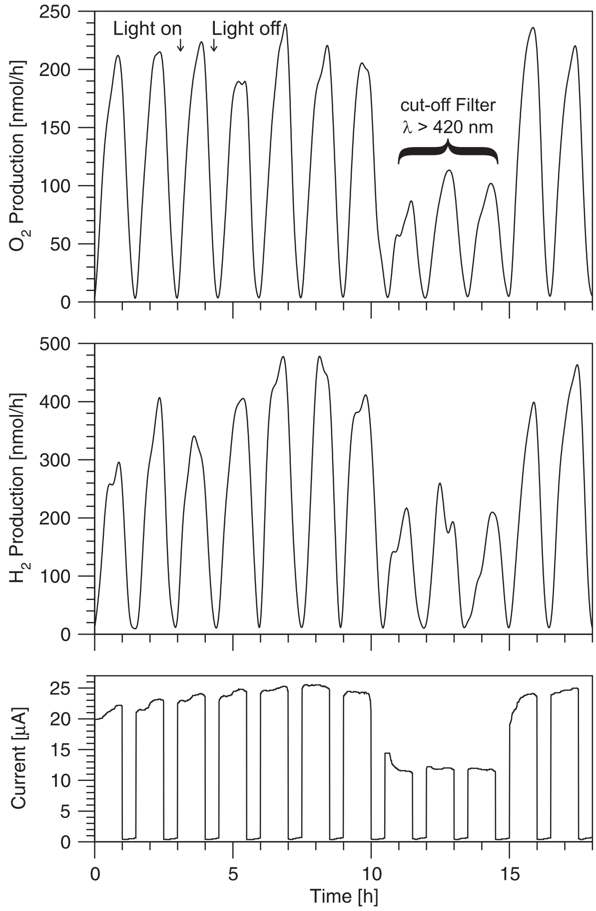
AgCl Schichten, die auf einem Glassupport elektrochemisch hergestellt werden, können in Gegewart von Ag^+ als Photokatalysator für die Oxidation von Wasser in Sauerstoff benutzt werden. Dabei entstehen Silbercluster auf der AgCl Schicht, die durch Anlegen einer Polarisationsspannung quantitativ wieder zu Ag^+ oxidiert werden. Diese Silbercluster sind auch für die Eigensensibilisierung verantwortlich, die es dem System erlaubt Licht im sichtbarem Wellenlängenbereich zu absorbieren [1,2]. Die niedrige Absorptivität des einfallenden Lichtes an der AgCl Photoanode beeinflusst die Effizienz des Ag/AgCl Systems entscheidend. Ein Methode um das Absorptionsverhalten der Schicht zu beinflussen ist die Zugabe von Verbindungen die im sichbaren Bereich des Sonnenspektrums absorbieren oder das Reaktionsverhalten verändern, und somit das System sensibilisieren. Mit der

Sensibilisierung der AgCl Photoanode mit Gold Nanopartikeln konnte die Effizienz des Ag/AgCl Systems markant verbessert werden [3].

Für die Spaltung von Wasser in Sauerstoff und Wasserstoff wurde eine AgCl Photoanode mit einem geeigneten Halbleiter als Photokatode kombiniert [4]. Die Versuchsanordnung besteht aus zwei getrennten Halbzellen die über eine Salzbrücke miteinander verbunden sind. Die eine Halbzelle wird für die O_2, die andere für die H_2 Produktion verwendet. Ein sehr wichtiger Beitrag zur Photoelektrolyse von Wasser ist uns bei der Verwendung von Solarzellen aus amorphem Silizium gelungen. Diese wurden mit einer Platinelektrode in der Halbzelle für die H_2 Produktion benutzt. Die photoelektrochemische Wasserspaltung mit AgCl als Photoanode konnte zum ersten Mal gezeigt werden, ohne das Ag/AgCl System durch einen externen Potentiostaten zu polarisieren. Diese Ergebisse wurden in Zusammenarbeit mit der Gruppe von Prof. R. Schropp (Universität Utrecht, NL) erzielt und sind in einer detaillierten Publikation beschrieben [5].



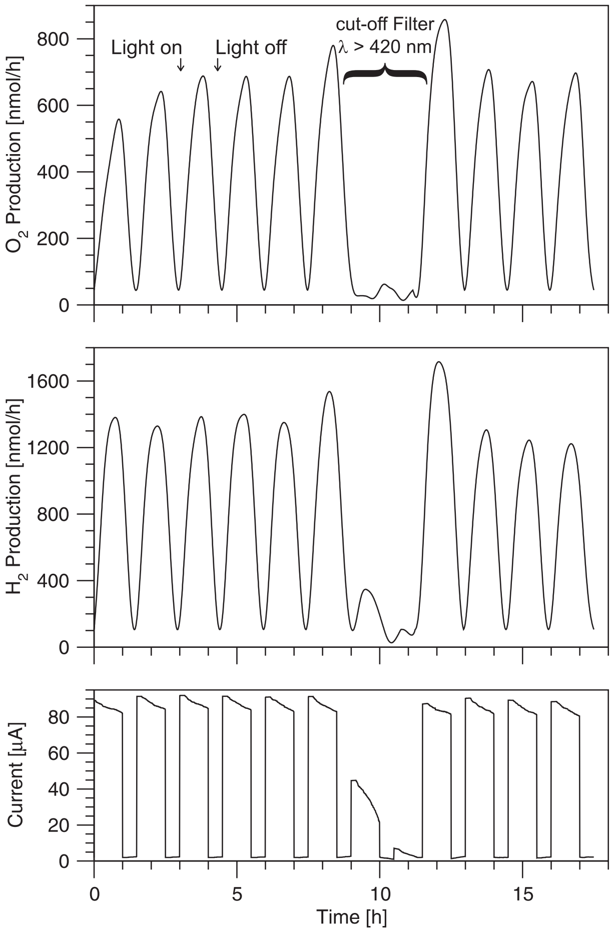
Figur 1) O_2 und H_2 Produktion zusammen mit dem Photostrom für eine Schicht aus TiO_2 Nanoröhren als Photoanode in Kombination mit einer Pt Katode und einer Solarzelle aus amorphem Silizium.



Figur 2) O_2 und H_2 Produktion zusammen mit dem Photostrom für eine mit Gold Nanopartikel sensibilisierten Ag/AgCl Photoanode in Kombination mit einer Pt Katode und einer Solarzelle aus amorphem Silizium

Durch die Erhöhung der Schichtdicke, und insbesondere durch Vergrössern der Oberfläche, kann das Absorptionsverhalten der Elektrode erheblich verbessert werden. Es werden deshalb neue Verfahren für die Herstellung von AgCl Schichten entwickelt, wie die Verwendung von Membranen oder von mikro- und mesoporösen Materialien als Matrix. Eine Strategie die wir verfolgen ist die Kombination des Ag/AgCl Systems mit bereits bekannten porösen Materialien wie z.B. Titanoxid (TiO_2)[i]

i) Q. Cai, M. Paulose, O. K. Varghese, C. A. Grimes, *J. Mater. Res.* **2005**, *20*, 230.



Figur 3) O_2 und H_2 Produktion zusammen mit dem Photostrom für eine Schicht aus TiO_2 Nanoröhren belanden mit Ag/AgCl als Photoanode in Kombination mit einer Pt Katode und einer Solarzelle aus amorphem Silizium.

Nanoröhren, mesoporöses Wolframoxid (WO_3)[ii] oder Aluminiumoxid (Al_2O_3)[iii] Membranen. Alle diese Oxide können durch Oxidation der entsprechenden Metalle unter geeigneten Bedigungen hergestellt werden.

Entscheidend für das weitere Vorgehen sind folgende Resultate [6]. TiO_2 ist als Halbleiter für die Oxidation von Wasser zu O_2 bereits bekannt. Für das Experiment in Figur 1 wurde eine Schicht aus TiO_2 Nanoröhren als Photoanode verwendet. Als Photokatode diente, wie für unsere Wasserspaltungsexperimente üblich, eine Kombination aus Pt Elektrode mit einer Solarzelle aus amorphem Silizium. Die Dauer der hellen und dunklen Perioden (beleuchtet, nicht beleuchtet) beträgt 60 bzw. 30 Minuten. TiO_2 Schichten aus Nanoröhren zeigen einen hohen Strom um 80 μA, und dementsprechend auch hohe O_2 und H_2 Signale (700 $nmol \cdot h^{-1}$ bzw. 1400 $nmol \cdot h^{-1}$). Um die photoelektrochemische Aktivität im sichtbaren Bereich des Lichtes zu untersuchen, wurde ein Kantenfilter (Schott, GG 420) vor die TiO_2 Photoanode gestellt, der nur langwelliges Licht mit $\lambda > 420$ nm passieren lässt. Alle drei Signale fallen ab, weil die TiO_2 Schicht im sichtbaren Wellenlängenbereich nicht photoaktiv ist.

Unsere AgCl Photoanode zeigt unter gleichen Reaktionsbedingungen kleinere Ströme von ca. 25 μA, und dementsprechend ein O_2 Signal um 200 $nmol \cdot h^{-1}$ und ein H_2 Signal um 400 $nmol \cdot h^{-1}$ (siehe Figur 2). Wird aber der Kantenfilter in den Strahlengang der Photoanode gestellt, zeigt die Ag/AgCl Schicht immer noch eine gute Photoaktivität. Die O_2 und H_2 Signale sowie der Strom fallen auf ca. 50 % ihres Wertes ab. Die Ag/AgCl Photoanode absorbiert wegen der Eigensensibilsierung durch Silbercluster auch Licht im sichbaren Wellenlängenbereich.

Um den Vorteil der TiO_2 Nanoröhren (höherer Strom) und denjenigen des Ag/AgCl Systems (Absorption für $\lambda > 420$ nm) zu kombinieren, wurden TiO_2 Nanoröhrenschichten mit AgCl belanden. Silber wurde entweder elektrochemisch (0.1 M $AgNO_3$, 1 mA, 3 min) oder durch aufdampfen (50 nm) auf der TiO_2 Schicht aufgebracht und anschliessend in einer KCl Lösung (0.2 M, pH $\approx$ 2) zu AgCl oxidiert. Wie das Experiment in Figur 3 zeigt, ist die Reaktivität der TiO_2 Nanoröhrenschicht beladen mit Ag/AgCl vergleichbar mit einer unbaladenen TiO_2 Schicht. Bei Verwendung des Kantenfilters fallen aber alle Signale ab. Keine O_2 und H_2 Produktion ist auf das Ag/AgCl auf der Schicht zurückzuführen. Mögliche Erklärungen könnten die zu niedrige Beladung mit AgCl und/oder ein ungünstiger Kontakt des Ag/AgCl auf der TiO_2 Schicht sein, was die Reoxidation des Ag/AgCl Systems verhindert. Verschiedene Reaktionsmechanismen für die Wasseroxidation zu O_2 zwischen dem Ag/AgCl System und TiO_2 könnten auch ein Grund für das schlechte Zusammenspiel sein.

Aufgrund dieser Beobachtungen führen wir vergleichbare Experimente mit mesoporösem WO_3 und Al_2O_3 Membranen. In Zusammenarbeit mit Prof. G. Hodes wurden Untersuchungen über die

ii) H. Tsuchiya, J. M. Macak, I. Sieber, L. Taveira, A. Ghicov, K. Sirotna, P. Schmuki, *Electrochem. Commun.* **2005**, *7*, 295.
iii) J. Choi, G. Sauer, K. Nielsch, R. B. Wehrspohn, U. Gösele, *Chem. Mater.* **2003**, *15*, 776.

chemische Ablagerung von AgCl (chemical solution deposition) durchgeführt [7]. Die Ablagerung durch chemische und elektrochemische Verfahren (electrochemical solution deposition) von AgCl in diesen mesoporösen Materialien soll im Rahmen dieser Zusammenarbeit untersucht werden.

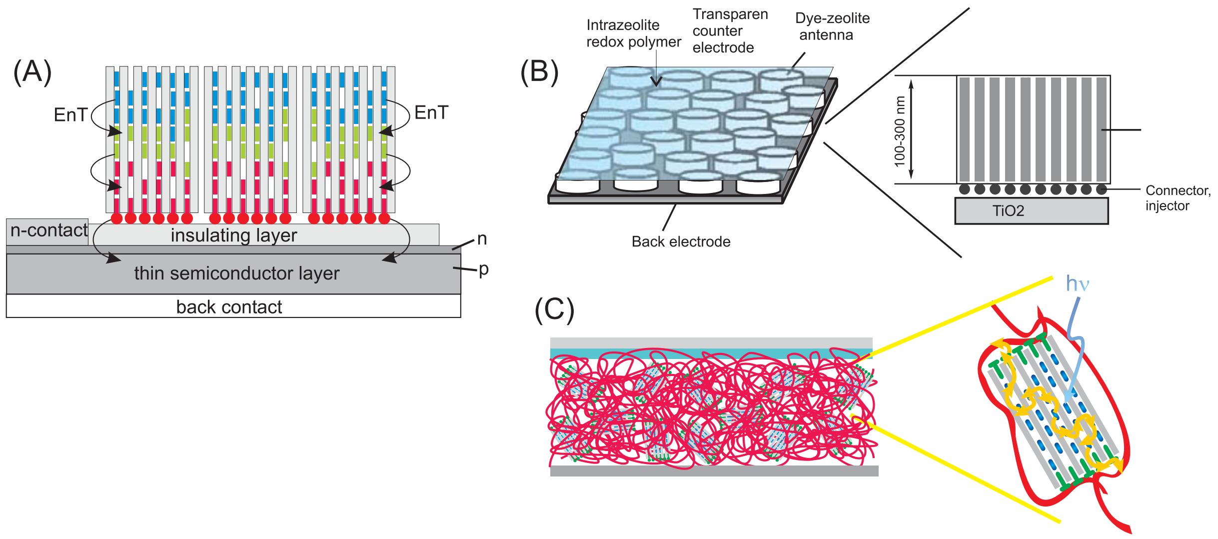
Zeolithe besitzen wegen ihres Kanalsystems eine grosse Oberfläche. Experimente mit Elektroden, die mit Ag/AgCl beladenen Zeolith A Kristallen modifiziert wurden, zeigen erfolgsversprechende Ergebnisse. Wir arbeiten zurzeit auch daran, regelmässige Zeolith A Monoschichten durch Sedimentation herzustellen. Die Leitfähigkeit der Monoschichten kann durch Beladung des Kanalsystems im Zeolithen erhöht werden. Wir werden nun analoge Versuche mit Zeolith L durchführen. Dabei werden wir scheibenformige Zeolith L Kristalle benutzen, welche von A. Zabala Ruiz im Rahmen ihrer Dissertation synthetisiert werden [16]. Als Vorteil gegenüber Zeolith A Monoschichten könnten sich die unidirektionalen Kanäle von Zeolith L, die grössere Öffnung der Knäle als auch die viel dünneren Kristall zeigen.

Dünnschicht-Antennen-Solarzelle

Unsere Antennenmaterialien zum Einfangen und strahlungslosen (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 mehrere hundert bis einige tausend Chromophore (vorwiegend Chlorophyllmoleküle) für das Einsammeln der Photonenenergie zur Verfügung. Unsere Antennenmaterialien tun dasselbe. Das Prinzip ist in Figur 4(A) illustriert. Im Blauen, Grünen und Roten absorbierende Farbstoffmoleküle transportieren die elektronische Anregungsenergie strahlungslos auf das 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 die 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 die in den Publikationen [8 – 20] beschriebenen Ergebnisse. Kürzlich konnten wir auch experimentell nachweisen, dass der strahlungslose Transport der elektronischen Anregungsenergie entlang der in Figur 4(A) eingezeichneten erwünschten Richtung erfolgt [11, 12], ein Ergebnis, das wir aufgrund einer theortischen Studie seit 1997 vermutet haben [9]. Damit die in Figur 4 dargestellten Solarzellentypen realisiert werden können, müssen drei weitere Voraussetzungen erfüllt sein. Für eine Realisierung der Solarzellentypen (A) und (B) ist es notwendig, dass ausreichend kompakte Zeolith L Monoschichten hergestellt und in nicht symmetrischer Art gefüllt werden können. Das ist uns jetzt gelungen [16]. Für die Plastik-Solarzellen sollten die mit Farbstoff beladenen Zeolith-Antennen solubilisiert werden. Auch dieses Problem konnten wir lösen. Details dazu sind in [17] beschrieben. Damit sind alle Voraussetzungen für den Einsatz unserer Antennenmaterialien für die Realisierung von Dünnschicht-Antennen-Solarzellen erfüllt. Wir sind in diesem Bereich weltweit führend, stehen seit kurzem jedoch unter zunehmendem internationalem Konkurrenzdruck.

Es wird nun der Reihe nach erklärt, wie die drei in Figur 4 beschriebenen Antennen-Solarzellen gebaut werden. Dabei wird besonderes Gewicht auf die Variante (A) gelegt, weil die bei diesen Arbeiten gewonnen Erkenntnisse weitgehend übertragbar sind.



Figur 4) Prinzip der Dünnschicht-Antennen-Solarzellen. (A) sensibilisierte Festkörper-Solarzelle, (B) sensibilisierte Farbstoff-Solarzelle und (C) sensibilisierte Plastik-Solarzelle.

A) Sensibilisierte Festkörper-Antennen-Solarzellen: Wir wissen, dass der via das Stopfenmolekül bewerkstelligte Übergang besonders wichtig ist. Eine Realisierung ist dank unseren Erfindungen [13] und [16] möglich geworden. Wichtig ist, dass wir dank einer neuen Prozedur ausreichend gute, gerichtete und stabile Monoschichten von Zeolith L Kristallen auf einem Substrat herstellen können und dass es gelingt, diese in einem nächsten Schritt so mit Farbstoffen zu beladen, dass die gewünschte supramolekulare Organisation entsteht. In Figur 5 zeigen wir die einzelnen Arbeitsschritte, die für den Aufbau unserer sensibilisierten Festkörper-Solarzelle verwendet werden und deren wichtigste Teile urheberrechtlich geschützt sind ([13], [16]). Jeder Schritt ist einzeln ausgetestet. Es gilt jetzt, die Bausteine zu einer funktionierenden Zelle zusammenzusetzen. Wir verfügen über die Möglichkeit und die notwendige Einrichtung, alle Schritte selber durchzuführen, werden aber zur Steigerung der Effizienz insbesondere beim Schritt 7.) mit Partnern zusammenarbeiten. Als Halbleiter wählen wir zur Zeit Si. Es werden weitere Versuche mit dünnen Si Photozellen, die selber nicht ausreichend viel Licht absorbieren, durchgeführt.

1.) Dieser Schritt entspricht einer Schicht von orientierten Zeolith L Kristallen. Er sieht hier trivial aus. An der genügend guten Realisierung dieses Schrittes haben wir allerdings mehrere Jahre gearbeitet und erst im Verlauf der letzten Monate eine so gute Methode gefunden, dass das Problem jetzt als gelöst betrachtet werden kann. Die Schichtdicke liegt in der Grössenordnung von 500 nm [16]. 2.) Diesen Schritt beherrschen wir seit längerer Zeit. 3.) Dieser Schritt ist Gegenstand eines erteilten US Patents [13]. Wir beherrschen ihn sehr gut. 4.) Hier handelt es sich um Standardverfahren, die keine grösseren Probleme schaffen. 5.) Hier handelt es sich um Standardverfahren, die auf dieses Objekt anzupassen sind. 6.) An diesem Schritt arbeiten wir zur Zeit. Die Halbleiterschichtdicke liegt im Bereich von 1 μm, so dass die aktive Schichtdicke nicht mehr als ca. 2 μm betragen wird. 7.) Sobald 6.) befriedigend gut gelöst ist, werden wir mit Partnern zusammenarbeiten.

B) Sensibilisierte Plastik-Solarzellen: In Gesprächen mit der Gruppe in Linz (Prof. S. Sariciftci) hat es sich herausgestellt, dass besonders der Einsatz von solubilisierten Zeolith-Nanoantennen zur Lösung von aktuellen Problemen der Plastik-Solarzelle und auch der sogenannten "Organischen Solarzellen" beitragen kann. Da es uns gelungen ist, das Solubilisierungsproblem zu lösen [17] sind wir jetzt in Zusammenarbeit mit dieser Gruppe dabei, Experimente entsprechend der Skizze in Figur 4(C) durchzuführen. Das Prinzip besteht darin, dass ca. 30 – 50 nm grosse Zeolith L Kristalle mit Farbstoffen gefüllt werden, die im gewünschten Spektralbereich Licht absorbieren. Die Enden der Kristalle werden mit geeigneten Stopfenmolekülen modifiziert. Anschliessend wird das so präparierte Material in geeigneter Weise in das photoleitende Polymer bzw. die "organische Halbleiterschicht" eingearbeitet. Dieses Material wird dann in Linz zu einer Solarzelle verarbeitet.

Figur 5) Arbeitsschritte zum Aufbau einer sensibilisierten Festkörper-Antennen-Solarzelle. Dazu gibt es einen Patentanspruch [16].

C) Sensibilisierte Farbstoff-TiO_2-Solarzellen: Es handelt sich hier um Verbesserungsmöglichkeit der insbesondere von Prof. M. Grätzel entwickelten Solarzellen. Die zu lösenden Probleme sind mit jenen zu A) und B) verwandt, hingegen ergeben sich etwas andere Aspekte bezüglich der Stabilität, die norch genauer studiert werden müssen.

D) Dünnschicht-Antennen-Tandemzellen (Festkörper Zelle): Wir haben bereits früher erklärt, dass es möglich sein sollte, mit Hilfe unseres Ansatzes eine Tandem-Solarzelle aufzubauen, bei der das "Stromanpassungsproblem" nicht auftritt [19, 20]. Da für diesen Schritt eine gute funktionierende sensibilisierte Festkörper-Antennen-Solarzelle Voraussetzung ist, haben wir diesen Ansatz noch nicht weiter verfolgt.

Nationale / internationale Zusammenarbeit

Wir pflegen regen Austausch mit verschiedenen Forschungsgruppen in der Schweiz und im Ausland. Siehe insbesondere auch das EU Projekt "Nanochannel" (barolo.ipc.uni-tuebingen.de/nanochannel/). Zu erwähnen sind auch:

Prof. Luisa De Cola	:	Faculty of Science, University of Amsterdam, Amsterdam, The Netherlands
Firma Clariant	:	Clariant Produkte AG, Muttenz, Schweiz
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Bewertung 2005 und Ausblick 2006

Photoelektrochemische Wasserspaltung

Für das Jahr 2006 wird der Schwerpunkt auf die Erhöhnung der Effizient der Ag/AgCl Photoanode gesetzt. Die Verwendung von Membranen oder von mesoporösen Materialien als Matrix bei der Herstellung von AgCl Schichten wird untersucht. Weitere Experimente mit TiO_2 Nanoröhren, als auch mit mesoporösem WO_3 und Al_2O_3 Membranen, sollen Aufschluss bringen inwiefern eine Kombination zwischen dem Ag/AgCl System und diesen Materialien möglich ist.

Mit der Sensibilisierung der AgCl Photoanode mit Gold Nanopartikeln konnte die Effizienz des Ag/AgCl Systems markant verbessert werden. Für die Sensibilisierung der Ag/AgCl Schichten können auch andere Verbindungen verwendet werden, wie z.B. Ag/Au, Au_2S und Ag_2S Nanopartikel. Es ist auch denkbar, das Ag/AgCl System durch Dotierung mit Übergangsmetallionen zu sensibilisieren.

Zeolithe besitzen wegen ihres Kanalsystems eine grosse Oberfläche. Experimente mit Elektroden, die mit Ag/AgCl beladenen Zeolith A Kristallen modifiziert wurden, zeigen erfolgsversprechende Ergebnisse. Wir werden analoge Versuche mit Zeolith L durchführen.

Sobald die Effizienzen der Ag/AgCl Photoanode durch neue Herstellungsverfahren verbessert ist, wird untersucht wie die Solarzellen aus amorphem Silizium von Prof. R. Schropp in unsere Versuchsanordnung so integriert werden können, dass direkter Elektrolytkontakt möglich ist.

Dünnschicht-Antennen-Solarzelle

Wir werden unsere Anstrengungen auf die Realisierung der in Figur 5 illustrierten Arbeitsschritte in der angegebenen Reihenfolge konzentrieren. Jeder Schritt wird einzeln charakterisiert. Ich rechne damit, dass wir bis Ende Juni 2006 beim Schritt 7.) angelangt sind. Der Zeitplan für die zweite Jahreshälfte wird dann festgelegt. Im Rahmen einer Doktorarbeit wird parallel dazu versucht in Zusammenarbeit mit der Gruppe in Linz eine sensibilisierte Plastik-Solarzelle zu realisieren. Diese Arbeiten sind soweit fortgeschritten, dass wir auch in diesem Fall bis Ende Juni 2006 eine solche Solarzelle in den Fingern haben werden. Dann wird entschieden, ob und in welcher Form in Zusammenarbeit mit Prof. Grätzel zusätzlich am System C) Sensibilisierte Farbstoff-TiO_2-Solarzellen gearbeitet werden soll. Es hat sich gezeigt, dass unser in den Schritten 1.) bis 4.) (Figur 5) aufgebautes Material grosse Chancen hat, die seit etwa 25 Jahren bestehenden Probleme der wieder hoch aktuell gewordenen Fluoreszenzkonzentratoren (die auch für diffuses Licht funktionieren) zu lösen. Wir arbeiten zur Zeit im Rahmen eines anderweitig finanzierten Projekts daran, das zu demonstrieren.

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Module und Gebäudeintegration

Annual Report 2005

Photovoltaics Modules with Antireflex Glass

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Duration of the Project (from – to)	1th August 2003 – 15.12.2006

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.

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 to reliably 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.

Ausgangslage / 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 im 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“).

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/m2 (Flash)
- Leistungsmessung bei verschiedenen Strahlungsintensitäten (Flash)
- Freiluftmessungen bei verschiedenen Einstrahlungswinkeln

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)

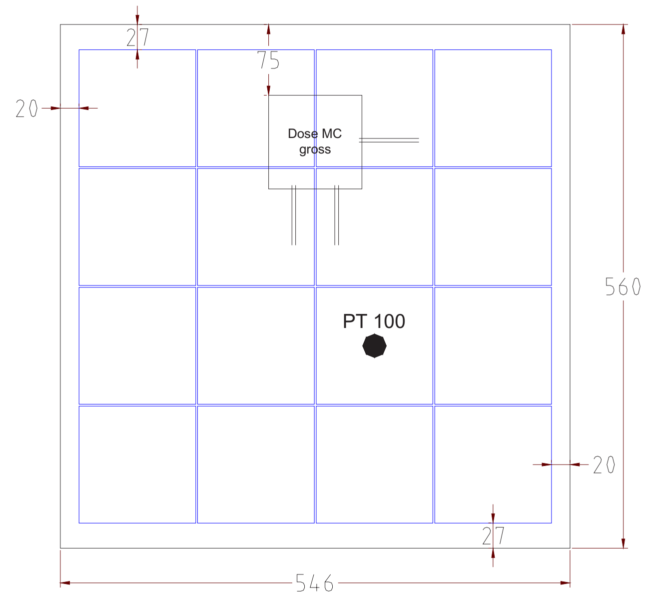


Abbildung 1: Modullayout

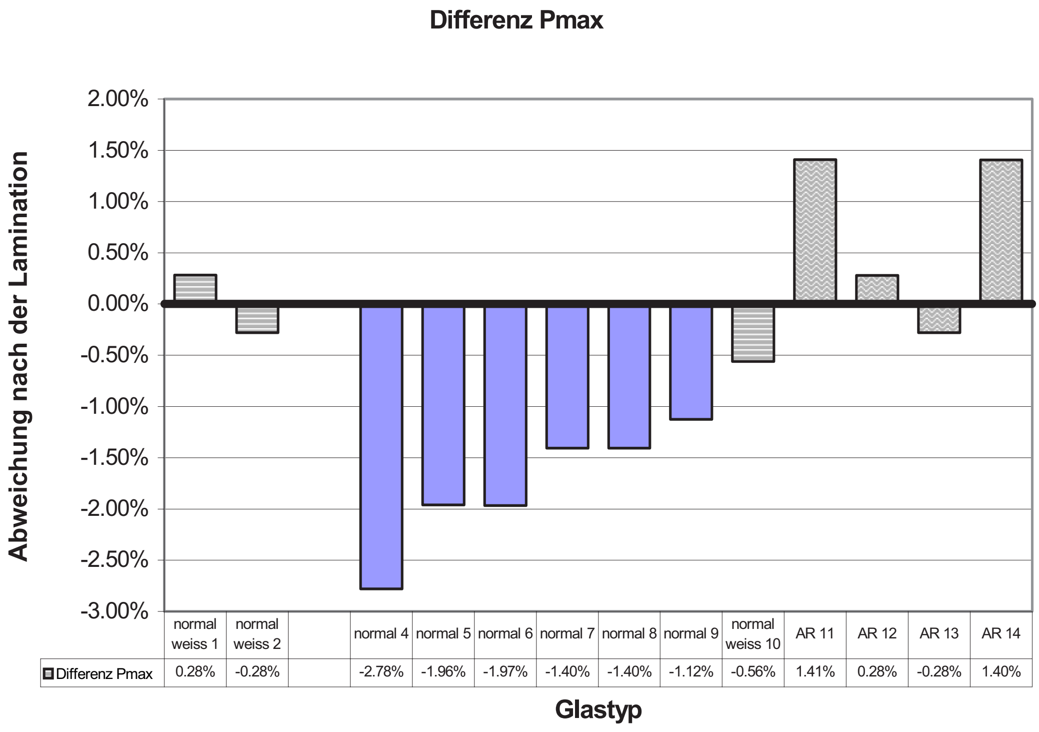
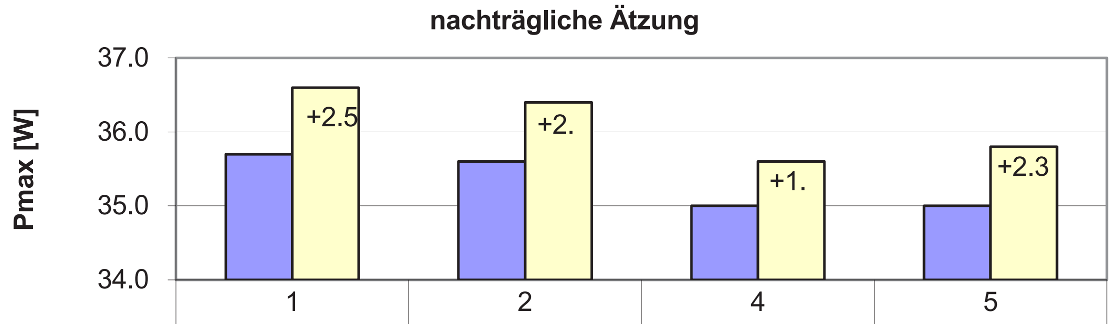


Abbildung 2: relative Differenz der Leistung zwischen dem Zellennetz und dem laminierten Testmodul

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 eine Flashmessung gemessen.



	1	2	4	5
Pmax2 [W]	35.70	35.60	35.00	35.00
Pmax2 [W]	36.60	36.40	35.60	35.80

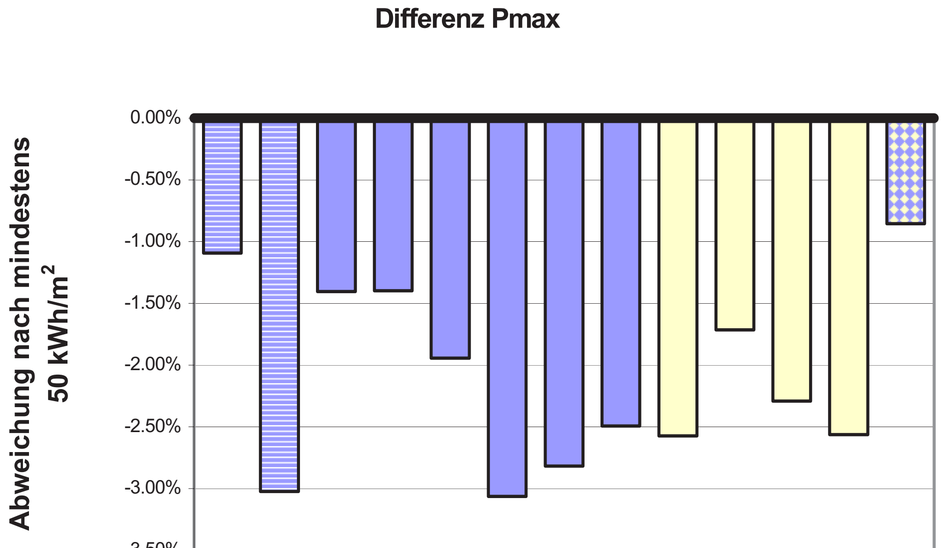
Modul Nr.

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%.

Freilandmessung

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



	AR weiss 1	AR weiss 2	AR 4	AR 5	AR 11	AR 12	AR 13	AR 14	normal 6	normal 7	normal 8	normal 9	normal weiss 10
Differenz Pmax	-1.09%	-3.02%	-1.40%	-1.40%	-1.94%	-3.06%	-2.82%	-2.49%	-2.57%	-1.71%	-2.29%	-2.56%	-0.85%

Glastyp

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.

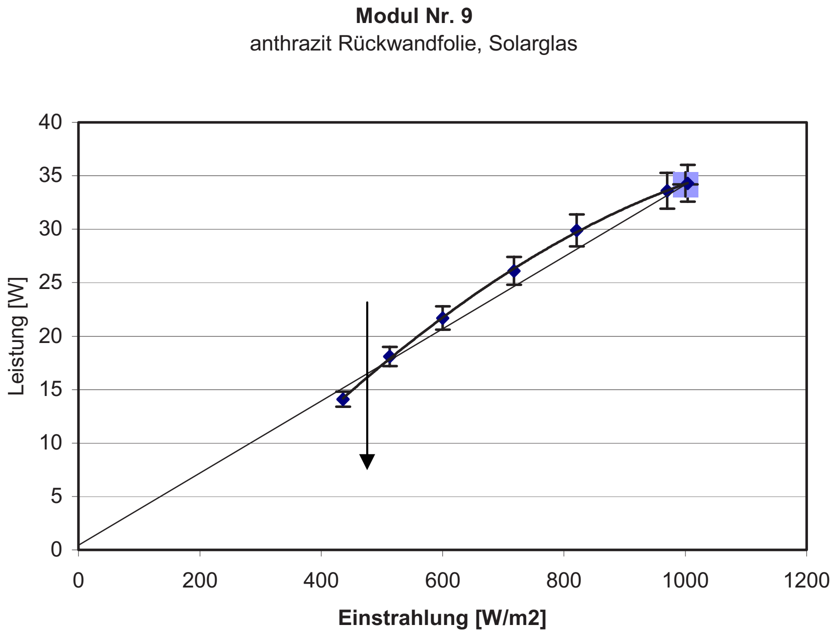


Abbildung 5: Messung der Leistung im Freiland bei verschiedenen Einstrahlungswinkeln, normales Glas

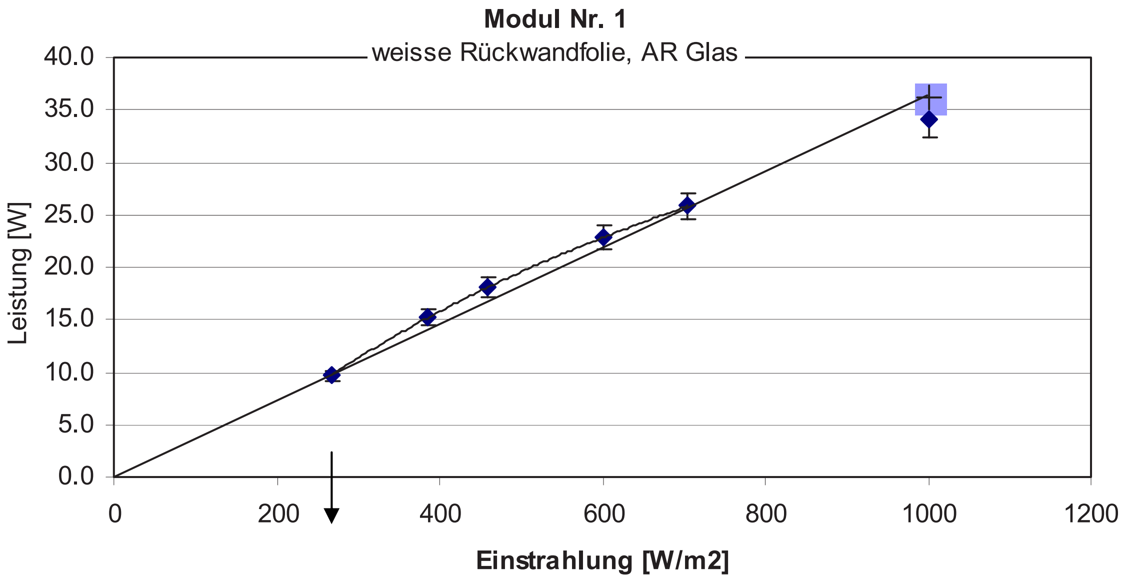


Abbildung 6: Messung der Leistung im Freiland bei verschiedenen Einstrahlungswinkeln, AR Glas

Je weniger Einstrahlung desto kleiner der Einstrahlungswinkel. Als Referenz wurden Flash Messungen mit definierter Leistung gemacht.

Als Vergleichspunkt wird derjenige Wert genommen, bei dem die interpolierte Freiluftkurve die Indoor-Gerade schneidet. Bei den Modulen mit normalen Solarglas ist dieser Wert zwischen 500 und 600 W/m^2. Bei den Modulen mit AR-Glas hingegen im Bereich von 300 bis 500 W/m^2.

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 durchgeführten Messungen nicht schlüssig quantifiziert werden.
Interessant wäre eine Verifizierung der relativen Differenz bei vordefinierten Einstrahlungswinkeln, sowie eine Studie über das Langzeitverhalten.

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. Detailliertere Untersuchungen betreffend Leistung vs. Einstrahlungswinkel könnten weitere wertvolle Aufschlüsse liefern. Altnernativ wäre eine Langzeit-Ertragsmessung interessant.

Die Leistungssteigerung spricht für den Einsatz dieser Gläser. So kann mit relativ wenig Zusatzaufwand ein ansprechender Effekt (bzw. Mehrertrag) erreicht werden.

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

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Annual Report 2005

BIPV-CIS - Improved integration of PV into existing buildings by using thin film modules for retrofit

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Duration of the Project (from – to)	1.1.2004 – 31.12.2007

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, eine definitive Antwort vom Patentamt ist noch ausstehend. Es wurden auch Materialtests durchgeführt, sowie Abklärungen betreffend Kompatibilität mit Bau- und Brandschutzvorschriften gemacht.

Bewertung 2005 und Ausblick 2006

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. Dieser Boom hat auch die 3S erfasst, zumindest im Geschäftsbereich Sondermaschinenbau für Photovoltaikmodule. Kurzfristig mussten daher Personalressourcen umdisponiert werden, weshalb für die Bearbeitung des vorliegenden Projektes während einiger Monate kein Personal zur Verfügung stand. Gegen Ende 2005 kommt das Projekt nun wieder voran, gegenüber dem Zeitplan ist allerdings eine Verspätung von einigen Monaten aufgetreten. Generell wird der Projektverlauf aber als ermutigend betrachtet.

Für 3S Swiss Solar Systems AG steht für 2006 die Herstellung einer Nullserie des neuen Dachelementes im Vordergrund. Im Vorfeld sind noch Materialtests notwendig, welche noch einige Monate in Anspruch nehmen werden. Parallel sind Verhandlungen mit potentiellen Grossabnehmern geplant.

Annual Report 2005

CONSOL
Connection Technologies for Thin-Film Solar Cells

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Project- / Contract Number	NNE5-2001-00556 / ENK6-CT-2002-00688
Duration of the Project (from – to)	01.01.2003 – 30.06.2005 (30 months)

ABSTRACT

CIGS solar modules consist of a stack of thin layers of metals and semiconductors deposited onto a glass substrate. They are connected to the external electrical circuit via two metallic tapes: on the Mo back contact and on the ZnAlO front contact of the stack. In this project, two connection technologies for attaching the tapes were investigated: i) using conductive adhesives and ii) ultrasonic welding. These techniques were applied and optimised for CIGS solar cells on conventional glass substrates as well as on flexible substrates (metal and polyimide substrates).

The most important technical goals concerning contact stability were to maintain a contact resistivity $\rho_c \leq 1000$ mΩcm^2 and a low power loss of $\leq 5\%$ (rel.) of the test modules even after exposure to a damp/heat environment (DH) with 85°C/85% humidity for 1000 hours and thermal cycling (TC: -40°C/+85°C) for 200 cycles. Moreover, the tape adhesion should be sufficiently high to prevent delamination.

The test structures were exposed to damp/heat (DH) and thermal cycling (TC) tests and the contact resistance, the 90° peel strength, and a minimum bending radius (using flexible substrates) were determined. Furthermore, 10x10 cm^2 test modules on glass substrates were also contacted by adhesive bonding and ultrasonic welding using the same contact configurations and tested in DH and TC tests.

The contact resistivity of Sn-plated Cu tapes bonded on Mo or ZnO/Mo with the best conductive adhesive remains on a low level. Tapes on ZnO/CIGS/Mo, however, show a significantly higher conductivity during DH.

A good and reliable bond for the ultrasonically welded contact tapes can be obtained with the contact configurations A (Mo/glass) and D (additional Al coating on the ZnO layer) using single welding points spaced 10 to 20 mm apart. Configuration A is prepared by scraping away the ZnO/CIGS layer. The welding areas must be thoroughly free of CIGS. Nevertheless, an increased fraction of glass outbreaks below the single welding points ("glass shelling") is still a problem with configuration A. Configuration D does not show any outbreaks. The 90° peel strength of tapes welded to Mo is significantly higher than for adhered tapes. Welded connections on Mo/glass showed a significant increase of the contact resistance after DH, caused by severe corrosion of the scraped Mo layer around the welding points. For a practical application, these areas must be protected by lamination and encapsulation. The increase of the contact resistance is much smaller during the TC test.

Executive summary

Objectives

CIGS solar modules consist of a stack of thin layers of metals and semiconductors (only a few µm thick in total) deposited onto a glass substrate. They are connected to the external electrical circuit via two metallic tapes: on the Mo back contact and on the ZnAlO front contact of the stack. In this project, two connection technologies for attaching the tapes were investigated: i) using conductive adhesives and ii) ultrasonic welding. These techniques were applied and optimised for CIGS solar cells on conventional glass substrates as well as on flexible substrates (metal and polyimide substrates).

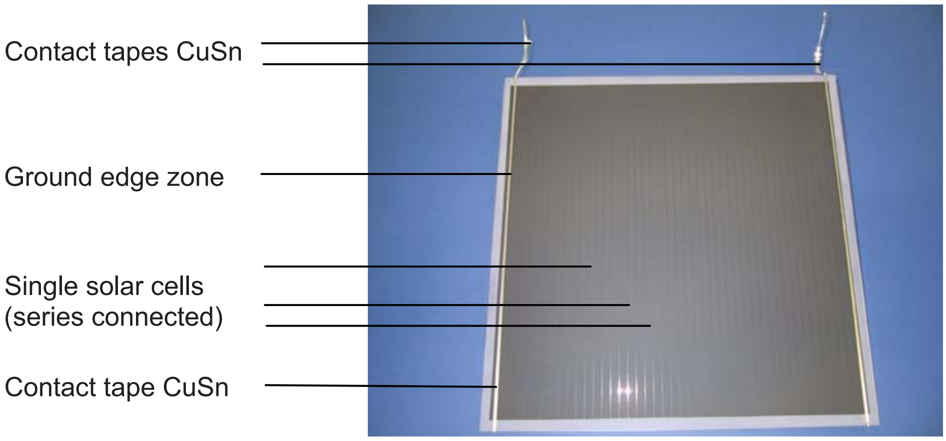

Fig. 1 CIGS solar module 30 x 30 cm^2

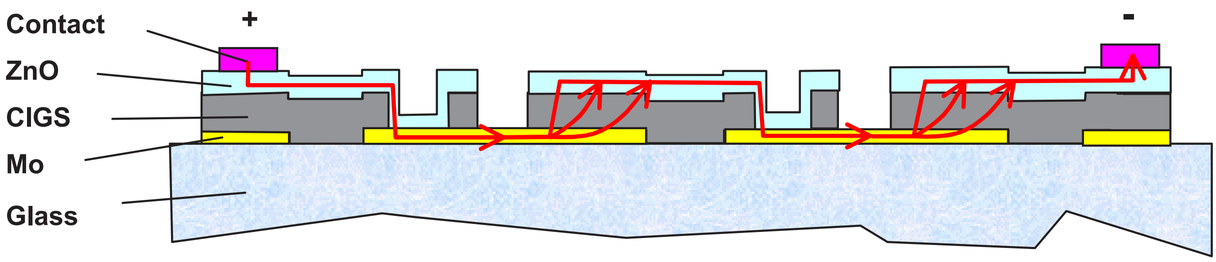

Fig. 2 Adhesive bonding

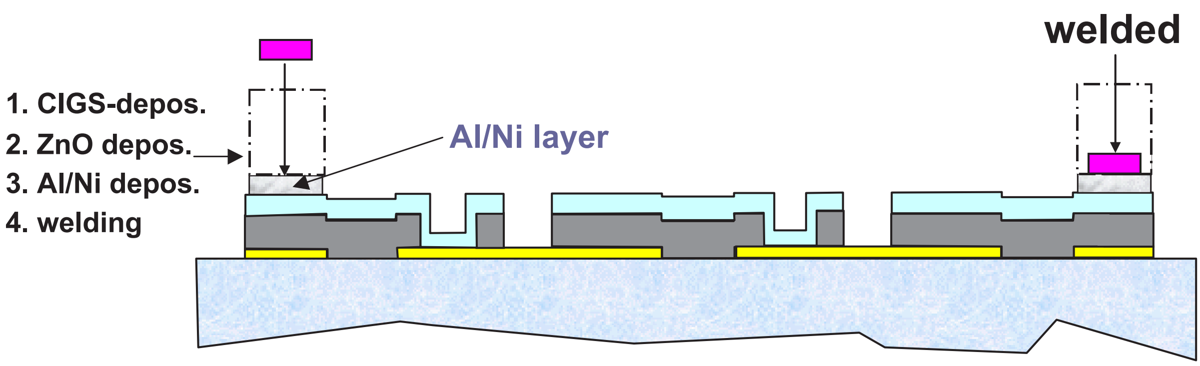

Fig. 3 Ultrasonic welding

Work performed and achievements

The activities pursued the following general goals:

i) to improve the stability and corrosion resistance (especially contact resistance and adhesion) of the bonded tapes

ii) to optimise material components and process parameters

iii) to develop concepts for the automation of the connection process

The most important technical goals concerning contact stability were to maintain a contact resistivity $\rho_c \leq 1000\ m\Omega cm^2$ and a low power loss of ≤ 5% (rel.) of the test modules even after exposure to a damp/heat environment (DH) with 85°C/85% humidity for 1000 hours and thermal cycling (TC: -40°C/+85°C) for 200 cycles, which generally results in increased contact resistance. Moreover, the tape adhesion should be sufficiently high to prevent delamination during the climate tests.

Most adhesive formulas investigated in this project were 1 K adhesives with epoxy-based resins and curing temperatures of about 150 °C. The silver content was between 70-75 wt%. A variety of such adhesives as well as some newly optimised formulations were applied for bonding Sn-plated Cu tapes to Mo (“configuration A”), ZnO/Mo (“configuration B”) and ZnO/CIGS/Mo (“configuration S”= standard) test layers deposited on glass, steel and polyimide substrates. All test samples were tested without encapsulation to get worst case conditions. In the case of ultrasonic welding (36 kHz), Al and Al-plated Cu and Ag tapes were bonded to the same test layers (excluding polyimide substrates). Ultrasonic welding on ZnO/CIGS/Mo needs an additional Al coating on the ZnO layer which we denote as “configuration D” in this project [3, 4].

These test structures were exposed to damp/heat (DH) and thermal cycling (TC) tests and the contact resistance, the 90° peel strength, and a minimum bending radius (using flexible substrates) were determined. Furthermore, 10 x 10 cm^2 test modules on glass substrates were also contacted by adhesive bonding and ultrasonic welding using the same contact configurations and tested in DH and TC tests.

The contact resistivity of Sn-plated Cu tapes bonded on Mo or ZnO/Mo with the best conductive adhesive remains on a very low level during the DH and TC test, far below the 1000 $m\Omega cm^2$ demanded by the project goals. Tapes on ZnO/CIGS/Mo, however, show a significantly higher conductivity, increasing up to values close to 1000 $m\Omega cm^2$ during 1000 h DH. This behaviour was demonstrated for test layers on all substrate types. The reason for the increase of ρ_c is the growth of a native SnO layer on the Sn-plated Cu tapes. At the same time, the sheet square resistance R_{sq} of the ZnO layer increases up to a factor of 10. Due to the increase of both ρ_c and $R_{sq,}$ the contact resistance R_c increases during DH up to values around 1000 $m\Omega cm^2$ in the case of 10 x 10 cm^2 test modules. Nevertheless the contact-related power loss remained below 5%, fulfilling another important goal in this project. TC testing does not significantly affect the resistance values.

Corrosion effects in the contact zone are decreased by chemical additives in the adhesive. The inhibitor component in conjunction with some other additives decreases the Sn oxidation considerably without completely preventing it. The peel strength is significantly decreased in the DH test but not in the TC test. No delamination of the tapes during the DH test was observed, however. Another version of this best adhesive was developed with improved dispensing properties and a higher work life of three days at room temperature (instead of one), but more bleeding. As bleeding does not affect the reliability of the connections, this version will be the preferred material.

For flexible substrates a “flexible” adhesive including a higher amount of flexible resin was developed. This adhesive shows a slightly decreased stability in damp heat and thermal shock testing compared to the best adhesives for non-flexible substrates. The technical requirements, however, are still fulfilled. The “flexible” adhesive enables a stronger bending of the substrates without delamination of the tapes.

A good and reliable bond for the ultrasonically welded contact tapes can be obtained with the contact configurations A and D using single welding points spaced 10 to 20 mm apart. Configuration A (“on Mo”) is prepared by scraping away the ZnO/CIGS layer. The welding areas must be thoroughly free of

CIGS for good adhesion. Nevertheless, an increased fraction of glass outbreaks below the single welding points ("glass shelling") is still a problem with configuration A. Configuration D does not show any outbreaks. The 90° peel strength of tapes welded to Mo (1.6-12 N) is significantly higher than for adhered tapes (0.4-0.75 N). Although the peel strength decreased after the DH test in both cases, the decrease was much more pronounced for adhered tapes. Welded connections on Mo/glass showed a significant increase of the contact resistance after 1000 h DH, caused by severe corrosion of the scraped Mo layer around the welding points. For a practical application, these areas must be protected by lamination and encapsulation. The increase of the contact resistance is much smaller during the TC test.

Fabrication concept for ultrasonic welding

On the basis of the project results a conceptual design has been drafted for the automation of an ultrasonic bonding process using configuration A. The size and welding velocity of such an equipment are designed for a 1.8 MW_p production line and described in detail in a separate report. The complete concept seems to be very promising. It comprises a concept for the tapes application head, Fig. 4a, and the welding sequence, Fig. 4b, as well as an estimation of costs.

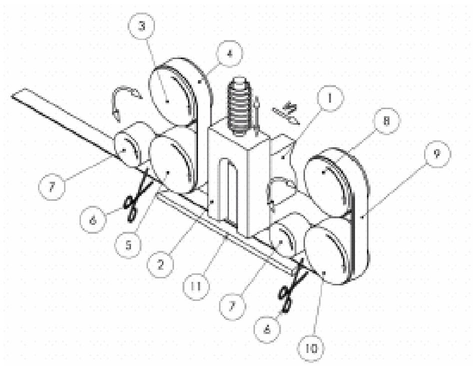

Fig. 4a Concept of welding/tapes application head

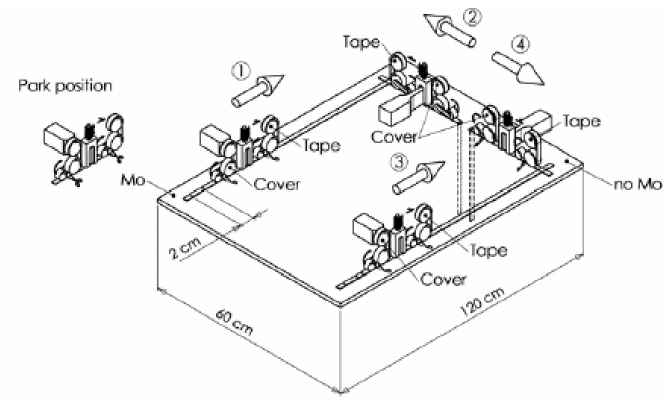

Fig. 4b Welding sequence

Assessment of results and conclusions

1. Best adhesives for connecting contact tapes to CIGS solar modules

Among a variety of adhesive materials two epoxy based types could be found fulfilling all requirements of the project goals and the practical application in a CIGS production line for connecting the contact tapes to the CIGS solar modules.

Adhesive for glass substrates

For the application on glass substrates CE 3103 WLV was the best with respect to workability (viscosity, work life) and stability in damp/heat and thermal cycling experiments. The adhesive therefor is now applied in the WS production line, where the contact tapes are attached in a semi-automatic manufacturing equipment.

The corrosion and ageing stability of this adhesive has proved, that the contact resistance of the adhered connections is sufficiently low and stable to ensure low Ohmic power losses in DH atmospheres and thermal cycling. As these tests are used to simulate possible environmental conditions contact-related power losses of < 5% in outdoor applications can be assumed even for not encapsulated modules. For encapsulated modules such power losses are still much lower.

Sophisticated corrosion analysis clarified the corrosion mechanism and the function of corrosion inhibiting ingredients. This enables further improvements of DH stability, i.e. by the application of different contact tape materials or coatings different from tin.

Adhesive for flexible substrates

To fulfill the goal of a possible minimum bending radius ≤ 5 cm without delamination of the contact tapes the „flexible“ adhesive B13409-62 proved to be the best. It enabled a still smaller bending radius of 1- 2 cm after DH and TS testing and contact resistance values remaining within the tolerance limits.

This adhesive will be a valuable tool for bonding of the next CIGS generation modules on metal and polyimide substrates. A lot of application sectors like spacecraft, aircraft, automotive industry, textile industry and architectural applications. are interested in such devices.

2. Ultrasonic welding for connecting contact tapes to CIGS solar modules

As an alternative to adhesive bonding ultrasonic welding is a very interesting technique. It incorporates the potential of a high flexibility of adaptation to different module sizes and geometrical relations and can be easily applied in an automated fabrication process.

In the project two possible contact configurations A and D have turned out to be suited for ultrasonic bonding. Both configurations, however, require an additional i) scraping or ii) vacuum deposition process. Additionally ultrasonic welding in configuration A still causes a specific percentage of welding defects (especially “glass shelling”) which is not yet solved completely.

Ultrasonic welding of the corner connection, however, would be an equivalent bonding process compared to adhesive bonding incorporating a better adhesion between the bonded tapes. This ultrasonic welding step could be integrated in the production process at first.

Glass substrates

As long as glass shelling related to configuration A can not be reduced considerably or completely be avoided, this technique will probably not be used in the fabrication process of WS, especially as the reasons seem to be related to material inhomogeneities from the production process. Some further investigations to analyse and to reduce the problem have to be continued. A practical application would be attractive after having achieved this goal.

Ultrasonic welding in configuration D is working well but probably will not be applied at the moment due to the additional vacuum deposition process.

Flexible substrates

For flexible metal substrates glass shelling is not relevant but there is a still more ambitious task to be solved: the SiO_x insulation layer of 3-4 µm must not be damaged during the welding process. Further R&D will be necessary to solve this problem.

Due to the specific properties of thin flexible polyimide substrates (25-100 µm) ultrasonic welding was not studied for such materials. Welding probably would be convenient for thicker polymer substrates (> 1mm) which are not interesting at the moment for the CIGS solar technology.

Fabrication concept

The fabrication concept for the automation of the welding procedure seems to be very attractive and straight-forward. It is a valuable basis for the integration of ultrasonic welding in the production process as soon as the problems described in detail will be solved.

Acknowledgement

We acknowledge the European Commission and the Swiss State Secretariat for Education & Research SER for the financial support of this project (EC contract No. ENK6-CT-2002-00688) as well as the particular research teams of the contributing institutions. We also acknowledge Dr. J. Wienke from the Energy Research Center of the Netherlands (ECN) for the valuable performance of specific ultrasonic welding tests and Dr. M. Winkler from the Institut für Solartechnologien (IST) in Frankfurt (Oder) for the co-ordination of the CIS cluster (SENSE, CONSOL, PROCIS, CISLINE, METAFLEX, NEBULES).

Most of the expected developments may be used by at least one project partner (WS). The industrial partners ECUM (manufacturer of adhesives), TELSONIC (manufacturer of ultrasonic welding equipment) and Würth Solar (manufacturer of solar modules) are able to exploit and commercialise the project results directly. Thus the preferred way of exploitation will be to integrate the improved process technologies and materials into the module production process.

Project partners

- ZSW, Zentrum für Sonnenenergie- und Wasserstoff-Forschung — D
- ECUM, Emerson & Cuming, ICI Begium NV — B
- IFAM, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V./ Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung — D
- TELS, Telsonic AG — CH
- WS, Würth Solar GmbH — D

Systemtechnik

Annual Report 2005

Centrale LEEE-TISO Periodo VII : 2003-2006

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Project- / Contract Number	36508 / 151135
Duration of the Project (from – to)	October 2003 - December 2006

ABSTRACT

During 2005, more than 2600 flashes were performed with the LEEE-TISO sun simulator 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).

During the last audit, the measurement of the temperature coefficients of PV modules underwent expert verification and the result has been positive. The official ISO 17025 accreditation of this measurement is foreseen for the beginning of 2006.

The “International PV module measurement intercomparison” between accredited laboratories shows that our measurement for c-Si are reliable as the differences from the mean value of all laboratories are in the uncertainty limits.

The laboratory performs spectral mismatch correction to be applied to all thin-film technologies tested during the coming test cycle as well for indoor and outdoor measurement, also thanks’ to the reinstallation of the outdoor spectroradiometer.

A new outdoor test cycle (10) on the most commonly sold PV modules on the market started at LEEE with two different procedures for crystalline silicon and thin-film technologies. Fourteen different module types have been chosen: 8 mc-Si, 2 sc-Si, 1 HIT, 2 a-Si and 1 CdTe , and initial performance measurements have been executed. Initial degradation for c-Si modules range from -1.0% to -2.7%. The maximum difference between the power of c-Si modules given by the manufacturer and the measured initial one is -2.5%, but not all the modules are within the initial minimum limits.

The inter-comparison of the indoor measured IV-curve and temperature coefficients with the STC corrected outdoor IV curves and the outdoor measured coefficients proved the validity of the new measurement facility with the sun-tracker system.

1 Introduction / Goal of the project

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

The goals for 2005 were:

- ISO17025 accreditation maintenance for I-V measurements with sun simulator.
- Accreditation procedure of performance measurements at different temperatures (thermal box).
- Performance measurements of thin film modules and spectral mismatch correction.
- Initial tests on modules of test cycle 10.
- Development, test and installation of the new MPPT electronics.
- Sun spectrum measurements.
- Optimization of a sun-tracker measurement system

2 Description of the project

The “LEEE-TISO Test Centre” is engaged in five main activities: indoor measurements with ISO 17025 accredited flash sun simulator, short, medium and long term outdoor analysis of the behaviour of PV modules under environmental conditions and photovoltaic building integration.

A class A pulsed Sun Simulator allows I-V curve standard measurement of crystalline silicon module (IEC 60904-1); the measurements are ISO 17025 accredited by the Swiss Accreditation Service (SAS). With a thermostatic chamber, it is possible to execute measurements at different temperatures. The accreditation certificate will be available in February 2006. Measurements of thin-film modules with spectral mismatch correction are also performed.

The LEEE-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 are exposed for 15 months. I-V measurements @STC are carried out every 3 months. The modules for each cycle of tests are fixed to an open-rack structure tilted at 45° and 7° south of azimuth. Each module is equipped with a Maximum Power Point Tracker adapted to its voltage and current range for greater accuracy measurements.

For fast and flexible characterisation method under real operating conditions and measurement of thin film modules, an outdoor module characterisation system with sun-tracker was developed.

3 Work carried out and results achieved

3.1 INDOOR I-V measurements (I)

During 2005 more than 2600 flashes were performed 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).

3.1.1 ISO 17025 accreditation

In November 2005 the sixth quality audit, for the ISO17025 accreditation maintenance, supervised by the Swiss Accreditation Service, was successfully passed. This audit was very important because the laboratory has to be reaccredited every 5 years. On behalf of the accreditation maintenance, a series of calibrations and measurements have to be regularly executed. During 2005 the stability of accredited measurements was very good, remaining within the ±1.0% range (mean annual variation).

3.1.2 I-V measurements at different temperatures

During the last audit the measurement of the temperature coefficients of PV modules underwent expert verification; the result has been positive.

The uncertainties of the temperature coefficients are the following:

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

The official accreditation of this measurement is foreseen for the beginning of 2006.

3.1.3 Round Robin Tests

Annual Round Robin with ESTI-JRC (I) and ECN (NL)

As requested by our accreditation procedure, comparison measurements with two reference European laboratories (ESTI-JRC and ECN) were performed.

International Intercomparison

The "International PV module measurement intercomparison" between accredited laboratories in order to verify the consistency of the measurements finished. Only accredited measurements were considered for the inter-comparison, in our case only c-Si measurements.

The measurements of our laboratory are reliable as the differences from the mean value of all laboratories are: **I_{sc}: -1.8 %; FF: 0.3 %; P_{max}: -0.6 %.**

All results will be published in a Technical Report edited by NREL, and then presented at the next 4^{th} World Conference on Photovoltaic Energy Conversion (Hawaii, USA).

3.1.4 Service measurements for third-parties

In 2005 a total of 263 I-V measurements were executed for third-parties (32 WPs), including the control measurements ordered by Canton Ticino within the subsidy program for the installation of grid-connected PV plants (2 WPs – 10 meas), and the "PV-Enlargement" project of the 5FP (5 WPs – 54 meas). The amount of third-party I-V measurements with the sun simulator is 199 meas./year.

3.1.5 Thin film measurement – spectral mismatch

In order to measure the absolute value @ STC of thin-film technologies it is necessary to calculate the spectral mismatch factor considering 4 parameters: tested specimen and reference cell spectral responses, solar simulator flash lamp and AM1.5 spectrums. The correction tool will be applied to all thin-film technologies tested during the coming test cycle. This will lead to an increased prediction accuracy at Standard Test Conditions.

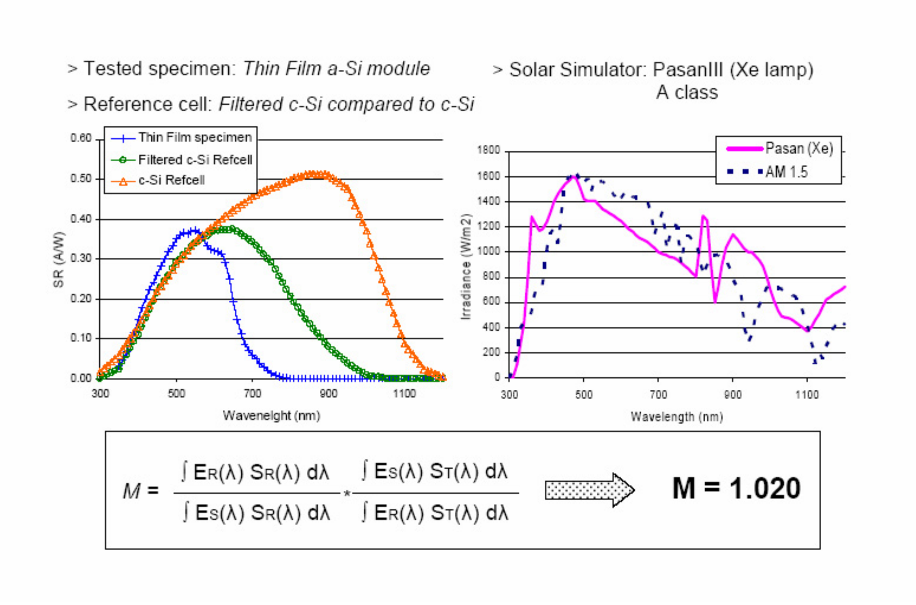
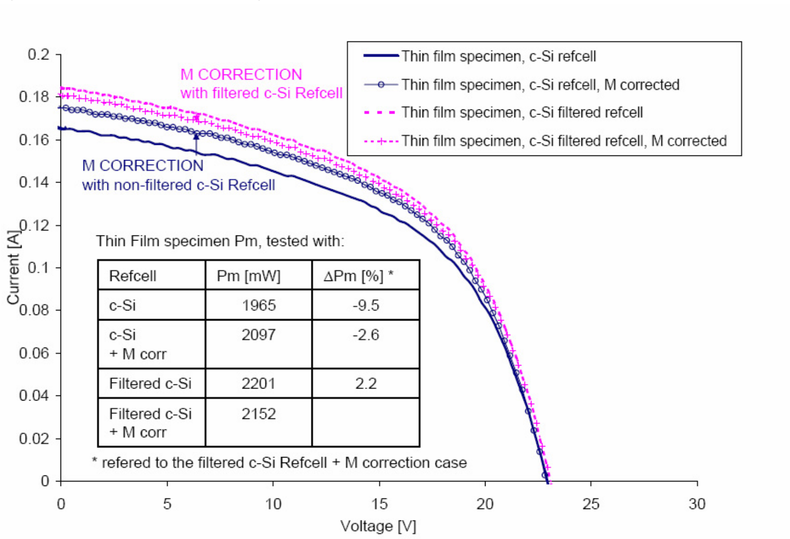


Figure 1: Spectral response of an a-Si single-junction module and the two reference cells (filtered e non-filtered), spectrum of the Xe-lamp and of the AM1.5 reference.



Moreover tests with spectrally matched reference cells will be further investigated.

In Figure 2 is represented an example of IV curve spectral mismatch correction procedure, for a thin film a-Si single junction specimen.

Figure 2: I-V curve of an a-Si single-junction module measured with and without a c-Si reference cell, with and without spectral correction.

3.2 *Medium term OUTDOOR module characterisation (OA)*

3.2.1 Test cycle 10

New testing procedures

A new test cycle on the most commonly sold PV modules on the market started at LEEE. Some changes on instruments and testing procedure have been done.

Two different procedures have been studied for crystalline silicon and thin-film technologies (see Figure 3). After the initial performance measurements to verify the power declared by manufacturers, the crystalline silicon modules will be subjected to a light soaking of about 40 kWh/m² and then indoor measured again.

Three modules per type instead of two will be tested.

For both procedures two modules of each type will be exposed under real operating conditions and continuously monitored. Indoor performance measurements will be periodically executed; more frequent controls will concern thin-film technologies.

For the third sample other outdoor and indoor measurements, like temperature coefficients, spectral response and characterization at different irradiances, are foreseen (see Figure 3 and Chapter 3.3).

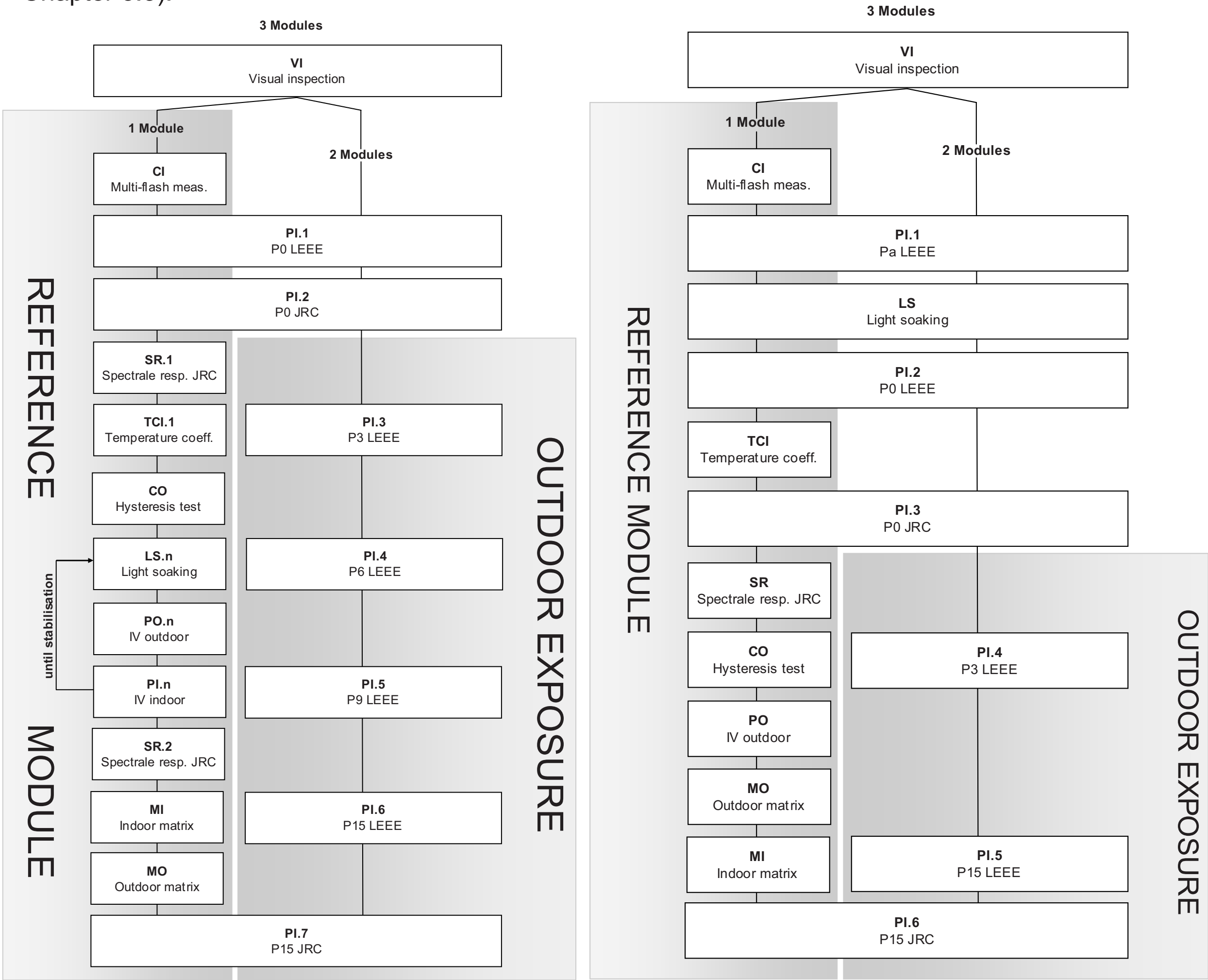


Figure 3: Thin-Film modules test procedure (left) and crystalline silicon test procedure (right).

First results

Fourteen different module types have been chosen, trying to include the greater part of available technologies: 8 mc-Si, 2 sc-Si, 1 HIT, 2 a-Si and 1 CdTe (see Table 1).

Initial performance measurements have been executed on 13 types of modules (out of 14); results and comparisons with nominal values are shown in Table 1.

Remarks regarding measurement of some types of modules are following described:

- 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 are performed with filtered reference cell (nominal power Pn refers to stabilized power);
- For CdTe samples the mismatch correction has been applied.

N°	Manufacturer	Module	Cell type	Pn [W]	Pa [W]	ΔPa_Pn (%)	Manufacturer warranty limit
1	RWE Schott	ASE-165-GT-FT/MC	MAIN mc-Si	165	163.2	-1.1%	± 4%
2	BP Solar	BP 7180	mc-Si	180	175.8	-2.3%	- 0 / + 2.5%
3	IBC Solar	IBC-215S Megaline	mc-Si	215	210.6	-2.0%	± 2.5%
4	Kyocera	KC125GHT-2	mc-Si	125	124.3	-0.6%	+ 10 / - 5%
5	MHH	MHH plus 220	mc-Si	210	204.8	-2.5%	± 3%
6	Mitsubishi	PV-MF130EA2LF	mc-Si	130	132.5	1.9%	+ 10 / - 5%
7	SolarWorld	SW165	mc-Si	165	164.8	-0.1%	± 3%
8	Suntech	STP150-24	mc-Si	150	151.1	0.7%	N/A
9	Sharp	NT-175E1	sc-Si	175	172.8	-1.3%	± 5%
10	SunPower	STM210 F	sc-Si	200	N/A	-	- 0 / + 3%
11	Sanyo	HIP-180NE1	HIT	180	180.5	0.3%	+ 10 / - 5%
12	Kaneka	K60	a-Si	60	84.0	39.9%	+ 10 / - 5%
13	Uni-Solar	ES-62T	a-Si	62	64.3	3.6%	± 5%
14	First Solar	FS-60	CdTe	60	64.0	6.6%	± 5%

Table 1: modules of the new test cycle at LEEE and results of initial measurements (comparison with declared power Pn).

Manufacturer	Module	Pn [W]	Pa [W]	P0 [W]	Initial degradation ΔP0_Pa (%)
RWE Schott	ASE-165-GT-FT/MC	165	163.2	158.7	-2.7%
BP Solar	BP 7180	180	175.8	173.1	-1.6%
IBC Solar	IBC-215S Megaline	215	210.6	N/A	-
Kyocera	KC125GHT-2	125	124.3	122.3	-1.6%
MHH	MHH plus 220	210	204.8	198.8	-2.9%
Mitsubishi	PV-MF130EA2LF	130	132.5	129.6	-2.2%
SolarWorld	SW165	165	164.8	N/A	-
Suntech	STP150-24	150	151.1	149.4	-1.2%
Sharp	NT-175E1	175	172.8	171.0	-1.0%
SunPower	STM210 F	200	N/A	N/A	-
Sanyo	HIP-180NE1	180	180.5	180.3	-0.1%

Most of the crystalline silicon samples have already been outdoor subjected to a light soaking of about 40 kWh/m². First results about initial degradation of crystalline silicon devices are shown in Table 2. Sanyo HIP180NE1 modules have been considered as crystalline silicon devices, and no degradation has been noticed after an outdoor exposure of 50 kWh/m² and 80 kWh/m².

Table 2: initial degradation of c-Si modules (light soaking > 40kWh/m²). Percentages refer to the initial power measured at LEEE (Pa).

3.2.2 Modification, improvement and substitution of electronic devices.

The new electronic device consists of a power and measurement unit (MPPT3000), a RS485 network, data loggers and a master PC unit. In particular, the new MPPT3000 - developed by LEEE - 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 electronic devices used for medium term photovoltaic module tests was renewed. The project is currently in the assembling phase. The Maximum Power Point Tracker functions are extensive tested.

Features :

Maximun Power Point Tracker (MPPT)
Simultaneous current and voltage measurement
Scanning of the I-V characteristic
Opto isolated UART RS485 communication
Real Time Clock (RTC)
Display and keyboard
2 x temp.sense input + 2 x analog imput
Vm + Im + 2 aux opto isolated analog output

Technical specifications :

Pmax in :	250W
Voc max :	150V selectable ranges
Isc max :	20A selectable ranges
Vm min :	5V
Operating temp. :	-20° - +70°C

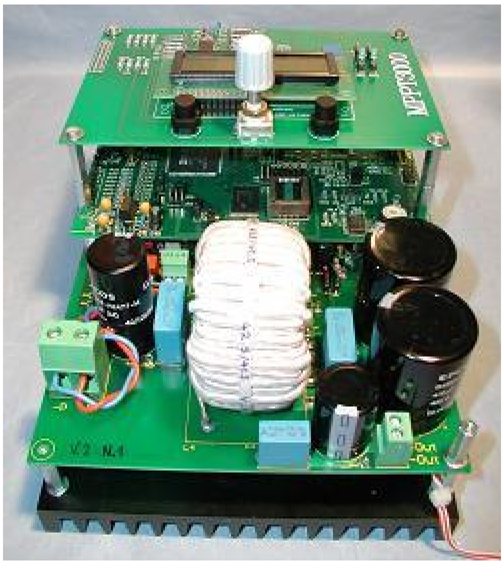
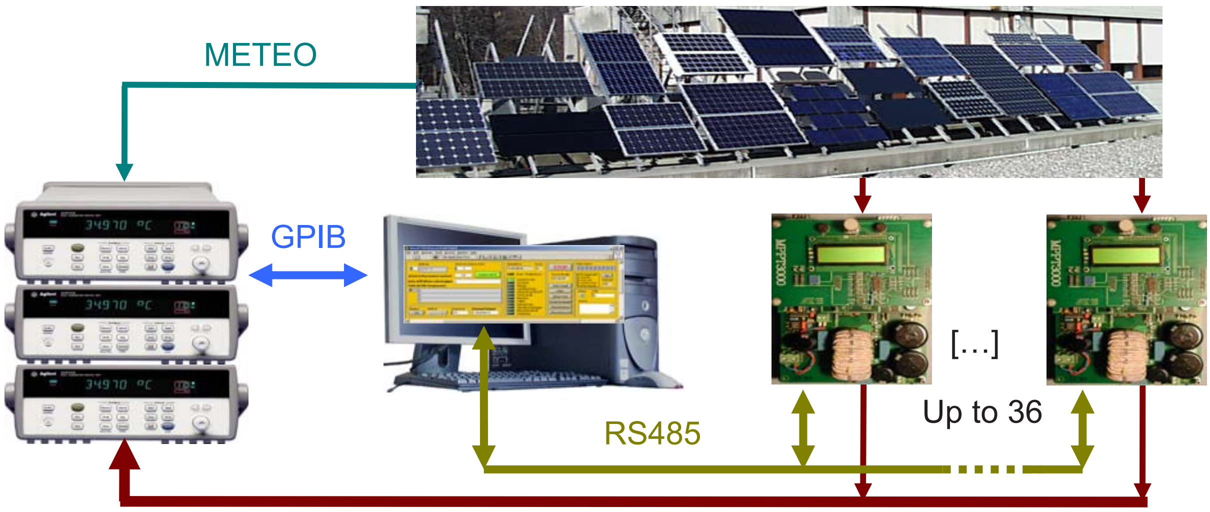


Figure 4: LEEE-TISO MPPT - features and picture.

3.2.3 Data logging and communication with MPPT.

The new MPPT allows communication for IV performance measurement and datalogging. Two systems are possible: In-circuit measurement and external analog measurement with Agilent datalogger.

The software was updated in order the include the new capability of the MPPT. (i.e.: setup Agilent Datalogger and MPPT, reading data from Datalogger (modules, weather, etc…) and MPPT (I-V curve, Energy, etc…). Unstore measures, sorting data, save to file. Synchronization between datalogger, monitoring channels, maintenance tests. Error alert per email.).



3.2.4 Outdoor spectroradiometer

The outdoor spectroradiometer, composed of a receptor (optic fiber), a sensor of 1024 photodiodes and a PC card as been reinstalled with a new PC and recalibrated. The sensor is fixed outside, -7 ° south, 45° tilt angle. The measured solar spectrum range from 250nm to 1100nm.

With the spectroradiometer it is possible to monitor and analyse modules characteristics with respect to solar spectrum, as well as irradiance sensors, and this for different technologies.

Measuring the solar spectrum in real time and knowing the spectral response of the tested module and the reference device measuring irradiance (pyranometer, reference cell), it is possible to calculate the spectral mismatch factor M (see also 3.1.5), which allows to characterize the module at Standard Test Conditions (1000 W/m^2, AM 1.5 and 25 °C).

Three main modes of operation have been implemented: *single measure*, *multi measure* and *measure in continuous mode*. The last one is the most used and allows to select a desired period of the day and monitor the solar spectrum each day, during the same period at the same measurement regularity. At the moment the spectroradiometer is working in a continuous mode, measuring solar spectrum each minute and each day from 5am to 10pm.

3.3 Short term OUTDOOR characterisations with sun-tracker (OB)

3.3.1 Introduction

As already mentioned in the previous chapter, within the new test procedure (see 3.2.1), it is foreseen to test three modules of each type instead of two. The third module, the so called reference module, will be only used for short term measurements. Many of these measurements will be done with the sun-tracker system.

Within the 10th test cycle the main objective of the measurement with the sun-tracker is to determine in very short time the power matrix - $P_m(G_i,T_a)$ - of each module type and to use this matrix to predict the annual energy production of the other two modules. The inter-comparison of the predicted kWh with the in reality over one year produced energy, will be used on one hand to validate the at LEEE developed energy prediction method (matrix method) and on the other hand to optimise the quality of the matrix extraction and the duration of the measurement it self. The influence of single meteorological parameters will be analysed and in the case of thin film modules main emphasis will be put into the analysis of spectral effects.

Another objective of the new system is to compare outdoor to indoor data and to investigate existing translation procedures with a special attention to thin film modules.

Last but not least an hysteresis test has been introduced, which allows to verify the presence of distortions due to high cell capacitances. Sweep speeds up to 2 ms can be reached. This corresponds exactly to the sweep speed of our indoor measurement system (see 3.1).

3.3.2 Progress in measurement system

Since the last reporting period the data acquisition software has been improved with further features and the electronic load has been terminated and calibrated. Figure 5 shows the last version of the software.

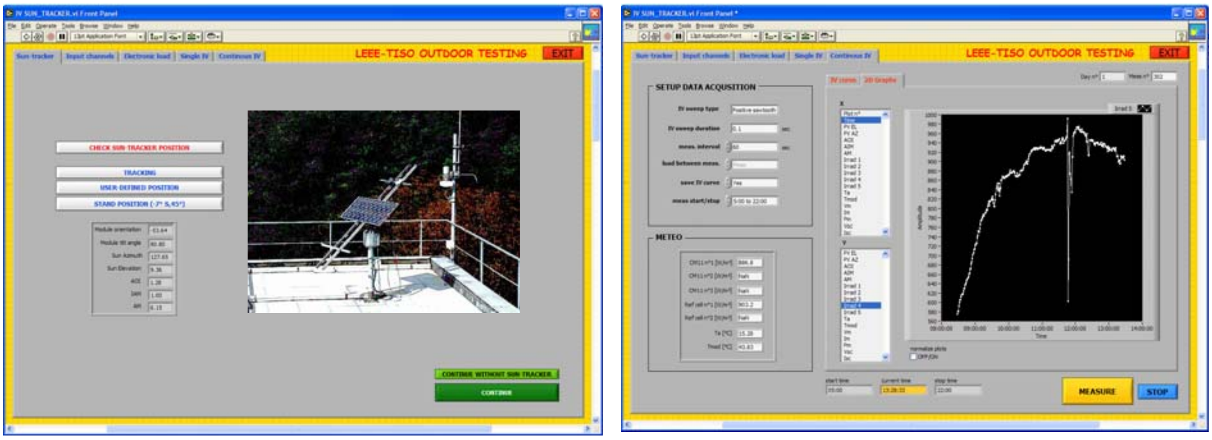


Figure 5: Two of the main windows “sun-tracker” and “continuous IV” of the data acquisition software of the sun-tracker.

The features added to the software are mainly dedicated to the continuous measurement of IV-curves. The program allows now to measure the IV characteristic of a single module at defined time intervals and for defined periods. A user can choose if he wants to save only a daily file with all measured parameter like (date,time,I_{sc},V_{oc},I_m,V_m,P_m,G_{i1},G_{i2},G_0,G_{diff},T_a,T_{bom},AM,…) or if he wants to save as well the complete IV-curves. The measured data can be viewed on line in two formats: 1. IV curve 2. user-defined xy graph. The set-up can be used to extract the whole power matrix or just the temperature coefficients of a module. To validate the whole system (measurement accuracy, STC correction accuracy and software) an indoor calibrated standard crystalline silicon module has been used. The inter-comparison of the indoor measured IV-curve and temperature coefficients with the

STC corrected outdoor IV curves and the outdoor measured coefficients proved the validity of the new measurement facility. Table 1 shows the results for the IV curve measurements.

	indoor	outdoor	
Pm	46.18	45.57	-1.3%
Isc	3.02	3.07	1.6%
Voc	21.10	20.83	-1.3%
Im	2.78	2.79	0.2%
Vm	16.59	16.36	-1.4%

Tabella 3: Difference of indoor and outdoor measured parameter of a reference module (indoor: Pasan simulator, outdoor: Sun-tracker system).

4 National and International Collaboration

Accademia di Mendrisio, Arch. Enrico Sassi, BELVAL SA Pierre-René Beljean, ENECOLO AG Peter Toggweiler and Sandra Stettler, VHF Tech. Diego Fischer, SOLTERRA SA Stefano Zappa, 3-S AG Patrick Hofer, CUEPE André Mermoud, HTI Burgdorf, prof. H. Häberlin;

ENERECO (I), Maurizio Battistella ; Poli di Milano (I), Arch. Niccolò Aste ; Università di Palermo (I) prof. Marco Beccali; Università di Lecce (I), prof. Lorenzo Vasanelli, Dr. Adriano Cola, Marco Pierro ; CREST (UK), Ralph Gottschlag; NREL (USA), Steve Rummel; ECN (NL), Mark Jansen; JRC Ispra W. Zaaiman, Dr. Ewan Dunlop, Robert Kenny, Roberto Galleano ; FhI-ISE (D), Klaus Kiefer; Sunlynx (FL), Robert Fessler.

5 Prospects for 2006

All actions foreseen for 2006 will proceed according to our time plan. All maintenance activities of the solar simulator will continue as before and accredited ISO17025 measurements of temperature coefficients will be added. Further tests on indoor measurements of thin film modules will be investigated (pre-conditioning, irradiance and temperature history, spectral mismatch effect, etc.) as well as outdoor STC extrapolation for thin film. The matrix method will be completed. Investigation on compatibility between indoor and outdoor performance test are planned.

The inter-comparison of the predicted kWh with the in reality over one year produced energy, will be used on one hand to validate the at LEEE developed energy prediction method (matrix method) and on the other hand to optimise the quality of the matrix extraction and the duration of the measurement it self. The influence of single meteorological parameters will be analysed and in the case of thin film modules main emphasis will be put into the analysis of spectral effects.

The new MPPT is in operation and the first results of the cycle 10 will be available. Ten system will be also installed at the University of Lecce for comparison purpose.

6 References and publications

[1] S.R. Williams, G. Friesen, D. Chianese et al.: ***Evaluating the State of the Art of Photovoltaic Performance Modelling in Europe***, 20th EPVSEC, Barcellona (S), 7-11 June 2004.

[2] G. Friesen: ***Il silicio amorfo: una valida alternativa ai moduli fotovoltaici al silicio cristallino?***, “Ilsolea360gradi” (ISES Italia), novembre 2005.

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[4] A. Bernasconi et al. : ***La centrale de test TISO - son histoire et ses développements futurs*** Symposium photovoltaïque national 2005, SIG Genève (CH), 24-25 novembre 2005.

[5] G. Friesen: ***2nd Workshop on Quality in the PV Sector*** (workshop), München (D), 28 January 2005.

[6] A. Bernasconi: ***Integrating solar in the built environment - Developing a Roadmap for BIPV*** (workshop), Sophia Antipolis (F), 13 May 2005.

[7] A. Bernasconi: ***Creare un ponte tra ricerca e applicazioni*** (tavola rotonda), PVTECH 2005, Milano (I), 23-25 novembre 2005.

Annual Report 2005

PV Enlargement

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Project- / Contract Number	n° OFES: 03.0004, n° EU: NNE5/2001/736
Duration of the Project (from – to)	01.01.2003 – 31.12.2006

ABSTRACT

In the project coordinated by WIP, 27 PV demonstration systems with an overall generation capacity of more than 1,150 kWp will be installed in 10 different European countries. At this stage of the project, 860 kWp, corresponding to 85% of the total project capacity, are fully operational.

"PV Enlargement" is not only a demonstration project, but it comprises as well various testing activities, which have mainly the scope to allow a realistic inter-comparison of PV module and system performance. The coordinator of the project is responsible of the quality control on system level and the LEEE laboratory is instead responsible of the quality control on module level. A correlation of system and module performance measurements will be used to compare the real Watt peak weighted energy output (kWh/Wp) of all monitored installations.

The LEEE laboratory is continuously monitoring the quality of single randomly selected modules. In this year 54 new modules of 9 different PV systems have been measured under standard test conditions. In total up to now 151 modules of various technologies (mono-crystalline Si, EFG Si, poly-crystalline Si, amorphous Si, CdTe, and CIS) underwent a quality control through our laboratory. The first test phase, with the objective to verify the initial power values, is almost completed. The second test phase, which will be dedicated to the determination of possible degradations, will start in 2006.

All PV systems have been equipped with crystalline silicon irradiance sensors, supplied by T.N.Z.. For this purpose 46 sensors were first light soaked and then calibrated by the LEEE laboratory. Calibration certificates have been prepared for all sensors.

In 2005 the official web page www.pvenlargement.com was updated by WIP with details about each single installation.

PV Installation Status 2005

Within the project coordinated by WIP, 27 PV demonstration systems (see Table 1) with an overall generation capacity of more than 1,150 kWp will be installed in 10 different European countries. At this stage of the project 20 of the 27 to be realised installations and 85% of the total project capacity, are fully operational.

Table 1: List of PV installations (status 12/2005)- the highlighted (yellow) ones are completed

Contractor #	System #	Country	Location	Name of contractor	PV capacity to be installed, kWp	Type of PV technology	Integration type	PV system components purchased	Installation completed	Foreseen PV system start-up
1	1	IT	Rome	WIP - Comune di Roma, Municipio XV	20	PC	T-FFI			11.2005
2	**2**	**DE**	**Munich Riem**	**Gehrlicher, Parkdeck Messe München**	**379**	**MC, PC, TF-CdTe, TF-CIS, TF-aSi**	**OR**	**Yes**	**Yes**	**operational**
2	**3**	**DE**	**Munich Haar**	**Gehrlicher, Bauhof Haar**	**26**	**PC**	**1NS, 2A**	**Yes**	**Yes**	**operational**
2	4	ES	Murcia	Gehrlicher	200	PC	2A, F			01.2006
3	**5**	**DE**	**Munich**	**FH Munich,** (PV system financed outside PV Enlargement)	**80**	**MC**	**OR**	**Yes**	**Yes**	**operational**
4	6	AT	Vienna	Vienna Univ., Naturhistorisches Museum	15	PC	ORI	in part		12.2005
4	**7**	**AT**	**Hochschwab**	**Vienna Univ., Schiestlhaus**	**8**	**PC, PC-T**	**FI+TFI**	**Yes**	**Yes**	**operational**
4	8	AT	Amstetten	Vienna Univ., AT8	9	TF-aSi	1EW	in part		01.2006
4	**9**	**AT**	**Mödling**	**Donau Univ. Krems, 'SOL4 Eichkogel'**	**29**	**PC**	**FFI**	**Yes**	**Yes**	**operational**
4	**10**	**AT**	**St.Johann**	**Donau Univ. Krems, 'Troppmair'**	**53**	**PC**	**FFI**	**Yes**	**Yes**	**operational**
4	**11**	**AT**	**Kriegerhorn**	**Donau Univ. Krems, Kriegerhornbahn Oberlech**	**10**	**PC-T**	**T-FFI**	**Yes**	**Yes**	**operational**
4	12	AT	Wien	Donau Univ. Krems, ARSENAL research Wien	15	PC, TF-aSi	T-FRI	in part		02.2006
4	13	AT	Amstetten	Univ. Innsbruck, AT13	27	PC	T-FRI	in part		01.2006
9	**14**	**BG**	**Gabrovo**	**TU Gabrovo, 10 kWp PV System**	**10**	**MC, TF-aSi**	**OR**	**Yes**	**Yes**	**operational**
10	**15**	**BG**	**Sofia**	**CL SENES**	**10**	**MC, PC**	**FS**	**Yes**	**Yes**	**operational**
11	**16**	**CZ**	**Brno II**	**SOLARTEC, Masaryk University Brno**	**40**	**MC, MC-T**	**FFI, FFI**	**Yes**	**Yes**	**operational**
11	**17**	**CZ**	**Prague**	**Charles Univ. Prague**	**20**	**MC**	**OR**	**Yes**	**Yes**	**operational**
11	**18**	**CZ**	**Brno I**	**Brno Univ. of Technology**	**20**	**MC**	**OR**	**Yes**	**Yes**	**operational**
11	**19**	**CZ**	**Ostrava**	**TU Ostrava** (PV system financed outside PV Enlargement)	**20**	**MC**	**OR**	**Yes**	**Yes**	**operational**
11	**20**	**CZ**	**Plzen**	**Univ. Plzen**	**20**	**MC**	**OR**	**Yes**	**Yes**	**operational**
11	**21**	**CZ**	**Liberec**	**TU Liberec**	**20**	**MC**	**OF**	**Yes**	**Yes**	**operational**
17	**22**	**EL**	**Pikermi**	**CRES**	**40**	**MC**	**OR, FRI**	**Yes**	**Yes**	**operational**
18	**23**	**EL**	**Athens**	**Agricultural Univ. of Athens**	**15**	**MC, PC,TF-CIS**	**OR, OF**	**Yes**	**Yes**	**operational**
19	**24**	**HU**	**Gödöllö**	**Szent Istvan Univ. Gödöllö**	**10**	**PC, TF-aSi**	**OR**	**Yes**	**Yes**	**operational**
21	**25**	**IT**	**Florence**	**Univ. of Florence**	**20**	**PC**	**FS**	**Yes**	**Yes**	**operational**
23	26	PL	Warsaw	Warsaw Univ. of Technology	21	MC, TF-aSi	FI, OR	in part		03.2006
26	**27**	**RO**	**Bucharest**	**Universitea 'Politehnica' din Bucuresti**	**31**	**MC, TF-aSi**	**OR + FL**	**Yes**	**Yes**	**operational**
				Total (by contract 1.014 kWp)	1'167	85% of PV capacity 'by contract' in operation				

PV systems in operation	(yellow)
PV systems to be installed	(white)
Suggested changes relative to T5	(green)
Changes requiring a contract amendment	(light blue)

(1) In the row '**Type of PV Technology**' the abbreviations stand for:
MC - mono crystalline Si
PC - poli crystalline Si
PC-T - semi transparent poli crystalline Si
TF - thin film (TF-aSi for amorphous silicon, etc.)

(2) In the row ' **Integration Type**' the abbreviations stand for:
F - Field installation
OR - On roof installation
RI - Roof integration. PV system is part of building envelope
FRI - Full roof integration. PV system replaces roof
FS - Freely suspended
OF - On facade installation
FI - Facade integration. PV system is part of building envelope
FFI - Full facade integration. PV system replaces facade of building
T-FFI - Full facade integration, semi-transparent. PV system replaces facade of building
1NS - One axis tracking (axis North-South inclined)
1EW - One axis tracking (axis East-West inclined)
2A - Two axis tracking

Testing activities within PV-Enlargement

The demonstration project “PV Enlargement” comprises various testing activities, which have mainly the scope to allow a realistic inter-comparison of PV module and system performance. The coordinator of the project is responsible of the quality control on system level and the LEEE laboratory is instead responsible of the quality control of single PV modules. A correlation of system and module performance measurements makes it possible to compare the real Watt peak weighted energy output (kWh/Wp) of all monitored installations.

LEEE Objectives

1. The first test phase of the project should be finished in 2005. The objective of this test phase was to determine the initial power of a large number of modules. After an outdoor exposure of at least 1 to 2 years some of the initially tested modules will be measured again to determine possible degradations. Especially for the amorphous silicon technologies, in which the so called stabilisation time can be of 1 year or even longer, this second measurement is very important. The second test phase will start only in 2006, when most PV plants have been operational for a long enough time.

2. The coordinator of the project (WIP) is responsible for all on-site I-V curve tests. To guarantee the quality of the outdoor PV module measurements, the LEEE has to verify the accuracy of the measurement system used for these tests (IV-tracer, irradiance sensor and STC correction procedure).

3. For a high quality monitoring, all PV systems have to be equipped with one or more calibrated silicon sensors for in-plane irradiance measurements. The calibration of each sensor will be executed indoor with our solar simulator system. Before calibration the sensors are undergoing a light soaking of at least 40kWh/m².

LEEE work progress in 2005

State of module performance tests

Until now 151 modules, of the 210 for the first test phase originally foreseen modules, could be tested by our laboratory. Table 2 shows the updated list. The difference is mainly due to delays in the realisation of the last 7 PV plants (see Table 1). In the next months it will be evaluated the alternative to conclude the first test phase without measuring the remaining modules and to increase the number of modules, foreseen for the final test campaign, from 50 to around 100.

Table 2: Modules tested within the first test cycle (status December 2005)

	partner name	**module technology**		**origin**	**n°**
1.	Università degli studi di Firenze	- Photowatt PW1250	c-Si	F	6
2.	Gehrlicher	- Antec ATF43 - RWE ASI-F 32/12 - Shell ST40 - Solon M210/6 - Würth WS11007/70 - Sanyo HIP-J54BE2 - Isofoton CER50 - First Solar FS55 - RWE ASE 275 - Shell SQ 175 - Shell SE160 - Isofoton I 165 - Solon P210	CdTe a-Si CIS c-Si CIS c-Si c-Si CdTe c-Si c-Si c-Si c-Si c-Si	D D D D D J ES USA D D D ES D	14 6 6 6 6 6 6 6 6 6 6 6 6

3.	ATB	- RWE ASE 300 - Fischer/ Power cell	c-Si c-Si	D D	6 1
4.	Solartec	- Solartec Radix72 dark blue - Solartec Radix72 marina blue	c-Si c-Si	CZ CZ	8 8
5.	Agri. University of Athens	- Shell S115C - Shell SQ150 - Shell ST40	c-Si c-Si CIS	D D D	6 6 6
6.	Szent Istvan University Gödöllö	- Dunasolar DS40 - RWE ASE100	a-Si c-Si	HU D	6 6
7.	FH München	- Solarfabrik SF100	c-Si	D	6

Test results of crystalline silicon modules

Within the first test cycle 101 crystalline silicon modules of 17 different types have been tested. The results are summarised in Table 3. All data are published in anonymous way. The first column lists the average initial deviation of the purchased module power from the nominal power (data sheet value), the second one the average degradation in the first days of outdoor exposure and the last column the final difference to the nominal power. The last value corresponds approximately to what one can expect to have for a module when the PV installation is going into operation. The initial degradation occurs only in new modules during the first hours of exposure and it is non reversible. It has not to be confused with the long term degradation percentages, which will be analysed within the second measurement campaign.

Table 3: Average results for each c-Si technology (status December 2005)

Module n°	Avg. initial difference to P_n	Avg. degradation after first light soaking (>20kWh/m²)	Avg. final difference to P_n (installed power)
1.**	2.7%	-0.3%	2.4%
2.	-3.0%	-1.6%	-4.6%
3.***	n.a.	n.a.	-6.3%
4.	-7.5%	n.a.	n.a.
5.	0.1%	-1.2%	-1.1%
6.***	n.a.	n.a.	0.9%
7.	-4.4%	-1.3%	-5.8%
8.*	-2.0%	0.1%	-2.0%
9.	-0.5%	-0.1%	-0.60%
10.	3.4%	-0.7%	2.7%
11.***	n.a.	n.a.	-0.9%
12.***	n.a.	n.a.	-5.0%
13.	-1.2%	-1.3%	-2.6%
14.	-9.4%	-0.9%	-10.2%
15.	-7.8%	-1.0%	-8.9%
16.	-1.3%	-3.3%	-4.6%
17.***	n.a.	n.a.	-2.1%

* module with capacitive effects (power determined by multi-flash measurement procedure)
** non-standard module without nameplate (only 1 module was available for testing)
*** already exposed modules (not new - first degradation not measurable)

The new European standard EN50380 “datasheet and nameplate information for photovoltaic modules” defines how manufacturers should declare their modules. The declared power has to correspond to the power after the first degradation, the so called stabilised power, and it should lie within the declared tolerance ranges. Figure 1 shows the during the first test phase measured stabilised power values in relation to the declared one. For 2 of 17 module types a tolerance declaration of 0 to +2% (dark green column) would be reasonable. For other 6 a tolerance of ±2% would be correct (green column), for other 4 a tolerance of ±5% (yellow column) and for the last 5 a tolerance of ±10% (red column).

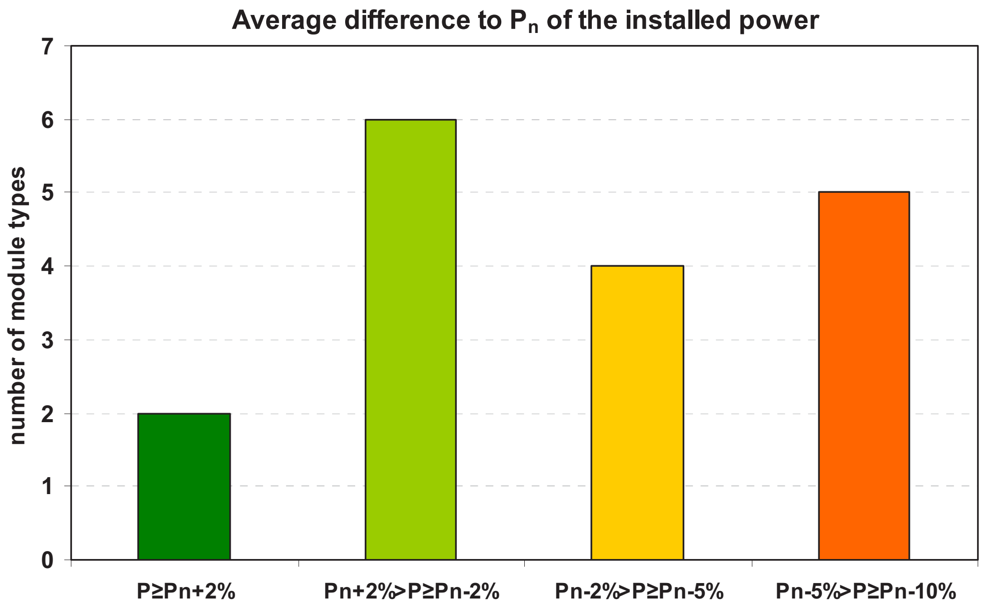


Figure 1: Power measured after light soaking: Number of module types with an average difference in the range of Pn+x% > $P_{meas,avg}$ > Pn+y%.

In Figure 2 are reported the standard deviations of these measurements. Generally 6 modules of each type were measured. The modules have been selected randomly, avoiding modules with consecutive serial numbers.

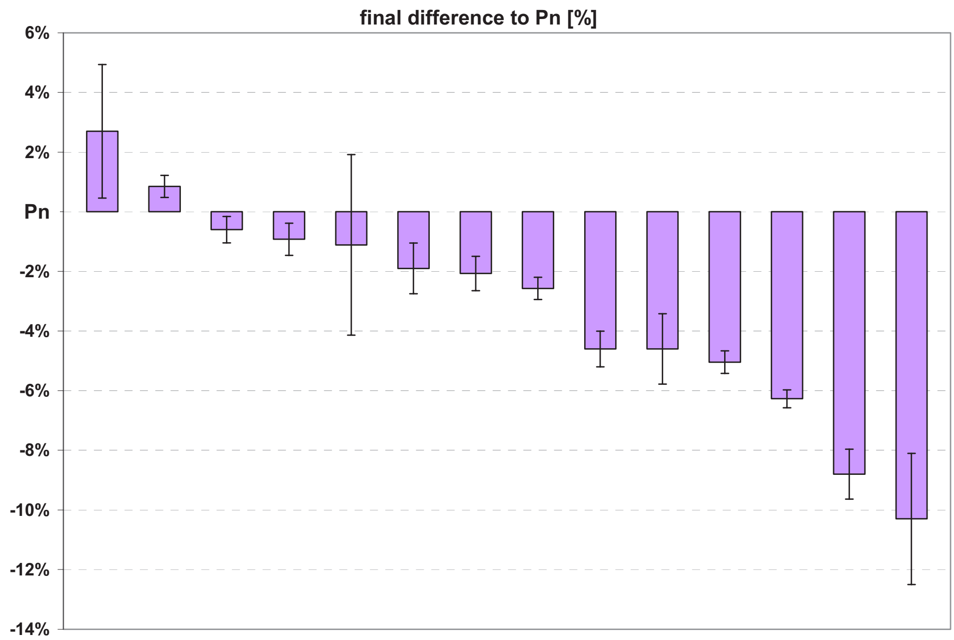


Figure 2: Power measured after light soaking: Average deviation from nominal power Pn with the standard deviation of the measured modules (6-8).

Thin-film module measurements

50 thin film modules have been measured up to now. In 2005 the tested modules were 6 CdTe modules of First Solar (FS50) and 6 a-Si modules of Dunasolar (DS40). Most thin film module technologies of this project will be measured again indoor and outdoor during the second test phase. The degradation of each technology will be quantified and effects influencing the performance measurement will be described in the final report.

Here only one example of a indoor measured CIS module (Fig.3) and the measurement difficulties which occurs within these tests. When reverse biased the non light soaked module shows a distortion of the I-V curve (in red), which is typical for modules with reverse bias diodes. After light soaking the distortion disappears (green I-V curve). This kind of distortion leads to an overestimation of the short circuit current. Pmax, FF and Voc seems to be less subjected by these effect. All modules of these manufacturer showed this behaviour. The influence of the light soaking on the IV measurement has to be further investigated.

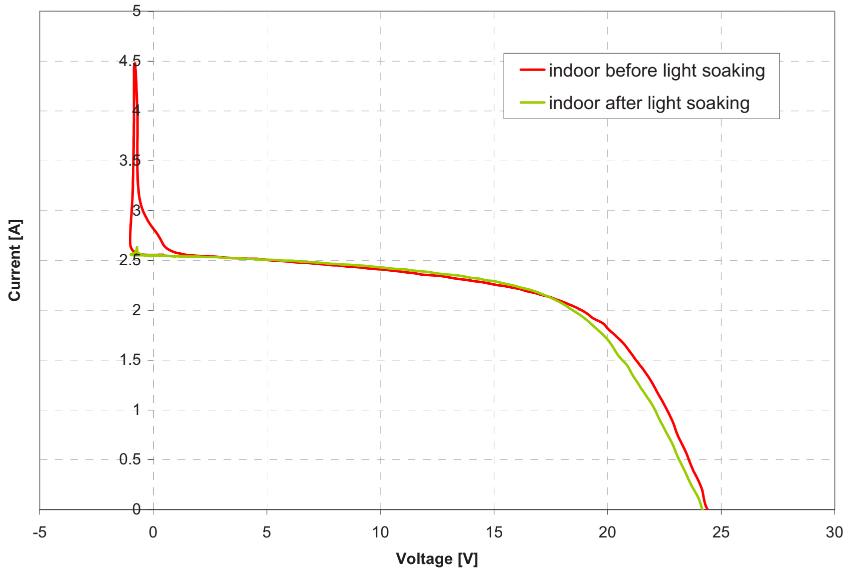


Figure 3: IV curves of a indoor measured CIS module (ST40) before and after light soaking.

Irradiance sensor calibration

To allow high quality in-plane irradiance measurements, all PV systems had to be equipped with crystalline silicon irradiance sensors. These sensors were all supplied by T.N.Z. and calibrated by LEEE. For this purpose 46 sensors have been first light soaked and then measured with our solar simulator. Calibration certificates have been prepared for all sensors. In average a calibration factor of 18.87 mV @ 1000 W/m² has been measured. The standard deviation was of ±1.1% (measurement accuracy ±1.4%).

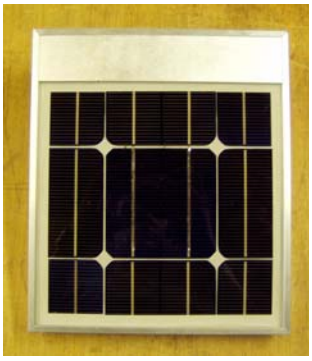
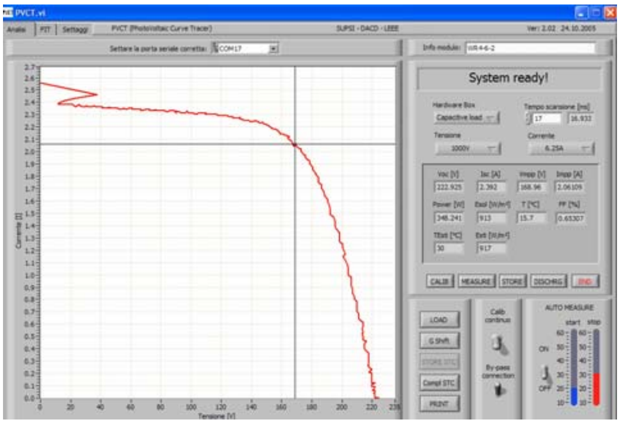


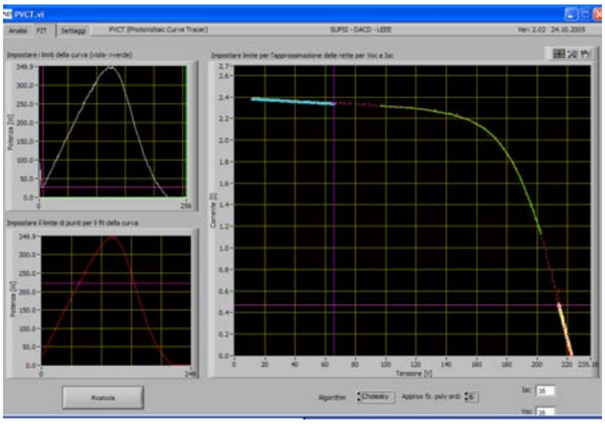
Figure 4: irradiance sensor supplied by T.N.Z. with electrical specifications.

Electrical Paramenters	
Analog Outputs	
1. Active and shunted PV cell	20 mV (±0,4 mV) @ STC For exact signal see TISO calibration protocol
2. Pt100	100 Ω @ 0°C ; α = 3,850 x 10^{-3} °C^{-1}

IV tracer for on site measurements

In 2005 the data acquisition and analysis software of the PVCT IV tracer, generally used by the LEEE for onsite measurement of PV installations and single modules, was rewritten in Labview. The measurement quality and flexibility of the program could be so further improved and directly combined with our program for the correction of I-V curves to standard test conditions. Within this project the system will be used to test the accuracy of the by WIP onsite used IV-tracer. An indoor calibrated reference module will be measured on both IV-tracer systems under identical weather conditions and with the same irradiance sensor. The system has been recalibrated in October 2005.





Prospects for 2006

- start of the second test phase, in which the degradation of single modules will be determined.
- detailed analysis of all thin film technologies.
- inter-comparison of portable IV-tracer systems by the use of an indoor calibrated reference module.
- correlation of system and module performance measurements and interpretation of kWh/Wp outputs.

Publications 2005

[1] see: ***http://www.pvenlargement.com***

[2] intermediate EU reports, ***T4 (02.2005)*** and ***T5 (09/2005)***

Acknowledgements

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Annual Report 2005

Photovoltaik-Systemtechnik 2005-2006 (PVSYTE)

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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)

ABSTRACT

Purpose and Goals of the project during 2005

- Extended semi-automated tests of grid-connected PV inverters from different manufacturers at least for 3 different DC voltages using the PV array simulators 25 kW and 20 (instead of 7,5) kW of the PV laboratory.
- Continuation of long-term monitoring of PV plants after end of former monitoring project LZPV2.
- Ongoing participation in national network of competence BRENET (building & renewable energy network).

Most important results in 2005

- Inclusion of over- and undervoltage and over- and under- frequency tests with new programmable AC-source in the inverter test procedure in order to examine inverter behaviour under unusual line conditions.
- Development and commissioning of a test facility with a large resonant circuit (Q_L and Q_C up to 12 kVar) for single-phase islanding tests according to new draft standard IEC 62116 and DIN VDE 0126-1-1.
- Development of fault-current measurement procedures for single phase inverters without transformers according to draft German standard DIN VDE 0126-1-1.
- Extended semi-automated tests performed at several new inverters (Solarmax 2000E, 3000E, 6000E, 6000C, 25C) with the new PV array simulators on 3 different DC voltage levels. 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 $\eta_{tot} = \eta \cdot \eta_{MPPT}$ vs. power can be determined.
- Extended test reports (in German) about inverters tested now available under www.pvtest.ch >publications.
- Confidential (paid) tests of different inverters for major PV trading companies to extend project budget.
- Purchase, commissioning and inclusion in automated measurement system of a new power meter (Yokogawa WT3000) with significantly increased measurement accuracy.
- To increase measurement accuracy of MPP-tracking efficiency η_{MPPT} further, a new MPPT-interface is being developed that can measure P_{MPP} and operational MPP-tracking behaviour with the very same electronic circuit, thus reducing measurement errors due to differences in absolute accuracies of two different measuring circuits used before.
- Continuation of long-term monitoring of PV plants. Examination of plants with significant reduction of energy production. Successful inclusion of the large PV plant Wankdorf (855 kWp, on the roof of the new football stadium “Stade de Suisse” in Bern) into the monitoring program in April 2005.
- 2 conference contributions at the 20th EU PV conf. in Barcelona, 3 conference contributions at the 20th PV symposium at Staffelstein/D, 3 poster contributions at the 6th Swiss national PV conference in Geneva and 3 publications in scientific journals on different project results.

Projektziele für 2005

- Integration der neuen 3·5 kW AC/DC-Quelle ins Testprogramm für Wechselrichtertests zur Ermöglichung von Wechselrichtertests bei ungewöhnlichen Netzbedingungen.
- Test neuer Produkte von Sputnik Engineering AG (trafolose Geräte und 25C) und ASP AG.
- Fortführung des Langzeit-Monitorings an allen Anlagen des Projektes LZPV2 (mit kristallinen und Dünnschichtzellen-Modulen). Integration der PV-Anlage Wankdorf ins Langzeit-Monitoring.
- Weitere Untersuchung des Verhaltens von Dünnschichtzellen-Modulen bei Teilbeschattung.
- Mitarbeit im Nationalen Kompetenznetzwerk BRENET (Gebäudetechnik / erneuerbare Energien).

Kurzbeschreibung der 2005 durchgeführten Arbeiten

Zu Jahresbeginn wurde die Ende 2004 beschaffte programmierbare AC/DC-Quelle von 3 · 5 kW (0 – 2,5 kHz) ins Testprogramm für die Wechselrichter-Tests integriert. Damit kann nun auch das Verhalten der Wechselrichter bei ungewöhnlichen Netzzuständen (Über- und Unterspannungen, starke Rundsteuersignale, Über- und Unterfrequenz, langsame und mittelschnelle Transienten auf dem Netz) untersucht werden. Entsprechende Tests wurden Anfang 2005 soweit möglich auch für die bereits 2004 getesteten Geräte (Sunways NT4000, Fronius IG 30 und IG 40 sowie Sunny Mini Central 6000 von SMA) noch nachträglich durchgeführt und in die Testberichte eingefügt. Ferner wurde die Leistung des kleineren Solargenerator-Simulators Anfang 2005 von 7,5 kW auf 20 kW erhöht.

Zur Gewinnung von Testresultaten von neueren Wechselrichtern erfolgten 2005 auch ausgedehnte Tests an einigen weiteren Geräten (Solarmax 2000E, Solarmax 3000E, Solarmax 6000E, Solarmax 6000C und an einem neuen dreiphasigen Solarmax 25C). Dabei wurden bei mindestens 3 verschiedenen DC-Spannungen auf jeweils 23 Leistungsstufen alle U, I und P auf der DC- und AC-Seite, der DC-AC-Umwandlungswirkungsgrad η, der statische MPP-Tracking-Wirkungsgrad η_{MPPT}, der 2004 eingeführte totale Wirkungsgrad η_{tot}, die Oberschwingungsströme und der cos φ auf der entsprechenden Leistungsstufe gemessen.

Momentan wird die Kennlinie auf jeder Messstufe mit einem unabhängigen Gerät (Kennlinienmessgerät) vor der automatischen Messung gemessen und gespeichert. Trotz der hohen Genauigkeit der einzelnen Geräte wirken sich dabei jedoch Fehler der absoluten Messgenauigkeit natürlich direkt aus. Deshalb wurde ein neues MPPT-Messinterface entwickelt, das sowohl die Kennlinienmessung als auch das MPP-Tracking im Betrieb über die gleiche Messelektronik misst, sodass dieser Effekt eliminiert werden kann. Das Gerät sollte Anfang 2006 in Betrieb genommen werden können.

Um die Wechselrichter-Testberichte bereits vor dem offiziellen Projekt-Schlussbericht einem breiteren Publikum zugänglich zu machen, wurden die Berichte über die einzelnen getesteten Wechselrichter auf dem Internet unter www.pvtest.ch > Publikationen allgemein zugänglich gemacht.

Da sich die internationale Normung immer weiter entwickelt, musste auch die vorhandene Testinfrastruktur weiter ausgebaut werden. Im Berichtsjahr wurde ein grosser Schwingkreis entwickelt, der auch Inselbetriebstests mit angepasster Last und einer relativ hohen Güte (Q = 1 … 2 je nach Land) gemäss den Entwürfen für IEC62116 und DIN VDE0126-1-1 ermöglicht. Ebenso wurde ein Testgerät für die Messung der DC-seitigen Fehlerströme bei trafolosen Wechselrichtern nach DIN VDE0126-1-1 entwickelt. Entsprechende Tests werden bei zukünftigen Tests in die Testroutine integriert.

Im Rahmen dieses Projektes wurde auch das Langzeit-Monitoring der im vorangegangenen Projekt gemessenen Anlagen mit nunmehr 62 Wechselrichtern (Stand Ende 2005) fortgesetzt. Im April 2005 wurde die Messtechnik der PV-Anlage Wankdorf in Betrieb genommen: Zunächst waren leider einige Strahlungssensoren falsch montiert, was die Messergebnisse in den ersten Monaten beeinträchtigte. Nach Behebung dieser Montagefehler funktioniert die Anlage nun zufriedenstellend. Die Ausfallrate bei den Photovoltaik-Wechselrichtern war 2005 nahezu gleich gross wie im Vorjahr. An einer Anlage in Burgdorf wurde infolge starker Verschmutzung eine (durch Reinigung reversible) Leistungsreduktion von 29%(!) festgestellt. Die im Herbst 2003 durchgeführte thermische Isolation der Anlage Newtech 3 scheint sich weiterhin zu bewähren, jedenfalls hat sich die weitere Degradation dieser amorphen Anlage deutlich verlangsamt. Dagegen scheint sich die 2004 erstmals festgestellte beginnende Degradation der 2001 erstellten CIS-Anlage Newtech 1 langsam weiter fortzusetzen.

Im Rahmen einer Semesterarbeit wurden an einigen 2004 produzierten CIS-Modulen von Würth Solar weitere Untersuchungen über von Teilbeschattungen hervorgerufene Degradationen durchgeführt, die

2003 an einem ST20 von Siemens festgestellt worden waren. In dieser Arbeit konnten an den Würth-Modulen keine durch Teilbeschattungen hervorgerufenen Degradationen nachgewiesen werden.

Im Berichtsjahr führte das PV-Labor für Dritte zudem verschiedene vertrauliche Kurztests an Wechselrichtern und anderen PV-Komponenten durch. Die vorhandene Testinfrastruktur hat sich bei Wechselrichtern verschiedenster Hersteller bewährt. Da die Tests voll bezahlt wurden, können ohne Erlaubnis der Auftraggeber keine Resultate publiziert werden. Dadurch konnten aber gewisse zusätzliche Einkünfte zur Erstreckung der Projektmittel und Verbesserung der Infrastruktur generiert werden.

Die Aktivitäten im Rahmen des nationalen Kompetenznetzwerks BRENET (Gebäudetechnik und erneuerbare Energien) waren im Berichtsjahr eher bescheiden. Die Aktivitäten in diesem Netzwerk konzentrieren sich mangels PV-Förderprogrammen momentan eher auf die thermische Optimierung von Gebäuden (Minergie) und solarthermische Anwendungen.

Teilprojekt Wechselrichter-Tests

Überblick über die im Rahmen dieses Projektes bisher durchgeführten Tests

Da der Bericht über den Solarmax 25 C dem Hersteller noch nicht zur Stellungnahme zugestellt werden konnte, sind in diesem Bericht noch keine entsprechenden Angaben enthalten.

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 *260* 280 *300* 350	91.0 *91.5* 92.1 *92.3* 91.6	99.8 *99.8* 99.7 *99.6* 99.5	90.8 *91.2* 91.8 *91.9* 91.2	0	++	+	+[4)]	+	++	+	+
Fronius IG40	04	3.5	HF	170 *260* 280 *350*	91.1 *91.6* 92.5 *91.8*	99.9 *99.0* 99.6 *99.5*	91.1 *90.7* 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	+	0[1)]	++	+	++	+	+
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 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)]

++	**sehr gut**	**1)**	Grenzwertüberschreitung für Frequenzen < 300kHz
+	**gut**	**2)**	Nur mit aktivierter ENS betreiben
0	**genügend**	**3)**	Relativ frühe Abschaltung bei RSS mit f=200Hz
-	**mangelhaft**	**4)**	Grenzwertüberschreitung für Frequenzen < 200kHz
--	**schlecht**	**5)**	Älteres Modell; erfüllt nur frühere ENS-Norm, heutige nicht mehr

Da die ausführlichen Wechselrichter-Testberichte auf dem Internet unter www.pvtest.ch > Publikationen allgemein verfügbar sind, wird aus Platzgründen hier auf die Darstellung weiterer detaillierter Testresultate verzichtet. Kurzberichte sind auch in den im Literaturverzeichnis angegebenen Publikationen enthalten, die ebenfalls vom Internet heruntergeladen werden können.

Ausbau der Test-Infrastruktur

Anfang 2005 erschienen wichtige neue Normentwürfe zu den Testsverfahren bezüglich Inselbetrieb nach einem Netzausfall (82/402CD für späteres Dokument IEC62116) sowie eine neue Version der deutschen Norm DIN VDE 0126-1-1, die neben dem Inselbildungs-Test auch den Test von DC-seitigen Ableitströmen bei trafolosen Wechselrichtern regelt.

Um hier mitarbeiten und entsprechende Tests vornehmen zu können, erwies es sich als notwendig, die vorhandene Testinfrastruktur auszubauen. Der gewichtigste Ausbau wurde notwendig, weil im Entwurf 82/402/CD neben der genauen Lastanpassung bezüglich Wirk- und Blindleistung auch noch ein Resonanzkreis mit Q = 1 (gemäss VDE 0126-1-1 sogar Q = 2!) gefordert wird. Für Wechselrichter mit P = 5 kW bedeutet dies, dass ein Resonanzkreis mit Q_L = 10 kVar und Q_C = -10 kVar erforderlich ist. Um auch Tests mit für den US-Markt bestimmten Geräten durchführen zu können, wurde die Testschaltung so ausgelegt, dass sie ausser für 230 V / 50 Hz auch für 115 V / 60 Hz eingesetzt werden kann. Damit können einphasige Wechselrichter bis 5 (resp. 10) kW nach den neuen Normvorschlägen auf Inselbetrieb getestet werden. Wenn sich diese Norm durchsetzt, sind für allfällige dreiphasige Tests zwei weitere derartige 10 kVar-Schwingkreise notwendig. Bild 1 zeigt die entwickelte Schaltung, die in der Praxis viel einfacher zu handhaben ist als die in 82/402CD vorgeschlagene Schaltung. Ein entsprechender Vorschlag wurde über das schweizerische TK82 eingereicht.

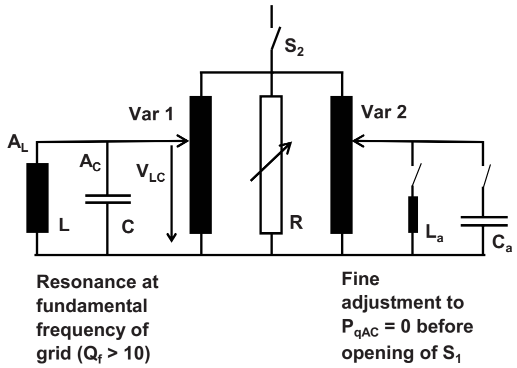


Bild 1:
Blockschema des entwickelten 50/60 Hz–Resonanzkreises von 10 kVAr für 230 V und 115 V für Inselbetriebstests nach DIN VDE 0126-1-1 und 82/402/CD.

Ferner wurde eine Testschaltung für die Messung von DC-seitigen Fehlerströmen realisiert. Bei zukünftigen Tests von trafolosen Wechselrichtern werden diese Fehlerströme ebenfalls gemessen.

Teilprojekt Langzeitverhalten von Photovoltaik-Anlagen

Wechselrichter-Ausfall-Statistik

Die seit 1992 geführte Ausfallstatistik wurde auch 2005 weitergeführt. Im Jahr 2005 sank die Ausfallrate leicht auf 0,12 WR-Defekte pro WR-Betriebsjahr (Stand November 05, hochgerechnet auf Ende Jahr) und lag damit im Bereich der Vorjahre. Die Anzahl überwachter Wechselrichter stieg durch die Integration der Anlage Stade de Suisse auf 62 Stück (Stand Ende 2005) an.

Neben der Gesamtstatistik (Bild 2) wurde auch die 2004 eingeführte zusätzliche Statistik mit Unterteilung der Ausfälle nach Wechselrichtern mit und ohne galvanische Trennung (Bild 3) weitergeführt.

Fünf von sieben Ausfällen betrafen trafolose Wechselrichter. Es waren dies 2 Solarmax S und 3 Convert 4000. Ferner traten auch bei einem Solcon 3400 HE und einem Top Class 4000 Grid III (beide mit Trafo) Hardwaredefekte auf. Einer der beiden Solamax S musste wegen eines Totalschadens ersetzt werden, die übrigen Geräte konnten repariert werden. Ein weiterer Top-Class Wechselrichter hatte sporadische Störungen im Betrieb, konnte aber mangels Reproduzierbarkeit des Fehlers noch nicht repariert werden. Wegen der Inbetriebnahme von 7 neuen Wechselrichtern Solarmax 125 in der neuen PV-Anlage „Stade de Suisse“ und dem Ersatz von 2 defekten Geräten durch neue Geräte sank das Durchschnittsalter der überwachten Wechselrichter in diesem Jahr leicht ab (siehe Bild 2).

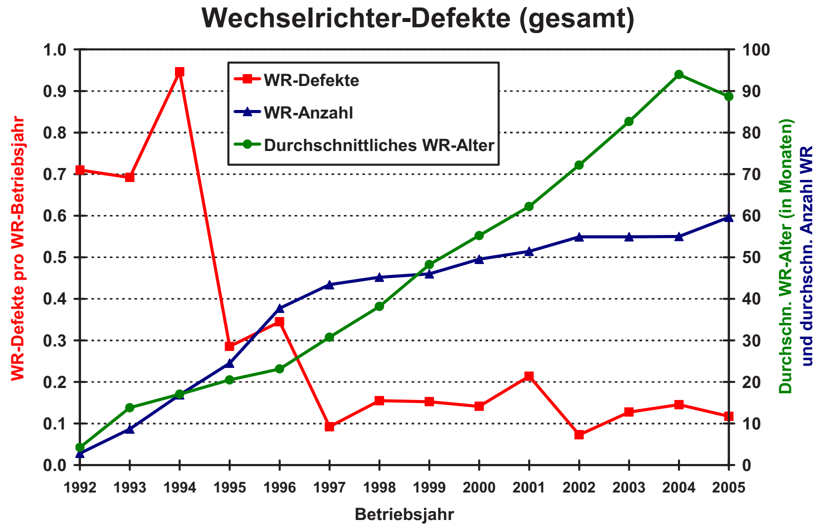


Bild 2:
Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr und durchschnittliche Anzahl von der HTI Burgdorf überwachter Wechselrichter (Hochrechnung vom Stand Ende November 2005).
Dank dem Einsatz von ins gesamt 9 neuen Wechselrichtern ist das Durchschnittsalter der Wechselrichter im Jahr 2005 etwas gesunken.

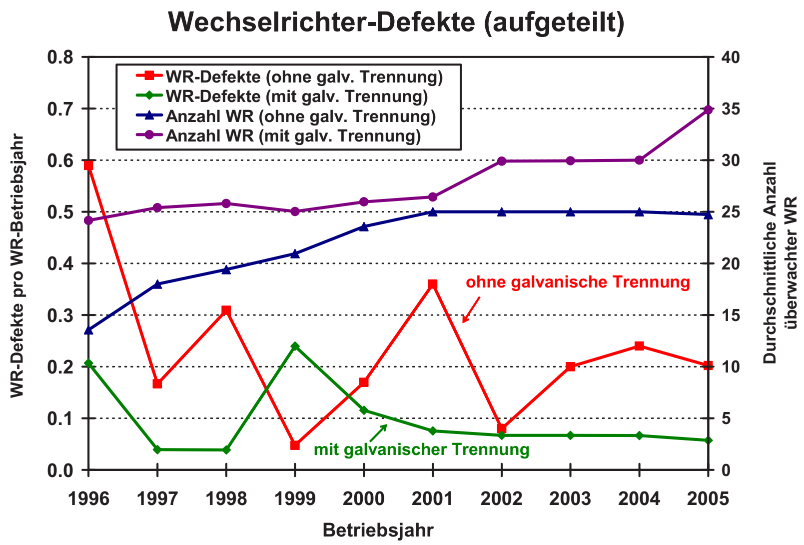


Bild 3:
Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr aufgeteilt nach Wechselrichtern mit und ohne galvanische Kopplung (Hochrechnung vom Stand Ende November 2005). Die bisher beobachtete Tendenz, dass die Zuverlässigkeit von galvanisch getrennten Wechselrichtern grösser ist, setzt sich weiter fort.

PV-Anlage Wankdorf, Stade de Suisse

Im Rahmen des neuesten BFE-Projektes „Photovoltaik-Systemtechnik 2003-2006“ wurde auch die PV-Anlage von 855 kWp auf dem neuen Stade de Suisse Wankdorf Bern in unser Messprogramm aufgenommen. Neben dem wissenschaftlichen Aspekt, dass dieses neue Messobjekt interessante Daten zum Verhalten solcher Anlagen liefern wird, ist die Messanlage im Stade de Suisse auch ein attraktiver Werbeträger für unsere PV-Projekte.

In Zusammenarbeit mit den am Bau der Anlage beteiligten Firmen wurden die nötigen Schnittstellen definiert. Teile der Messtechnik (Sensoren, Messumformer, Verdrahtung, usw.) wurden im Auftrag der Bauherrschaft bereits von den Firmen Tritec und Newlink aufgebaut. Unsere Aufgabe besteht in der Weiterverarbeitung der Messsignale. Die Einrichtung zur Erfassung dieser Werte wurde vom PV-Labor in Burgdorf aufgebaut und mit einem handelsüblichen Datenlogger mit Modem ausgerüstet. Zur Analyse der Daten musste zudem die vorhandene Konvertierungssoftware erweitert, aktualisiert und modernisiert werden.

Seit dem 1. April 2005 ist die Messtechnik in Betrieb. Es werden die verschiedenen Einstrahlungen, Temperaturen, DC- und AC-Leistungen registriert. Das PV-Labor hat auch bereits eine Online-Darstellung der aktuellen Messwerte im Internet realisiert. Zusätzlich wurde eine Vorschau auf eine normierte Jahresstatistik auf der Labor-Webseite www.pvtest.ch veröffentlicht (siehe auch Bild 5). Erste aussagekräftige Langzeitstatistiken sind ab 2006 zu erwarten.

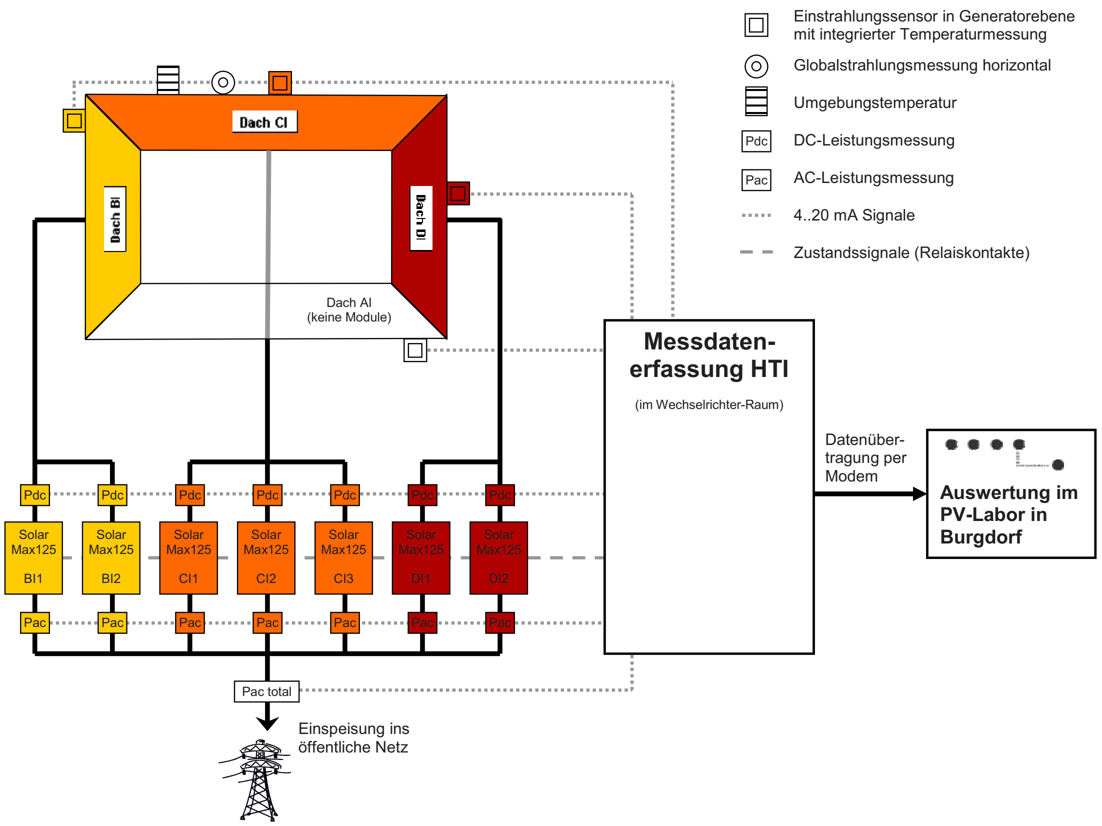


Bild 4: Blockschaltbild der Datenerfassung der PV-Anlage Wankdorf (Stade de Suisse)

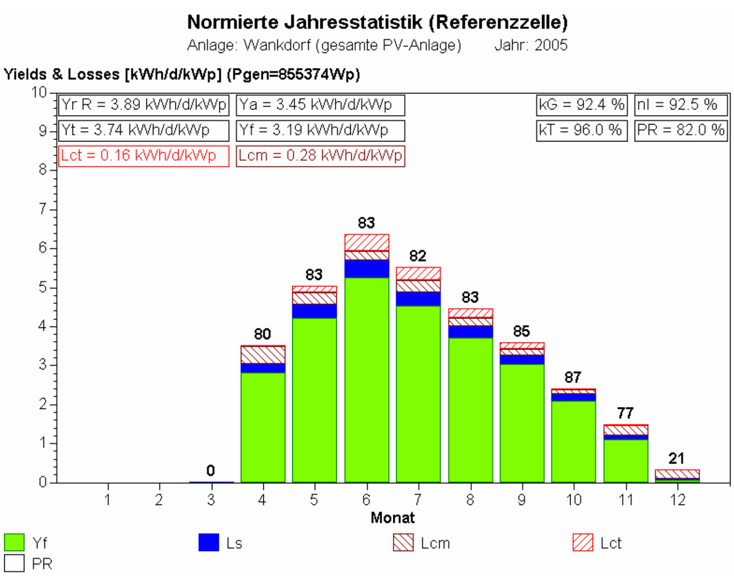


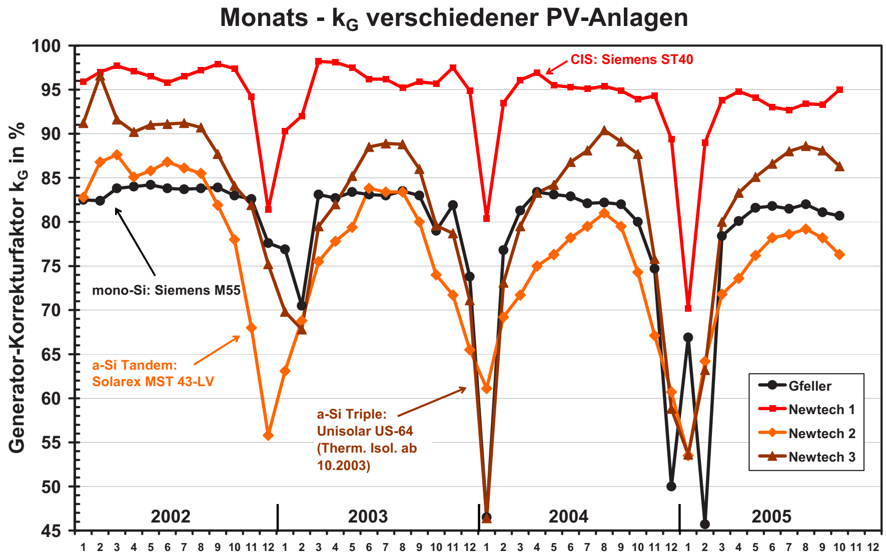
Bild 5:
Normierte Jahresstatistik der PV-Anlage Wankdorf Stade de Suisse vom 1.4.05 bis 11.12.05.
Wegen des flachen Anstellwinkels hat die Anlage in den Sommermonaten eine sehr hohe spezifische Energieproduktion und hohe Werte von k_G und PR, vor allem dank der Tatsache, dass die effektiv gelieferte PV-Leistung im Bereich der Nennleistung liegt. Allerdings ist die Winterproduktion tendenziell geringer und besonders anfällig auf Ertragsverluste infolge längerer Schneebedeckung. *Hinweis: Die automatische Hochrechnung auf ein Jahr ist wegen der hier noch fehlenden Wintermonate zu optimistisch.*

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 eigenen ASP Top Class Spark Wechselrichter (mit Trafo) ins Netz.

In Bild 6 werden die Generator-Korrekturfaktoren $k_G = Y_a/Y_T$ der drei Newtech-Anlagen und von einer Anlage mit kristallinen Siliziumzellen miteinander verglichen.

Bild 6:
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 (im Vergleich zu Newtech 2) deutlich gebremst. Wegen der geriffelten Oberfläche der Module US-64 ist Newtech 3 im Winter empfindlicher auf Schneebedeckung.



Anlage Mont Soleil

Die 1992 errichtete Anlage Mont Soleil hatte in den letzten Jahren immer wieder sporadische Ausfälle einzelner Teilfelder, die wegen der knapp dimensionierten Sicherungsautomaten der Teilfelder wahrscheinlich durch kurzzeitige Strahlungssspitzen oder thermische Überlastungen ausgelöst wurden. Bereits in verschiedenen früheren Publikationen wurde immer wieder auf dieses Problem hingewiesen.

Die Sanierung erfolgte in mehreren Teiletappen zwischen Ende April und Anfang Juni 05. Wegen der dazu notwendigen zeitweisen Abschaltungen der Anlage war die Produktion in dieser Zeit deutlich geringer. Vom 29.7. - 3.8.05 war der Wechselrichter wegen einer andern Störung ausser Betrieb. Seit Anfang August läuft der Betrieb nun besser, es wurden seither keine wesentlichen Störungen mehr registriert (siehe Bild 7).

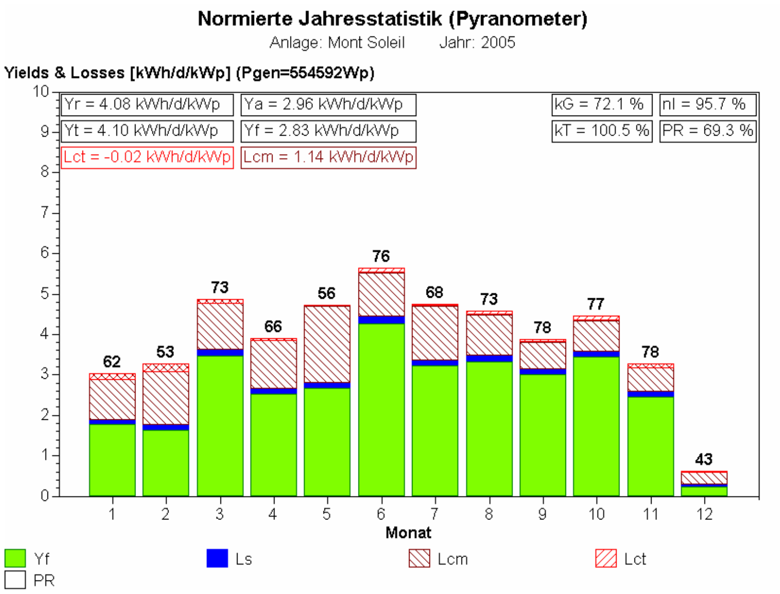


Bild 7:
Normierte Jahresstatistik der PV-Anlage Mt. Soleil für 2005 (Daten bis 11.12. 05).
Die hohen Lcm-Verluste im Winter sind vorwiegend auf Schneebedeckung, diejenigen in den Frühlingsmonaten auf sporadische Teilgenerator-ausfälle und die entsprechenden Sanierungsmassnahmen zurückzuführen. Es ist klar zu erkennen, dass sich die Situation seit August deutlich verbessert hat.

Anlage Jungfraujoch

Dank günstiger Wetterverhältnisse war die Produktion dieser Anlage im Frühling 2005 durch Schneebedeckung nur wenig gestört. Da auch die bisher (bis 11.12.05) in diesem Jahr registrierte Einstrahlung sehr hoch war, dürfte die Anlage in diesem Jahr einen neuen Rekord für die spezifische Energieproduktion (> 1500 kWh/kWp) aufstellen, wenn nicht noch ein schwerer Defekt oder extrem schlechtes Wetter auftritt.

Extremer Produktionsverlust bei einer Anlage in Burgdorf infolge Verschmutzung

Bei einer im Januar 1997 erstellten PV-Anlage auf dem Dach eines Schnellimbiss-Restaurants in Burgdorf, das an einer stark befahrenen Hauptstrasse und einer Regionalbahnlinie und zudem in unmittelbarer Nähe eines Sägewerks liegt, wurde im Laufe des Jahres 2005 ein deutlicher Abfall des spezifischen Energieertrags festgestellt. Die Anlage wurde daraufhin im Oktober 2005 vom Photovoltaik-Labor der HTI näher untersucht. Es wurde eine verschmutzungsbedingte Leistungsreduktion von gegen 29% festgestellt, was einen absoluten Rekord darstellt.

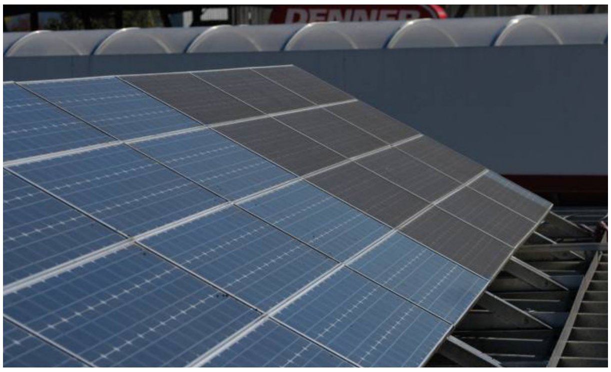


Bild 8:
Ansicht eines Teils des Solargenerators mit β = 30° der 3,3 kWp-Anlage mit Modulen M55 auf dem Dach eines Schnellimbiss-Restaurants in Burgdorf. Die Module vorne sind frisch gereinigt. Im Gegensatz zu früher gemessenen Anlagen sind die Module hinten hier nicht nur an der Unterkante, sondern auf der ganzen Fläche gleichmässig stark verschmutzt, deshalb ist der gemessene Leistungsabfall hier wesentlich stärker.

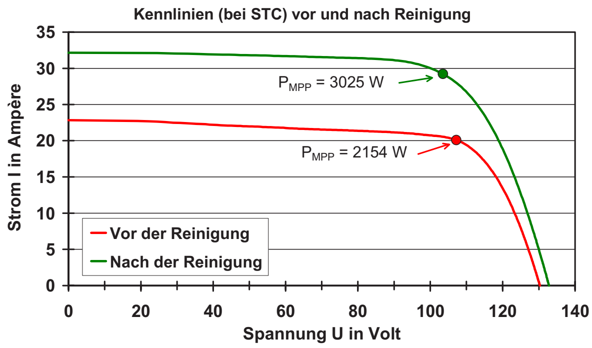


Bild 9:
Auf STC umgerechnete I-U-Kennlinie der PV-Anlage von Bild 8 mit einer Nennleistung von 3,3 kWp vor und nach der Reinigung.
Die vor der Reinigung gemessene Leistung P_{MPP} = 2154 W ist im Vergleich zur nach der Reinigung gemessenen Leistung von 3025 W um 28,8% geringer.

Nationale und internationale Zusammenarbeit

- Test von Wechselrichtern der Firma Sputnik Engineering AG.
- Test eines von einer Schweizer Firma entwickelten Kennlinienmessgerätes vor der Markteinführung.
- Durchführung vertraulicher Wechselrichtertests im Auftrag einer ausländischen PV-Grosshandelsfirma.
- Besuch einer Delegation von SMA und einer chinesischen Delegation im PV-Labor der HTI.
- Mitarbeit im NKN BRENET.

Referenzen / Publikationen **(online unter www.pvtest.ch > Publikationen)**

[1] H. Häberlin: "Wirkungsgrade von Photovoltaik-Wechselrichtern – Bessere Charakterisierung von Netzverbund-Wechselrichtern mit den neuen Grössen 'Totaler Wirkungsgrad' und 'Dynamischer MPPT-Wirkungsgrad'". Elektrotechnik 2/2005.

[2] H. Häberlin, L. Borgna, M. Kämpfer und U. Zwahlen: "Totaler Wirkungsgrad – ein neuer Begriff zur besseren Charakterisierung von Netzverbund-Wechselrichtern". 20. Symposium Photovoltaische Solarenergie , Staffelstein / D, 2005.

[3] H. Häberlin: "Langzeiterfahrungen mit zwei hochalpinen Photovoltaikanlagen". 20. Symposium Photovoltaische Solarenergie , Staffelstein / D, 2005.

[4] H. Häberlin und M. Kämpfer: "Optimale DC-Betriebsspannung bei Netzverbundanlagen - Wahl von U_{MPP}-Werten zur Wirkungsgradmessung bei Wechselrichtern und Wahl von $U_{MPP-STC}$ bei PV-Anlagen". 20. Symposium Photovoltaische Solarenergie, Staffelstein / D, 2005.

[5] H. Häberlin: "Rendement des onduleurs photovoltaïques - rendement total et rendement MPPT dynamique". Le monteur électricien 5/05.

[6] H. Häberlin, L. Borgna, M. Kaempfer and U. Zwahlen: "Total Efficiency η_{tot} – a new Quantity for better Characterisation of Grid Connected PV Inverters". 20th EU PV Conf., Barcelona, Spain, 2005).

[7] H. Häberlin: "Optimum DC Operating Voltage for Grid-Connected PV-Plants". 20th EU PV Conf., Barcelona, Spain, 2005).

[8] H. Häberlin: "Photovoltaik in der Schweiz – Die Schweiz droht in Europa abgehängt zu werden". Elektrotechnik 11/2005.

Ferner: Ausführliche Testberichte über Wechselrichtertests unter www-pvtest.ch > Wechselrichter-Testberichte.

Informationen über weitere Aktivitäten des Photovoltaik-Labors der HTI in Burgdorf und weitere Publikationen (teilweise online) sind unter http://www.pvtest.ch zu finden.

Annual Report 2005

The European Polymer Solar Battery EURO-PSB

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Project- / Contract Number	02.0248 / ENK5-CT-2002-00687
Duration of the Project (from – to)	01.01.2003 to 31.12.2005

ABSTRACT

The aim of EURO-PSB is to develop a self-rechargeable solar battery, i.e. a « tandem module », by coupling a polymer solar cell together with a thin rechargeable lithium-polymer battery. This completely new tandem device would have performances (capacity, voltage, current output, etc) and specifications (dimensions, efficiency and lifetime) compatible with small devices mentioned below. The use of organic polymers allows the use of flexible substrates like plastic sheets. It would then reduce the size and weight of conventional solar batteries and avoid dangers related to glass substrates. Beside, organic materials to be used here are absolutely non-toxic molecules, in sharp contrast to materials used in today's batteries (lead, etc).

The self-rechargeable polymer solar battery is a new concept that would not only overcome problems but also open new markets. A battery recharging itself by just leaving it exposed to room or day light for a few hours or devices with its power supply open to illumination through a transparent window and thereby powering itself (e.g. in remote controls, electronic games, wireless headsets, wireless keyboards for computers, safety lights for bikes, electronic tags) might even one day replace most of primary and rechargeable batteries sold today.

Introduction / Project goals

The objective of **EURO-PSB** is to develop a thin (<1mm) and flexible solar battery module by coupling on top of each other a polymer solar cell together with a lithium-polymer battery. The use of organic materials allows voltage matching (typically a few volts) between both components of the tandem device as well as specifications compatible with small planar devices (sensitivity to low or diffuse illumination, lifetime>10 years, flexible plastic substrates, etc). Integration of a self-rechargeable battery into small planar and mobile objects (cellular phones, smart cards, tags, remote controls, etc…) can revolutionize their use.

Brief description of the project

Our objectives are to design and fabricate the two appropriate individual components (the solar cell and the battery) and then interface them into a final solar battery module. The technical specifications (output currents, power and capacity of the battery as well as the respective sizes of both elements) will be adapted depending on the targeted application. For example, the output power required by a wireless keyboard for computers is obviously lower as compared to that required by a mobile phone.

*Example of a **Polymer Solar-Battery (EURO-PSB)** adapted as the self-rechargeable power source of a wireless computer mouse (courtesy of **Varta AG**).*

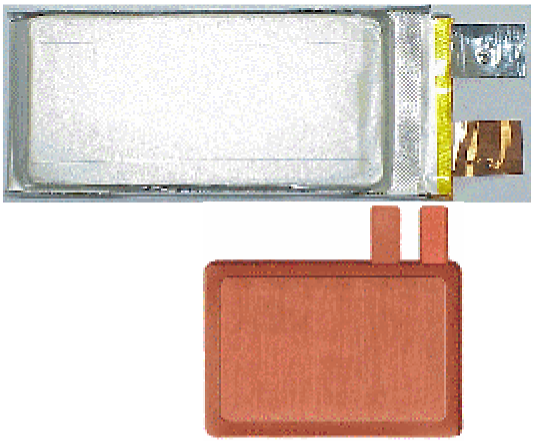
The polymer solar cell:

Polymer solar cells recently emerged as a potential alternative to Si-based or thin film photovoltaic systems. They are based on the use of interconnected polymer networks - composite materials prepared by mixing an organic material acting as p-type (hole transporting) and an organic or inorganic n-type (electron transporting) semiconductors respectively. A power conversion efficiency of 3.2% under a simulated solar spectrum (AM 1.5) has recently been obtained at the **Linz Institute of Organic Solar Cells** with a device using a fullerene C_{60} derivative as the electron transporting material and phenylene-vinylene polymer as the hole transporting material [1].

The rechargeable polymer battery

The rechargeable Lithium Polymer Batteries (LPB) is today's the most advanced battery technology. This batteries has low environmental impact, longest self life and highest energy density by moderate costs. Today's LPB are of similar technology as used for manufacturing lithium ion batteries where the Japanese dominated about 90% of the total world market. The use of more or less coiled lithium ion standard electrodes in a soft package of aluminium laminated film needs less additional investments in machine for LPB production but limits flexibility for design for batteries < 1 mm thickness.

In this project a flexible, thin lithium polymer battery will be developed by using thermal bonded electrodes of high flexibility. Even the shape of the new polymer battery can be adjust to the surface geometry of the **EURO-PSB** electronic devices. In comparison to Japanese technology, the thin LPB developped by **Varta AG** is leakage-free because the electrolyte is completely absorbed by the polymers (see below). In combination with a solar module, charge efficiency and high temperature stability has to be improved.



Two flexible portable batteries developped by Varta AG
Right: 0,4 mm primary Lithium Smard Card Battery. Left: 780 mAh Lithium Polymer Battery

The production of polymer batteries by **Varta AG** leads to an assembly startegy, which is in perfect agreement with the final assembly of the plastic solar cell be developed in our project. This even points to a possible "all-in-one" integration of the two devices in a further step into one integrated package.

The EURO-PSB workplan spans over 3 years. It comprises three essential technical parts:

1. Construction of the polymer solar cell and polymer battery,
2. Development of a substrate terminal with electrical interconnections,
3. Assembly of both the battery and the solar cell into a prototype tandem module.

It is divided into seven workpackages also including design and industrial checking, encapsulation, exploitation plan and management.

The first 18 months of the EURO-PSB project will be devoted to the design of the tandem module, evaluation of its performances and definition of its specifications. The two main components of the final solar battery module (solar cell + battery) will be developed separately while guidelines for market needs and technical specifications will be constantly refreshed. The main milestones will consist in delivering specimens of polymer solar cells, polymer batteries as well as writing a mid-term assessment report including revised specifications sheet and an updated exploitation plan. Specimens of individual components are intended to be delivered at mid-term of the project.

At the begining of the 2nd term of EURO-PSB, the electrical interface substrates aimed at hosting and interconnecting the solar cell and the battery, will be developed. The three components (solar cell, battery, and interface substrate) will then be assembled together into prototype modules. These prototypes will be encapsulated to prevent degradation from humidity, oxygen or light (battery only) and subjected to various technical evaluation tests (performances, durability, etc). Integration of prototypes into selected applications (smart cards, etc) will then be realized. Market tests will be performed in tight cooperation with developers in order to optimize the solutions brought by the new product and fulfill the customer's requirements.

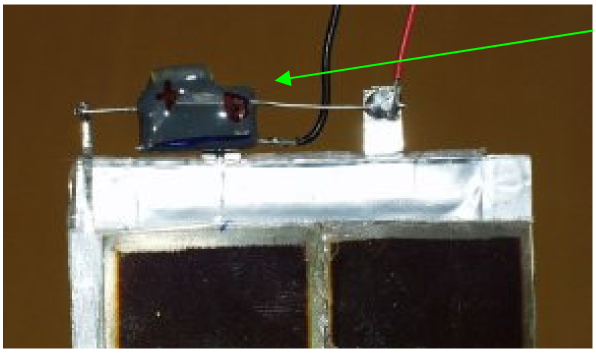
The last project year was focued on the realization of functional prototypes, having a thin polymer battery, a flexible solar cell and the corresponding matching/adapting circuitry – all integrated into an electronic application to demonstrate the proof of principle of the Euro-PSB flexible self rechaging solar battery.

Solaronix SA is responsible for the final prototype assembly, integrating all elements coming from the project partners.

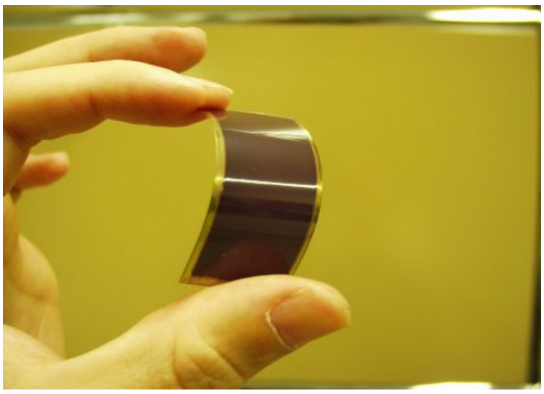
Work performed and results

Works done at **Solaronix** during the third and last project year.

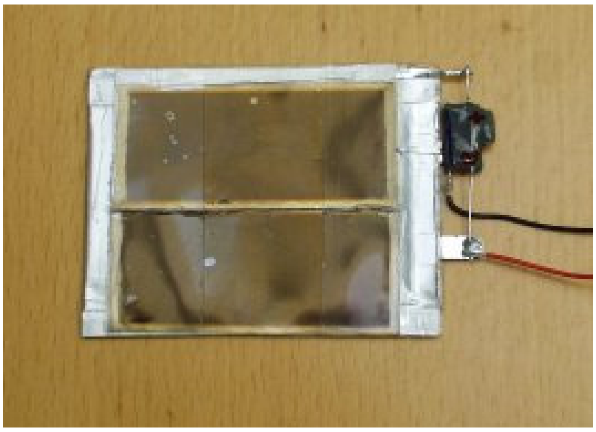
1. The DC/DC converter & battery controller (Version 4) was optimized for operation with 2 solar cells in low-light conditions.

 DC/DC converter connected to Li-ion battery and Dye Solar Cell module with 2 cells forming the Euro-PSB assembly	DC/DC converter (V4), size 13 x 7 x mm Quiescent current ~ 0.4 µA Charging voltage 4.1 V for Li-ion Maximal charging current ~ 20 mA Efficiency ~ 75 %

2. Flexible Dye Solar Cells were realized on 125 micron thick titanium foils

 Flexible Ti-foil based Dye Solar Cell	The Flexible Dye Solar Cell has a working electrode made on 125 µm thick titanium foil covered with ca. 10 µm nanocristalline TiO_2 as photoelectrode coated with red ruthenium dye. The counter-electrode with the Pt-catalyst is made of PET coated with ITO at 60 Ohm/sq surface resistance. The electrolyte is composed of iodide molten salt which cannot evaporate and giving good response in low-light conditions. Typically at 1000 lux (1 mW/cm^2) fluorescent light, the voltage is ca. 400 mV and the current is ca. 25 $\mu A/cm^2$ at the operation point.

Complete Euro-PSB modules consisting of the PoLIFlex Li-ion battery, the flexible Dye Solar Cell module with 2 or 4 cells and the converter/controller electronics were assembled and characterized.

	
Top view of Euro-PSB assembly composed of flexible Dye Solar Cell module, DC/DC converter and Li-ion battery. The entire package is flexible and can be bend around a radius of ca 10 cm. Size: 5 x 7 cm	Side view of Euro-PSB assembly, thickness < 1mm on battery area, ~ 3mm on converter electronics parts.

Finally working prototypes of electronic thermometers with radio transmitters were assembled using the Euro-PSB flexible solar battery as power source. Other prototypes were also tested with the original organic solar cell modules made at the University of Linz together with Solems for the laser pattering.

These prototypes are the final deliverables of the Euro-PSB project, to be handed out to the partners and the European Commission.

	
Back side of thermometer with radio transmitter equipped with the Euro-PSB flexible self rechaging solar battery based on Dye Solar Cells.	Thermometer equipped with fullerene / polymer organic solar module on glass made by Uni Linz. The module having a size of ca 5 x 6 cm, consists of 7 cells in series, separated by a YAG-laser scribing. In this prototype, the electronics are only controlling the battery voltage not to exceed 4.2 V during recharging.

National and international collaboration

The coordinator of **EURO-PSB** is **CEA-Saclay, France**. Since rechargeable lithium-polymer batteries are now a mature technology we have used use the ultra-slim Li-polymer battery developped by the German large company **Varta AG, Germany**, and having a thickness of 400 μm and a capacity of 25 mAh. Polymer solar cells are still in the development stage although their conversion efficiency has been considerably increased up to 2-3% recently. In this project, emphasis has been put on the polymer solar cell by combining the efforts of **CEA-Saclay** (materials synthesis and characterization), **Linz University, Austria** (device manufacturing and testing), and **Tallinn University, Estonia** (materials optimization). The substrate terminal and electrical interconnections between both components of the tandem device have been developped by **Solaronix S.A.**, **Switzerland**. Prototype assembly has been performed by **CEA-Saclay**, **Linz University** and **Tallinn University**. Application needs and industrial exploitation plan have been essentially under the responsability of a french SME **Solems S.A.**, **France**. Finally, as the coordinator of **EURO-PSB**, **CEA-Saclay** has been in charge of management.

Evaluation 2005

The last year was dedicated to prototype assembly and the latest batteries from Varta were received at Solaronix. Glass and polymer based organic solar cells were sent by Uni Linz. Solaronix also produced flexible Dye Solar Cells based on titanium metal foils and transparent conductive coated PET-foils, as backup in case the flexible organic solar cells would not be ready timely, as these rely on barrier layers that might not be available from the suppliers.

After verifying the function of the battery and the solar cells, prototypes of electronic thermometers and humidity sensors were made to test the functionality of the flexible battery/solar cell power source in various light conditions. It seemed that the Ti-foil based Dye Solar Cells worked perfectly well, even in very low light conditions and these type of solar cells might be an alternative to purely organic based solar cells, requiring extremely good oxygen and humidity barrier materials as subtrates.

Prototypes powered by Varta POLiFlexLi-ion batteries being recharged by organic solar cells (on glass to start with) and by flexible Ti-foil based Dye Solar Cells were shown in the final meeting in presence of the European Commision Officer. Later-on each partner and the EC-Officer will receive such a prototype made by Solaronix as "hands-on" deliverable of the project.

The continuation of the Euro-PSB collaboration is envisaged (in the form of a FP7 project ?) as the inductrial partners showed interest in developing commercial product based on the project's results and findings.

References and publications

Publication submitted to Solar Energy by G. Dennler et al.

Patent application under investigation.

Diverse Projekte und Studien

Annual Report 2005

SUNtool - A Sustainable Urban Neighborhood Modelling Tool

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Project- / Contract Number	EU NNE5-2001-753, OFES 02.0066
Duration of the Project (from – to)	January 2003 to December 2005

ABSTRACT

The project SUNtool (Sustainable Urban Neighborhood modelling tool) aims at elaborating a design tool for the urban planners, taking into account the criteria of sustainable development, and particularly the energy and resource flows. In particular, the renewable energy sources and the energy savings are considered.

The size of projects to be handled by the future tool can be anything between a small group of buildings and a whole urban area (maximum size considered should be around one km^2). A graphical user interface will allow the planners to enter the geometric data, and a smart building properties entry system will allow sensible default values, depending on building use, location and climate, and similar data, to be automatically chosen, with the possibility given to the tool user to override them.

The project has been started on January 2003. Its planned duration is 3 years, i.e. until December 2005. The tool version delivered by the project will be a "beta" version, ready for use by practitioners but with some space left for improvements.

The preceeding reports (years 2003 and 2004) presented rather in details the goals of the project and the results of the two first years of the project. The interested reader should refer to these reports for a complete description. In the present report, essentially the results of the last year of the project, as well as the perspectives for future work, will be presented.

Work programme and results already reached

The project is divided into 7 work packages:

- WP 1: Define project goals
- WP 2: Define data solver structure
- WP 3: Define GUI structure
- WP 4: Data acquisition
- WP 5: Develop prototype models
- WP 6: Develop graphical user interface and educational tool
- WP 7: Application

The project has suffered from some delay, essentially because one partner has retired from the project after one year of collaboration, and the work that it has done was finally not usable within the framework of the project. The delay was partially caught up, but never completely recovered. Currently, the definition phase (WP 1, 2 and 3) has been completed, as well as the data acquisition (WP 4). The prototype models (WP 5) have been also developed and implemented, except that some integration work still remains to be done at the solver level. The graphical user interface (WP 6) is also nearly completed, except some bugs remaining to be corrected; the educational tool is essentially completed, but only for the part that is not depending on WP 7. Finally, case studies (WP 7) was delayed because the solver was available later than anticipated (end of 2005 instead of mid 2005).

International and national collaboration

The project SUNtool is a collaboration between 6 partners. Each partner is in charge of a different aspect, depending on its main qualifications.

- BDSP Partnership, London, UK (coordinator): coordination, models of outside conditions and daylighting, solver.
- LESO-PB/EPFL, Lausanne, Switzerland: solver, stochastic models for the occupancy-related variables, data collection.
- EDF, Paris, France: solver, renewable energy systems models.
- CTU (Czech Technical University), Prague, Czech Republic: models of outside conditions, validation, data collection.
- IDEC, Piraeus/Athens, Greece: educational tool.
- VTT Building and Transport, Espoo/Helsinki, Finland: educational tool.

It should be noted that one partner (IESD/De Montfort University, Leicester, UK, in charge of the graphical user interface, building characterization and iDefaults) has withdrawn from the project. It has been replaced by a subcontracting to a small software company (Q-Sphere, London, UK), which has already done a significant part of the work.

At the Swiss level, two subcontractors of LESO-PB/EPFL, the municipalities of Lausanne and Morges, are participating to the project as data providers. They also committed to test the software when available.

Perspectives for the last months of the project

Since minor tasks are still remaining, it has been accepted by the partners that we use the 3 months delay accepted by the European Commission for the remittance of the deliverables, including the final report, i.e. until end of March 2006, to complete the remaining tasks.

The perspective for end of 2005 and beginning of 2006 at the Swiss level include the following:

- The finalization of the model development (completing of the implementation of stochastic models);
- The continuation of data collection, in order to make the available dataset larger (that data is needed for the validation of stochastic models);
- A comprehensive validation of stochastic models;
- The use of the completed tool on a case study (for Switzerland, several buildings of the Bellevaux district in Lausanne), both by EPFL and the communes of Lausanne and Morges, in order to get feedback for further improvements.

References and publications

(The technical reports and deliverable reports are not listed here, but they will be available at the end of the project. A list of deliverables is available on the public web site, see below.)

[1] SUNtool public web site: ***http://www.suntool.net***

[2] SUNtool public web site forum: ***http://www.suntool.net/forum***

[3] D. Robinson (BDSP), S. Stankovic (BDSP), N. Morel (EPFL), F. Deque (EDF),M. Rylatt (De Montfort University), K. Kabele (Czech Technical University), E Manolakaki (IDEC), J Nieminen (VTT): ***"Integrated Resource Flow Modelling of Urban Neighborhoods: Project SUNtool"***, IBPSA Conference, 2003

[4] D. Robinson (BDSP), S. Stankovic (BDSP), J. Page (EPFL), N. Morel (EPFL), F. Deque (EDF), M. Rylatt (De Montfort University), K. Kabele (Czech Technical University), E. Manolakaki (IDEC), J. Nieminen)VTT): ***"Integrated Resource Flow Modelling of Urban Neighborhoods: Project SUNtool"***, CISBAT Conference, Lausanne, 2003

[5] D. Robinson (BDSP), A. Stone (BDSP): ***"Solar radiation modelling in the urban context"***, Solar Energy 77 (2004), pp 295–309

[6] J. Page (EPFL), N. Morel (EPFL), D. Robinson (EPFL), J.-L. Scartezzini (EPFL): ***"Simulating Stochastic Demand of Resources in an Urban Neightborhood"***. CISBAT Conference, Lausanne, 2005

Annual Report 2005

PVSAT2 - Intelligent Performance Check of PV System Operation Based on Satellite Data

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Project- / Contract Number	BBW Nr. 02.0236 , ENK5-CT-2002-00631
Duration of the Project (from – to)	November 2002 until November 2005

ABSTRACT

PVSAT-2 is part of the EU program „energy, environment and sustainable development“ and aims to reduce outage time and maintenance effort of PV systems by developing a satellite based, fully automated monitoring via internet. The procedure calculates reference values of the energy production with the help of irradiance data derived from satellite pictures. On a central server these reference values are collected and compared with the monitored energy yield of the PV systems. (Monitored energy yield is transferred to the central server with a hardware device). Monitored and measured energy yields are automatically compared and analysed on a daily basis with an automated routine. This Failure Detection Routine considers also the behaviour of the PV system in the past and not only detects but also identifies different failures. All data and results are communicated to the operator of the PV system on a password protected internet platform. In case of a malfunction there's also the possibility of alarms via email or sms.

The PVSAT-2 project ended in November 2005 after a half year field test with 100 PV systems all over Germany, the Netherlands and Switzerland. The results showed that the procedure functions well and that the Failure Detection Routine could detect several failures as e.g. defect inverter, degradation, shading and power limitation due to undersized inverter. Accuracy of the irradiance derived from satellite data is about 10% on a daily basis and 5% on a monthly basis. Main problem was the transfer of the energy yield from the PV system to the central server, as the data logger developed within the project didn't function properly.

Enecolo will set up the PVSAT-2 procedure as a commercial service together with the company Meteotest with the name SPYCE. SPYCE will be commercially available in 2006 (www.spyce.ch)
The procedure will be further developed in other projects. Especially quality of irradiance data will be improved with a better model for snow and cloud detection and with the integration of actual aerosol data. These improvements are expected within one or two years. Information about snow cover will additionally be helpful for the Failure Detection Routine. The Failure Detection Routine will be extended by adding new failures and refining the methods for analyzing the failure patterns.

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Introduction / Project goals

PVSAT-2 is part of the EU program „energy, environment and sustainable development“ and aims to reduce outage time and maintenance effort of PV systems by developing a satellite based, fully automated monitoring via internet. Project partners are University of Oldenburg, University Utrecht, Meteocontrol GmbH, Fraunhofer Institut für Solare Energiesysteme (ISE), Hochschule Magdeburg-Stendal and Enecolo.

Within the PVSAT-2 project the following procedure shall be brought to readiness for marketing and tested in a one year field test:

- The hourly energy production of the PV systems is electronically registered and forwarded daily to a central server with a low cost hardware device.
- The reference energy yield of the PV system is calculated hourly with values of the global irradiation derived from satellite and ground measured data and with technical information about the properties of the PV system.
- Daily the Failure Detection Routine runs on the central server. It compares the effective and the theoretical energy production and searches for failures in the PV system.
- In case of a severe malfunction, the operator of the PV system is instantly informed per email or sms. All information about the performance of the PV system and the results of the Failure Detection Routine are permanently available on the internet for registered users.

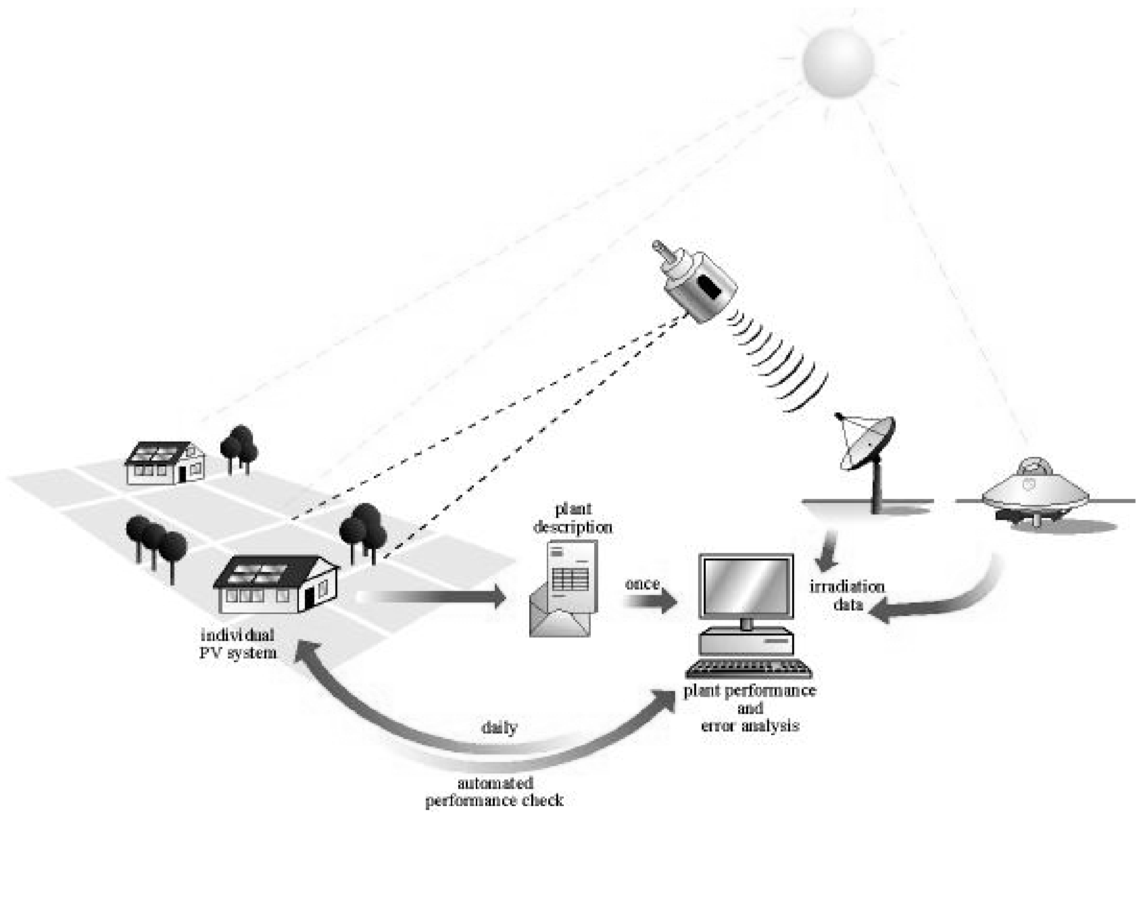

Figure 1: Functional principle of PVSAT-2

Brief description of the project

Within the project – coordinated by the University of Oldenburg – first all components of the PVSAT-2 procedure are developed and integrated. The whole service then is tested in a one year field test with 100 PV systems. The components to be developed and improved are:

- **Low cost hardware device** that will be integrated into the PV systems for automated measurements and two-way communication with a central client-server. This will increase the reliability of the on site energy production data and make the PVSAT-2 application more easy to use. Meteocontrol is responsible for this work package
- **Irradiance calculation scheme**: University of Oldenburg has developed in former projects a method to calculate irradiance from satellite data. Within PVSAT-2, University of Oldenburg will increase the accuracy of this method by using the new MSG data and additional on-line ground data for a kriging-of-the-differences interpolation. To support the decision making system, additionally information on the expected quality of the derived irradiance values is supplied.
- **Failure Detection Routine (FDR):** Enecolo develops a software which runs daily on the central server and automatically analyses the performance of the PV systems. Data basis are the monitored and simulated energy yields. In case of a malfunction, the FDR also determines its cause using different analyses. An integral part of the FDR is the **footprint method** which was developed at Fraunhofer ISE and considers not only the actual but also the former performance of the PV system.
- **Operational PVSAT-2 server**: the PVSAT-2 procedure will be set up operationally on a server of Meteocontrol and it will be tested in a one year test phase with 100 PV systems. University of Utrecht will evaluate the test phase.

The results of the project will be distributed in a workshop, with publications and with an internet presentation to the industrial PV community and to science.

Executed work and achievements in 2005

2005 was the last year of the PVSAT-2 project. The developments of the different components were mainly finished in 2004. In 2005 the PVSAT-2 procedure was tested in a half year test phase and the results were communicated in two workshops: one in Barcelona at the European PV Conference and one in Freiburg (D) at the Intersolar.

Enecolo had four main tasks in 2005:

- **Data logger:** in Switzerland 25 PV systems should have been equipped with the data logger developed by Meteocontrol and take part in the test phase. It turned out that the data logger doesn't function in Switzerland due to communication problems. In consequence the hourly energy yield of the PV systems had to be polled manually.
- **Failure Detection Routine (FDR):** The FDR was intensively checked with data sets of several PV systems in the test phase and with historical data. During these tests, several problems and possibilities for improvements were detected. Most of them could be solved by slightly changing the programming code or the configuration set. The most important improvement was the increase of the reliability interval from 66% to 95% for the calculation of the significant energy loss. Thus, the FDR will start erroneously at maximal 5% of the days. The FDR was additionally upgraded by including 2 new failures in the failure list of the FDR. (more details see below)
- **SPYCE**: Enecolo decided to set up the operational PVSAT-2 service together with the company Meteotest as a commercial service. This service will be called SPYCE and will be operated on a server of Meteotest. Test phase shall start in December 2005 and commercial start is planned in January 2006. Further information see www.spyce.ch.

- **Dissemination of the results**: Enecolo could present the Failure Detection Routine in an oral presentation at the European PV Conference in Barcelona, at the two PVSAT-2 workshops and at the 3rd IEA-PVPS Task2 Expert Meeting in Hameln. There were also several presentations of SPYCE and PVSAT-2 to potential customers of SPYCE and a flyer was distributed to more than 100 owners of PV systems, installation companies and inverter manufacturers in Switzerland and Germany.

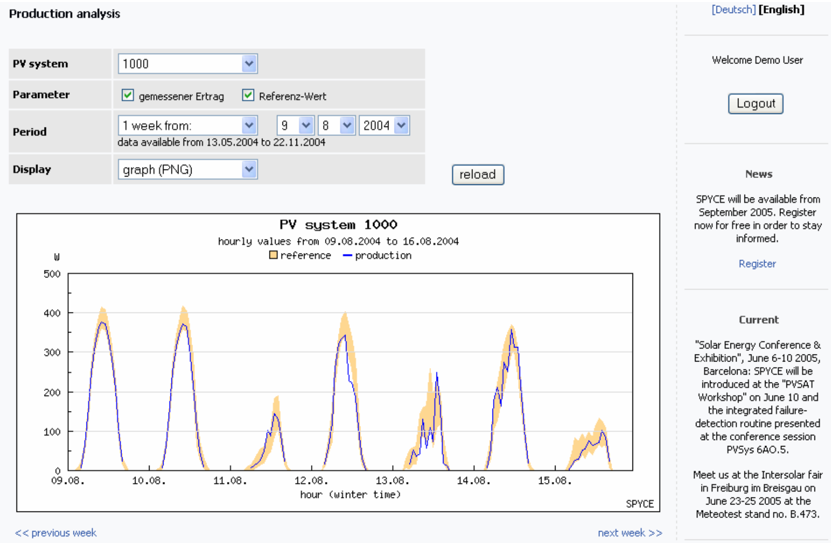

Figure 2: monitored and simulated energy yield of a PV system on the homepage spyce

Experiences with the Failure Detection Routine (FDR)

The results show that total blackouts were detected very fast and also daily energy losses of more than 20% were reliably detected at nice days. Lower energy losses can be detected at days with high irradiance in summer. The FDR not only detects failures but also identifies them. It can distinguish very well between constant energy losses of some percent (degradation, soiling, string or module defect), total blackout (due to inverter defect or defect control devices) and short-time changing energy losses (shading, hot inverter, MPP tracking etc.). Additionally thanks to the consideration of the ambient temperature it detects snow cover only at cold winter days and hot modules only at hot summer days.

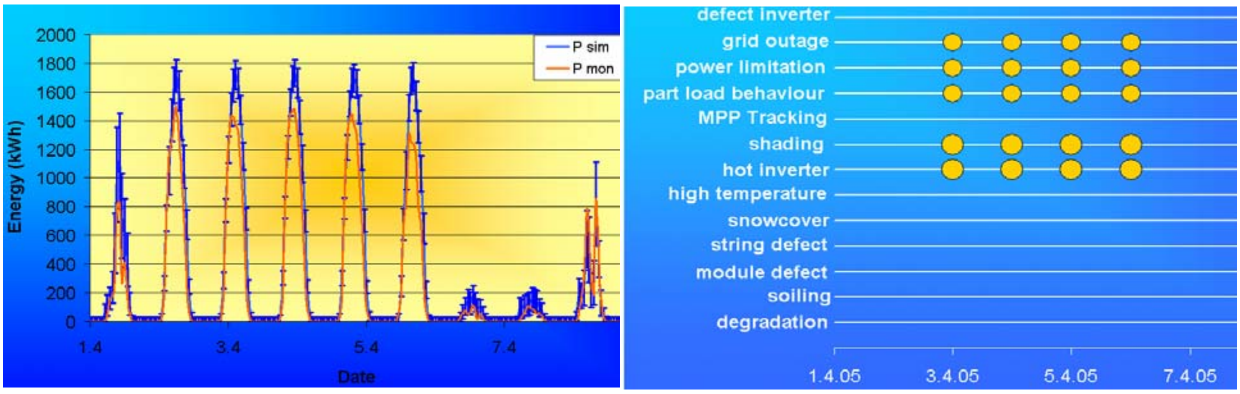

Figure 3: Power limitation at high irradiances in PV system CH-Tessin 3B. Simulated and monitored energy yield in the left picture, results of Failure Profiling in the right picture

The FDR only detects a failure if the measured energy yield is significantly lower than the reference energy yield. This means that erroneous starts of the Failure Detection Routine occur in at most 5% of the days (provided that the measured and reference yields are correct). Because the reliability of the irradiance calculation is higher at clear sky conditions and at high sun elevations, the potency of the Failure Detection Routine is highest at nice days in summer.

Of course results of the FDR were only reliable, if the necessary input data (measured and reference yields) were correct. In the test phase it occurred very frequently that the data logger did not send the energy yield to the central server. In these cases the FDR found a total blackout of the PV system and in consequence indicated a defect inverter or defect control devices. Another frequently occurring problem was a wrong system description (wrong azimuth angle, wrong installed power) which leads to wrong reference yields.

As a consequence, the FDR is very suitable in the actual version to detect total blackouts and, at nice days, also daily energy losses higher than 20%. Precondition are correct input data (measured and simulated energy yield). Several different failure classes can be distinguished very well (i.e. total blackout, constant energy losses, changing energy losses and snow cover). Within one failure class it is very hard to distinguish between individual failures, because the failure patterns are very similar. This will have to be improved in future versions of the FDR as well as a plausibility check of the input data will be necessary.

Results of the test phase

The test phase showed that the PVSAT-2 procedure is very helpful in monitoring the performance of PV systems. There were several failures detected, as e.g. power limitation due to undersized inverter, total blackout of inverter, degradation, snow cover etc.

But the test phase showed also different problems and restrictions of the PVSAT-2 procedure which are still not solved satisfactorily:

- **Hardware device:** the data logger developed within the PVSAT-2 project is not operational and the other data logging systems tested (e.g. MaxComm, SunnyBoy) are not fully automated and/or have high rates of data losses.
- **System description:** For a correct simulation of the energy yield a technical description of the PV system is crucial. It is intended that the owners of the PV systems fill in a form on the internet to describe their system. About 30% of the test users didn’t fill in the form correctly, which lead to wrong simulation results. It will be necessary to reduce these faults to get appropriate results.
- **Learning phase:** In more than 20% of the test systems, defects or problems were detected that could not be solved (e.g. shading, undersized inverter, degradation). By adapting the system description (e.g. reducing the installed power, adding horizons etc.) such failures can be excluded in a way that they are not detected by the FDR any more. This process needs an intensive cooperation with the operator of the PV system and therefore is very time consuming. It will have to be standardized to allow efficient handling of adaptations.
- **Irradiance calculation:** especially at cloudy days and at low sun elevations, uncertainties of the irradiance are still very high. Hourly uncertainties are in average about 20%, daily uncertainties about 10%. The kriging with ground data didn’t improve the accuracy as much as expected (at high irradiances accuracy is even better without kriging). In future projects accuracy shall be improved by using actual aerosol data and better snow and cloud detection schemes.
- **Failure Detection:** Although the FDR functions reasonably well it has still a high potential for improvement. As new input data for the routine information about snow cover would be of high value.

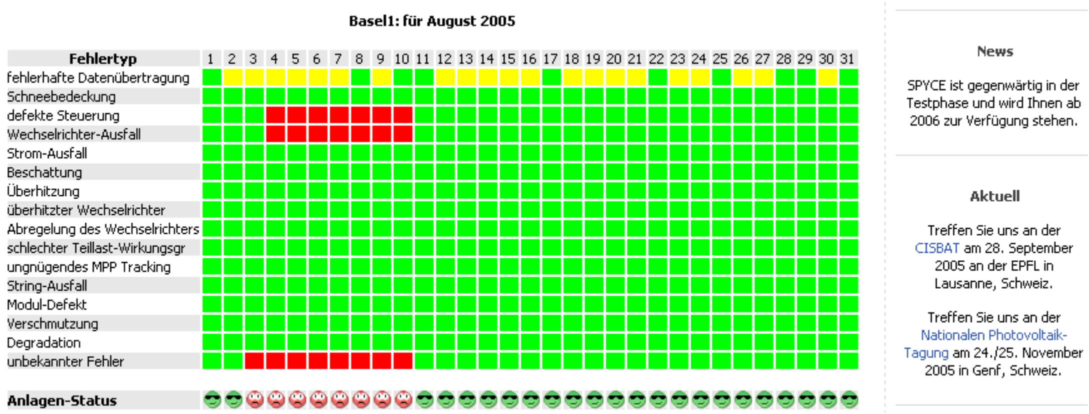

Figure 4: results of the Failure Detection Routine for a PV system with defect inverter from 4th to 10th August 2005

National / international collaboration

To set up the test phase and for preparations of the workshops, the collaboration with the project partners of PVSAT-2 was very intensive in 2005. There were several meetings and regular exchanges of information and data via email and telephone.

For our commercial service SPYCE we had intensive cooperation with Meteotest and regarding delivery of irradiance data for the SPYCE service, proceedings with Meteocontrol and University of Oldenburg were ongoing for almost one year. The intention of Enecolo was to purchase reference yields and irradiance data - equally to Meteocontrol - from University of Oldenburg. It turned out that there exists a contract between Meteocontrol and University of Oldenburg that guarantees exclusive rights for irradiance data acquisition to Meteocontrol. As we could not find a satisfactory solution, Enecolo finally decided to renounce on the irradiance data delivery from University of Oldenburg. Instead, Armines/ Ecole des Mines (France) will deliver irradiance data from MSG satellite for the SPYCE service. This solution has technical disadvantages as Ecole des Mines uses an older calculation procedure for irradiance data with higher uncertainties.

During the test phase of PVSAT-2, Enecolo had contact with several owners and operators of PV systems in Switzerland (e.g. Edisun Power AG, Allgemeine Baugenossenschaft Zürich ABZ, TNC, private persons) and also with installation and manufacturer companies (e.g. Sputnik, BENetz, TriTec, SMA). Feedback to the PVSAT-2 procedure was in general very positive, although the accuracy of the irradiance data was critically questioned. As soon as the SPYCE service will be operational, contact with these companies will go on in order to establish customer relationships. Several PV systems monitored by LEEE-TISO took part in the test phase, too. The results were communicated to TISO and will be discussed and analysed.

As the data loggers used in the test phase did not function reliably, Enecolo contacted several companies that produce and /or sell data loggers. There were contacts with about 15 companies, as e.g. Camille Bauer, Tixi, GMC Instruments, AS Solar, TriTec, Proton automation etc. Some of these contacts are continued and will hopefully result in an appropriate data logger for the SPYCE service.

Enecolo also checked the possibility of developing an own data logger. For this purpose there was an intensive contact with Istvan Szever, a student of the University of Budapest. Within his diploma thesis, he analysed technical possibilities of transferring energy production data to a central server and developed prototypes of data loggers.

International collaboration is also going on in the project ENVISOLAR, which has a strong link to PVSAT-2. ENVISOLAR is part of ESA's Earth Observation Market Development (EOMD) activities. It will help to set up the service chain SPYCE using ENVISAT and MSG data, see also www.envisolar.de.

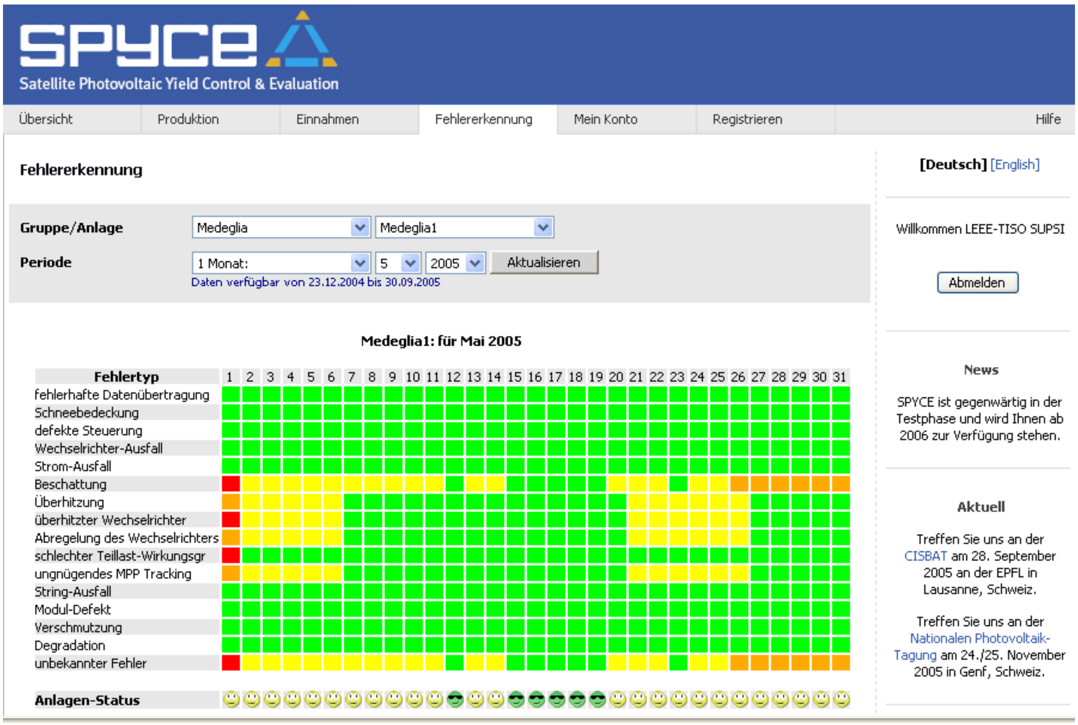

Figure 5: results of the Failure Detection Routine for a PV system with shading and power limitation at days with high irradiance

Evaluation 2005 and outlook 2006

The PVSAT-2 project ended in November 2005. Main new development within the project was the Failure Detection routine which was very successful. The test phase showed that the PVSAT-2 procedure helps to detect failures and to identify them.

Despite of this, not all goals of the project could be fulfilled completely: the data logger which should have been developed by Meteocontrol didn't function in Switzerland. Enecolo therefore had lots of hours of extra effort to test different data loggers and to collect monitoring data of PV systems.

The simulated energy yield proved to be accurate enough to detect energy losses in the range of 20%. This allows to start a commercial service for smaller PV plants, but to fulfil the quality criteria of bigger PV plants accuracy has to be improved.

At the beginning of the PVSAT-2 project it was intended that the companies Meteocontrol and Enecolo will set up a commercial service together. As it turned out that a teamwork of Meteocontrol and Enecolo would not be successful, Enecolo decided to set up its own service together with the company Meteotest. This cooperation has been very successful up to now and has resulted in the service SPYCE which will be operational from January 2006 on. As mentioned above, there occurred several problems in the acquisition of irradiance data due to an exclusivity contract between University of Oldenburg and Meteocontrol. As the proceedings were not successful, irradiance data for the SPYCE service now will be purchased by Armines/ Ecole des Mines (France).

Despite these problems the PVSAT-2 project was very successful for Enecolo: the Failure Detection Routine gained recognition in the scientific and the industrial community and will be developed further and maybe extended to other fields of application. The PVSAT-2 project also resulted in the commercial service SPYCE which will be started in 2006 and is intended to be continued for the next years. Cooperation with most of the project partners is going on in the project ENVISOLAR, which will endorse market trials for satellite derived irradiance data.

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Annual Report 2005

Energy specific Solar Radiation Data from Meteosat Second Generation: The Heliosat-3 project

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Project- / Contract Number	ENK5-2000-00332 / SBF 00.0364
Duration of the Project (from – to)	2001 - 2005

ABSTRACT

Remote Sensing from satellites is a central issue in monitoring and forecasting the state of the earth's atmosphere. Geostationary satellites such as Meteosat provide cloud information in a high spatial and temporal resolution. Such satellites are therefore not only useful for weather forecasting, but also for the estimation of solar irradiance since the knowledge of the light reflected by clouds is the basis for the calculation of the transmitted light. Additionally an appropriate knowledge of atmospheric parameters involved in scattering and absorption of the sunlight is necessary for an accurate calculation of the solar irradiance.

An accurate estimation of the downward solar irradiance is not only of particular importance for the assessment of the radiative forcing of the climate system, but also absolutely necessary for an efficient planning and operation of solar energy systems. Within the EU funded HELIOSAT-3 project solar irradiance data with a high accuracy, a high spatial and temporal resolution and a large geographical coverage will be provided, using the enhanced capabilities of the new MSG satellite.

Introduction / Project goals

The Meteosat Second Generation satellites (MSG, launched in 2002) will provide not only a higher spatial and temporal resolution, but also the potential for the retrieval of atmospheric parameters such as ozone, water vapour and with restrictions aerosols. With this more detailed knowledge about atmospheric parameters it is evident to set up a new calculation scheme based on radiative transfer models using the retrieved atmospheric parameters as input. Unfortunately the possibility of getting aerosol information from MSG data is limited, but appropriate information about aerosols is important for an accurate calculation of solar irradiance, especially for clear sky cases. Hence within the scope of energy meteorology applications this limitation is a weakness of the instrument design and the reason for the need of using additional satellite instruments (e.g. GOME/ATSR-2)

Work performed and results

Validation of the Solar Irradiance Scheme was the major task of this reporting period. Since a new cloud optical depth based scheme was not available in time, a scheme consisting of the new SOLIS clear sky method combined with an adapted and improved cloud index method was used. This is called the operational Heliosat-3 method. Different atmospheric inputs for the SOLIS clear sky model were tested. The Heliosat-1 method using Meteosat 7 data and the Heliosat-1 method using MSG data served as references. The data were validated on five test-sites in Western-Europe, three sations in south eastern Europe and twenty stations on the Canary islands.

It was found that:

- The use of MSG data, rather than Meteosat 7 data gave a significant improvement for all test-sites.
- Regarding the global horizontal irradiance, the operational Heliosat-3 method performed comparable with that of the Heliosat-1 method using MSG data for the west European test-sites.
- Regarding the global horizontal irradiance, the Heliosat-3 method performed considerably better than the Heliosat-1 method using MSG data for two Greek sites and the Canary Islands sites.
- The operational Heliosat-3 method gave a significant improvement for direct and diffuse horizontal irradiance for all locations, compared to the Heliosat-1 method using MSG data.
- The optimal aerosol input for the SOLIS clear sky module differed from location to location.
- The use of the NVAP water vapour database, instead of a default value, as input the SOLIS clear sky gave an improvement for all locations.
- The accuracy goals set in the proposal, an RMSE of 20%, 10%, and 5% for hourly, daily and monthly data have been achieved for most test-sites.
- It is expected that the use of NRT atmospheric data can further improve results.

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Annual Report 2005

Optimisation Technico-économique de systèmes de pompage photovoltaïques

Outil pédagogique et de simulation dans le logiciel PVsyst

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Project- / Contract Number	2005.04
Duration of the Project	July 2005 – March 2006

ABSTRACT

The main objective of this project is the elaboration of a general procedure for the simulation of photovoltaic pumping systems, and its implementation in the PVsyst software.

This first implies establishing a general model describing the pump electrical and hydraulic behaviour, valid over any running conditions encountered within a photovoltaic system. In order to be useful in such a general software, this model should be built using data usually available in the manufacturer's data sheets. We have developed a phenomenological model, which may be completely determined from several kinds of manufacturer specifications, including simplified to very detailed running data sets. The model precision will of course be function of the completeness of the input parameters data set.

This model will then be included in a simulation process of the whole PV and pumping system (hourly-step simulation), taking the environmental conditions into account, and involving the major technologies available on the market (direct coupling, booster, DC-input or MPPT converters or inverters, buffer batteries, use of conventional AC pumps, etc). Beyond the usual environmental variables (meteo, user's needs), many other operating characteristics should also be user-defined (variable static level over the year, dynamic drawdown level in a buried well, head corrections for pressure or level in the tank, friction losses, level limits, etc).

The simulation results include a great number of significant data, and quantify the losses at every level of the system, allowing to identify the system design weaknesses. This should lead to a deep comparison between several possible technologic solutions, by comparing the available performances in realistic conditions over a whole year.

This will be completed by a "preliminary design" tool performing a quick pre-sizing of the system. The whole design procedure will be extensively explained in the "Help", making a practical and pedagogic tool for pumping systems study, even for not quite expert engineers.

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Introduction / Buts du projet

Avec l'acuité croissante des problèmes d'approvisionnement en eau, surtout dans les Pays du Sud, le pompage photovoltaïque est appelé à prendre une grande importance dans les prochaines années.

Néanmoins le dimensionnement des systèmes de pompage photovoltaïque est un problème complexe. Plusieurs ensembliers ou fabricants de pompes proposent des solutions standard "clé-en-main", selon leur propre expérience ou leurs outils d'étude dédiés. Mais il n'existe (à notre connaissance) aucun outil informatique indépendant, permettant de dimensionner et simuler de tels systèmes en détail, avec suffisamment de généralité et de précision.

L'ingénieur ne dispose donc d'aucun moyen pour effectuer l'optimisation d'un système de pompage exactement adapté aux besoins d'un projet particulier. L'objectif de ce projet est de lui fournir les bases de calcul nécessaires, tant pour le dimensionnement que pour la comparaison détaillée des performances de diverses options technologiques, ainsi que son évaluation économique.

Ce projet comprend les étapes suivantes:

- Etablir un modèle général décrivant le **comportement électrique et hydraulique d'une pompe**, valable pour toutes les conditions de fonctionnement rencontrées dans un système photovoltaïques. Pour pouvoir être utilisable dans un logiciel général, ce modèle doit pouvoir être établi à partir de données usuellement accessibles dans les spécifications des fabricants. Nous avons développé un **modèle phénoménologique**, complètement déterminé à partir de divers ensembles de paramètres, allant du très simplifié au très complet. La précision du modèle sera évidemment fonction de la complétude des paramètres d'entrée.
- Implémenter ce modèle de pompe comme **composant du logiciel PVsyst**. Rappelons que PVsyst est un logiciel de simulation de systèmes photovoltaïques, largement utilisé dans le monde entier (340 licenses, 750 utilisateurs dans 48 pays). Il est généralement considéré comme l'outil de référence pour l'étude de systèmes PV.
- Donner à l'utilisateur les moyens de définir les paramètres nécessaires au modèle, avec vérifications de cohérence, et affichage détaillé (graphiques) du comportement de ce modèle en fonction de divers paramètres. Création d'une fiche de spécifications exhaustive décrivant les paramètres et le comportement du modèle pour chaque pompe modélisée.
- Créer une **base de données** des principaux modèles de pompes adaptées à l'utilisation dans un système photovoltaïque, disponibles sur le marché. Cette base pourra évidemment être complétée par l'utilisateur.
- En collaboration avec le CIEMAT (Centre de recherches, Madrid), qui dispose d'un banc de mesures spécialisé, vérification de la **précision des résultats** du modèle à l'aide de mesures détaillées effectuées par cet Institut sur plusieurs pompes de diverses technologies.
- Ce modèle est inclus dans un **processus général de simulation** du système de pompage complet (simulation heure par heure), tenant compte des conditions environnementales (météo, besoins de l'utilisateur) et des diverses technologies actuellement disponibles (couplage direct, booster, convertisseurs de puissance, batterie tampon, pompes en cascade, reconfiguration du champ PV selon puissance).
- Les technologies de couplage PV-Pompe sont déterminées par les caractéristiques d'un composant "Régulateur", qui permet de définir en détail les paramètres de chaque type de convertisseur envisageable (limites de fonctionnement, efficacité selon la puissance, etc.).
- Plusieurs types de systèmes de pompage sont implémentés: puits foré (avec ses caractéristiques dynamiques), pompage dans un lac ou un cours d'eau, système de pressurisation, etc. Les besoins de l'utilisateur peuvent être spécifiés en détail.

L'implémentation de cet outil dans le logiciel PVsyst **garantit son accessibilité à tous**, et permet de bénéficier de l'environnement général déjà existant pour l'étude et la simulation de systèmes photovoltaïques.

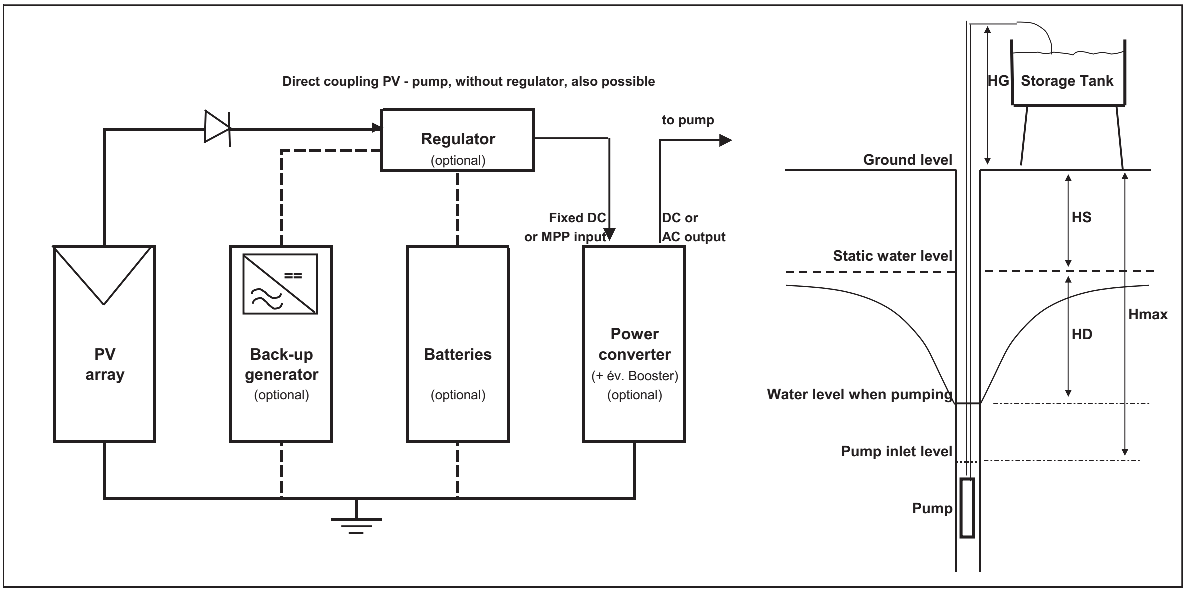

Fig 1.: Schéma global d'un système de pompage –
Avec quelques options possibles pour la simulation

Brève description du projet

Dans ce projet, le point crucial est la modélisation de la pompe. Dans la littérature solaire, on trouve quelques rares tentatives de modélisation, toujours basées sur les paramètres physiques spécifiques d'un ensemble moteur-pompe, obtenus par des mesures ah hoc pour une pompe donnée.

Les conditions pour l'implémentation d'un modèle de pompe utilisable dans un logiciel général de simulation, sont les suivantes:

- Le modèle doit décrire l'évolution dynamique d'une variable de sortie – le débit – en fonction de variables d'entrée pertinentes, qui sont la puissance absorbée et la pression dynamique requise. Pour diverses configurations (et notamment l'étude du couplage direct), il est également nécessaire de connaître la caractéristique courant/tension d'entrée. Contrairement aux systèmes de pompage classiques (réseau), qui fonctionnent à tension fixée et puissance déterminée, ces relations doivent être établies **dans toute la gamme des conditions de fonctionnement** possibles dans un système solaire. De plus, certaines pompes requièrent des conditions spéciales de démarrage dont il faudra tenir compte.
- Le modèle doit être capable de couvrir **tous les types de pompes** disponibles sur le marché (centrifuges ou à déplacement – piston, membrane, diaphragme, cavité progressive, déplacement rotatif, etc. –, avec diverses technologies de moteurs CC ou AC). Ceci justifie le choix d'un modèle phénoménologique agissant sur les variables d'entrée/sortie, sans entrer dans les détails technologiques.
- Les paramètres nécessaires à l'établissement du modèle doivent être **disponibles dans les spécifications du fabricant**. Le modèle sera calqué principalement sur les performances annoncées dans certaines conditions de fonctionnement. Des considérations générales, établies grâce aux mesures détaillées soit trouvées dans la littérature, soit effectuées par le CIEMAT, doivent nous permettre d'étendre la modélisation aux conditions marginales de fonctionnement. Bien entendu, la modélisation sera plus précise lorsque les données couvriront une gamme de conditions de fonctionnement plus large.
- Le dimensionnement d'un système de pompage et le choix optimal d'une technologie de couplage PV-pompe dépendent de nombreux paramètres, liés aux conditions météorologiques, aux besoins de l'utilisateur, aux caractéristiques du puits et du stockage, ainsi qu'aux modes de financement. Il n'existe pas de solution "standard". La compréhension profonde du comportement

d'un tel système ne peut s'appuyer que sur une simulation détaillée de différentes options, dans les conditions réelles d'utilisation.

- Par les possibilités de simulation et les résultats qu'il présentera à l'utilisateur, ce logiciel constituera un **outil pédagogique** de valeur pour l'approche d'un système de pompage. Nous prévoyons un développement important de la présentation des diverses solutions envisageables dans l'aide en ligne, tenant lieu de cours détaillé sur les systèmes de pompage photovoltaïques.

Travaux effectués et résultats acquis

Modélisation de la pompe

Nous disposons maintenant d'un modèle de pompe conforme à nos prévisions citées ci-dessus, et parfaitement utilisable dans le processus de simulation. Ce modèle a été validé en utilisant les données mesurées en détail au CIEMAT [3]. Nous avons testé la précision de plusieurs modes de définition du modèle, en restreignant dans chaque cas les paramètres utilisés pour établir le modèle selon divers sous-ensembles choisis dans les données.

Un premier exemple illustre les résultats obtenus avec une pompe à "déplacement positif" (cavité progressive), model BU de Watermax. La figure 2 en montre le comportement général, ainsi qu'une grille de 16 points de fonctionnement à différentes tensions, choisis comme base du modèle.

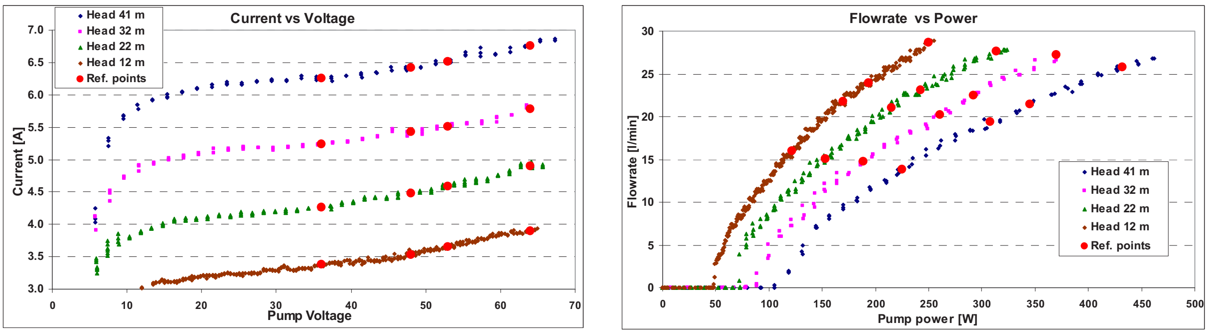

Fig 2.: Mesures de la pompe Watermax BU, avec points de référence à tensions fixes.

On peut alors constater que le modèle basé sur ces 16 points de fonctionnement donne d'excellents résultats, permettant de calculer le débit dans toutes les conditions d'utilisation, avec une très bonne précision hormis aux très petites tensions ou débits.

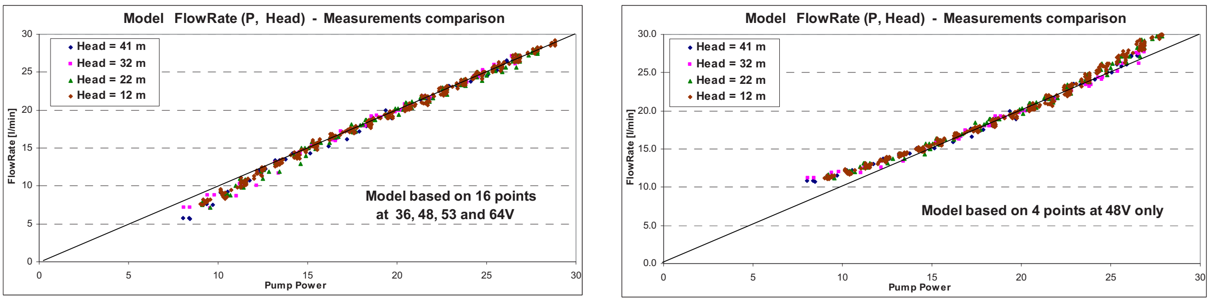

Fig 3.: Comparaison du débit simulé avec les valeurs mesurées, pour les données ci-dessus

D'autre part, si nous ne disposons que de 4 points de fonctionnement pour établir le modèle, les performances se dégradent un peu pour les tensions extrêmes, mais restent encore acceptables pour réaliser de bonnes simulations.

Les pompes centrifuges spécifiques pour les applications solaires sont en général bien spécifiées par les fabricants, par un réseau de courbes Débit/Puissance pour différentes pressions. Ces données permettent d'établir le modèle avec une précision comparable à celle décrite ci-dessus.

Avec le développement de convertisseurs adaptés [1], les pompes centrifuges "standard" destinées à une utilisation à tension fixe sur le réseau, sont susceptibles de prendre une part importante du marché dans les installations solaires, du fait qu'elles sont plus courantes et donc moins chères. Cependant les fabricants ne donnent en général qu'une seule courbe de pression en fonction du débit, pour la tension (vitesse) nominale. L'établissement d'un modèle pour PVsyst nécessite alors la donnée de l'efficacité ou la puissance pour trois points au moins sur cette courbe.

Le modèle tire parti d'une propriété spécifique aux pompes centrifuges, appelée "lois de similarité" [1, 7] qui stipule qu'à efficacité égale, la puissance varie avec le carré du débit, et la pression avec son cube. Ces lois conduisent à une modélisation qui fonctionne étonnamment bien autour des conditions nominales, mais s'écarte des données mesurées autour du seuil de fonctionnement.

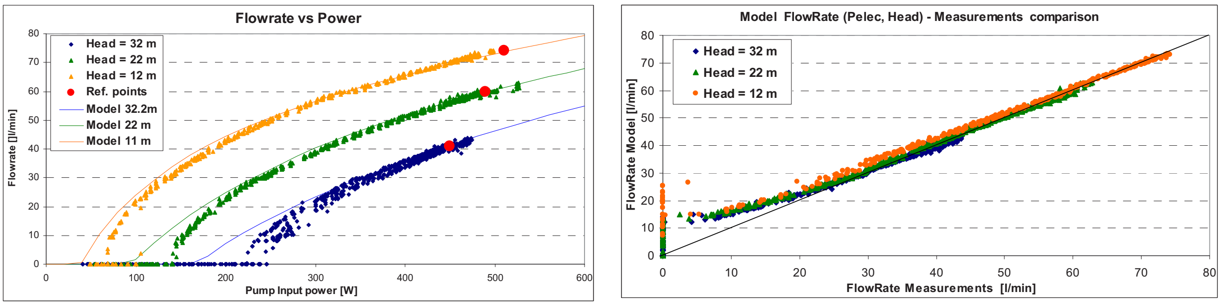

Fig 4.: Pompe centrifuge: modélisation selon 3 points de fonctionnement (Puissance, Débit, Pression) à tension nominale (78V).

PVsyst offre la possibilité de corriger cet écart dans la partie inférieure, mais au prix d'une définition explicite du seuil de fonctionnement par l'utilisateur, donnée rarement disponible.

Une fois le modèle établi, PVsyst permet d'afficher et d'appréhender le comportement du modèle grâce à une série de graphiques d'une grande valeur pédagogique, et propose un outil pour évaluer le fonctionnement de la pompe dans n'importe quelles conditions spécifiées.

Simulation détaillée du système de pompage

La spécification du système débute par la définition du type de configuration (puits foré, avec baisse de niveau dynamique selon le débit, pompage dans un plan d'eau, pressurisation pour la distribution, circulation, dimensions du stockage). L'utilisateur est ensuite invité à définir les besoins en eau (au besoin en valeurs mensuelles), et une éventuelle variation annuelle des niveaux. La fig 5 en donne un exemple.

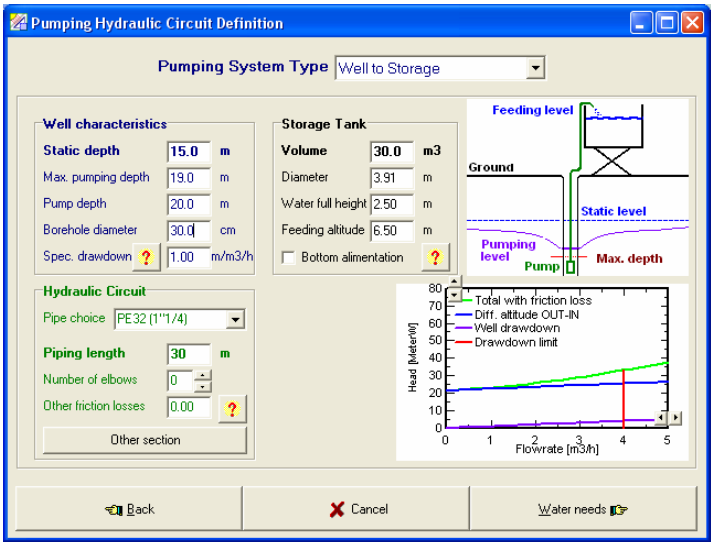

Fig 5. : Dialogue de définition de la configuration système

Bien entendu, la signification de chaque paramètre et ses implications sera définie en détail dans l'aide en ligne (notamment accessible à l'aide des petits boutons "?").

Le dimensionnement du système (pompes et champ PV) est un point extrêmement délicat. En particulier pour les systèmes à couplage direct, l'adaptation électrique des caractéristiques PV aux conditions de fonctionnement de la pompe dans le système considéré nécessite une évaluation détaillée, en tenant compte des seuils, des courants de démarrage éventuels, et des surcharges (en tension ou puissance) que peut endurer le système de pompe(s). Ce dimensionnement est facilité par un graphique, dans lequel la caractéristique pompe tient compte de tous les paramètres système (pertes de charge et de "drawdown, puissance et tension maxi, etc). Un graphique analogue illustrera les configurations spéciales comme le démarrage de pompes en cascade, ou encore la reconfigurati0on du champ PV selon l'irradiance.

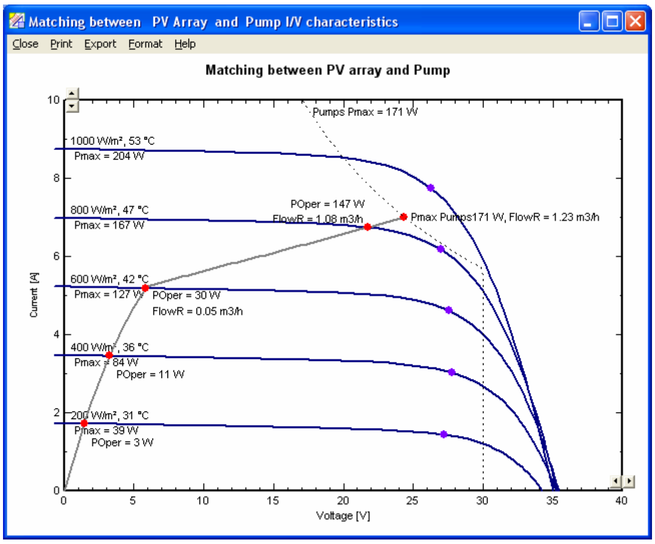

Fig 6.: Aide au dimensionnement électrique pour les systèmes à couplage direct

La configuration électrique du système, et notamment du couplage PV-pompe, est définie par les propriétés du régulateur, au cœur du système.

Elle comprendra le couplage direct PV-Pompe, avec diverses variantes telles que Booster pour le courant de démarrage, démarrage de plusieurs pompes en cascade selon l'irradiance, reconfiguration du champ PV pour optimiser le seuil de courant de démarrage. Le régulateur pourra inclure un convertisseur de puissance (input DC fixe ou à recherche du point de puissance maximum), sortie DC ou AC selon la technologie de la pompe, un régulateur pour une batterie-tampon, et/ou un générateur auxiliaire.

Le régulateur doit également gérer diverses conditions de fonctionnement, comme l'arrêt du pompage lorsque le stockage est plein ou le niveau de soutirage est inférieur au minimum. D'autre part, comme l'illustre par exemple la figure 6, il doit limiter la puissance, la tension ou le courant appliqués au système de pompes selon les caractéristiques de ces dernières, pour éviter tout risque de les endommager.

Dans une première passe de la simulation, l'utilisateur peut choisir seulement le mode de fonctionnement et les contraintes, dans le cadre d'un régulateur virtuel par défaut. Le choix d'un régulateur réellement existant sur le marché peut se faire dans une deuxième phase du développement du projet.

Finalement, la simulation détaillée complète aboutit, outre le rapport et les nombreux graphiques de résultats habituels dans PVsyst, à un diagramme complet des pertes du système, qui permet d'évaluer immédiatement les points faibles du système et de son dimensionnement.

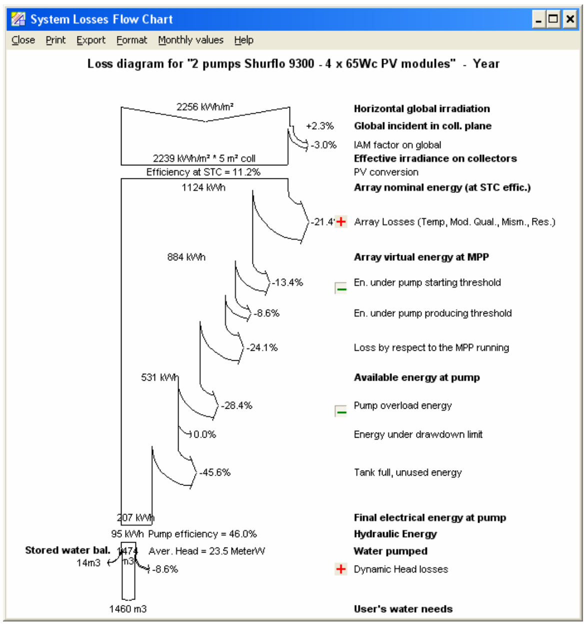

Fig 7. : Simulation détaillée: diagramme des pertes

Nous disposons donc maintenant de la structure générale du logiciel, jusqu'à la gestion de la simulation détaillée. Il nous reste à en consolider le fonctionnement, à compléter l'interface-utilisateur pour la définition des divers types de systèmes envisagés, et à parfaire les valeurs-guides proposées à l'utilisateur pour un dimensionnement raisonnable, ainsi que les limites imposées à la définition des paramètres

Collaboration nationale et internationale

Nous avons des échanges extrêmement fructueux avec le CIEMAT, à Madrid. Ce laboratoire de recherche a effectué des mesures systématiques du fonctionnement de diverses pompes commerciales, destinées à un usage photovoltaïque. Mesures dont il nous a gracieusement fourni les résultats, qui ont servi de base pour la mise au point et les tests de notre modèle.

M. Miguel Alonso nous a également fait part de ses réflexions et de son expérience sur la modélisation de pompes – notamment centrifuges – et nous lui soumettons nos résultats pour évaluation.

Nous avons également des contacts avec l'Association Ingénieurs et Architectes Solidaires, organisation ayant déjà réalisé plusieurs installations de pompage en Afrique. Nous comptons sur leur expérience de terrain pour une évaluation ultime du logiciel et de son aide en ligne pédagogique.

Évaluation de l'année 2005 et perspectives pour 2006

Le projet a suivi normalement son cours durant l'année 2005. Nous disposons maintenant:

- d'un modèle de pompe cohérent, avec son interface de définition par l'utilisateur,
- de la structure logicielle nécessaire à la simulation complète du système,
- de la forme générale de la partie "pré-dimensionnement".

Pour l'année 2006, il nous reste à compléter le processus de simulation pour d'autres typologies de systèmes plus complexes (notamment pressurisation et systèmes à batteries), à établir des fiches de paramètres imprimables pour la présentation du système et des résultats, et à déterminer les paramètres raisonnables, nécessaires au pré-dimensionnement ainsi qu'à la définition des limites lors du dimensionnement du système, en s'appuyant sur les simulations détaillées.

Il nous reste également à compléter la base de données des pompes, ainsi qu'à rédiger l'aide en ligne détaillée qui doit guider l'utilisateur dans le développement de son projet. Nous espérons pouvoir mettre cette nouvelle version de PVsyst à disposition des utilisateurs dans le courant du printemps 2006.

Références et publications

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[10] ***PVsyst software.*** CUEPE, University of Geneva. www.pvsyst.com

Annual Report 2005

PV Catapult - WP9

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Duration of the Project (from – to)	01.12.2003 – 31.01.2006

ABSTRACT - WP9 ENERGY PREDICTION OF PHOTOVOLTAICS

The accuracy of several modelling methodologies of the energy yield of photovoltaic devices has been investigated within this work-package of the PV-Catapult project.

The starting point was the existence of a number of different modelling approaches but a lack of knowledge of accuracy of these (most are validated for single sites only). The aim was to identify accuracy and research needs in energy production approaches.

The work have been split into four stages:

1. Review of existing energy prediction methods on the basis of a questionnaire
2. carry out ‘best-case’ round robin comparison of prediction methodologies
3. carry out ‘realistic’ round robin of prediction methodologies
4. Phrase the lessons learnt in guidelines to be used for future use

Crystalline as well as thin film modules were investigated within these round robins. The best case round robin leaded to statistical variations in the order of 2-3% deviation of the predicted energy yield with respect to the measured values. Once translations from one site to another are considered, this inaccuracy goes up to 4-6% as long as the precise efficiency of the module is known. If the modules have changed significantly or the name-plate efficiency of the module to be modelled deviates significantly from the input, errors in the 15% range were observed. Overall the rating is the single most important input into any of the models, as this has a direct influence on the accuracy of energy prediction.

1. Evaluation of Prediction Methodologies

A questionnaire was developed and sent to all participants in this work-package and other interested parties. This represented a large proportion of the methods under development within the EU, although no commercial tools were included. Six questionnaires were returned, the results are summarised in the following. The description of the single methods can be found in the final report which will be shortly published.

Name of Modelling Method	**Developed By**
Matrix	LEEE
MOTHERPV	CEA
Back Temperature	CEA
On-Line Yearly Yield Simulator	ECN
SOMES	UU
SSE	CREST

Table 1: List of the performance models reviewed in this work along with the location of their research centres.

2. First Round Robin 'Best-Case-Scenario'

The first round robin (RR) was then carried out by giving each centre 2 years of data for 5 different PV modules from 3 locations. Table 2 lists these modules with information about their location and main STC values. Each centre was sent the data for the first year including environmental and PV electrical measurements. The data for the second year was limited to environmental measurements only, for the purpose of the simulation of a blind RR. The 3 sites chosen provide a good representation of the climatic conditions experienced in Europe.

Module Generic Name	cSi_1	cSi_2	cSi_3	CIS	aSi-2j
Location	A	B	C	C	A
Latitude	43°39	51°06	46°01	46°01	43°39
Pmax /W	105	36.15	100	40	40
Temp.Coeff. (Pmax) %/C	-0.43	-0.44	-0.47	-0.6	-0.22
Eff/ %	11.7	14.5	12.1	9.4	5.3

Table 2: PV modules with their STC values. A= Cadarache, F; B= Wroclaw, Pl; C= Lugano, CH.

Each modelling method required certain input parameters, which are listed in Table 3. Where the parameter was not measured or the method required it to be calculated as it is common practice by the particular institution. In the case of SSE, where the spectrum is typically measured, this was simply neglected, which will in turn add an error of 3-5% over the normal accuracy.

Environmental Inputs	**Matrix**	**MOTHER PV**	**Module Back Temp**	**On-Line Simulator**	**SSE**
Ambient Temperature	X			X	
Device temperature		X	X	XC	X
Irradiance in plane (POA)	X	X	X	XC	X
Irradiance horizontal				X	X
Spectral information					X

Table 3: Environmental inputs required by each model, XC indicates the variable will be calculated.

Results

The first task of the RR was to identify how accurately the energy production could be re-calculated for the base line year, i.e. the year where the electrical data was used for the calculation. This clearly is not an independent test but represents the best case scenario. Figure 1 shows the error during this characterisation year between the measured and modelled energy yield.
It might be expected that the errors arising from this same-year consistency check would be low. This is generally the case, but with a noticeable difference between the SSE and On-line Simulator and the other models. In the case of the online simulator this is largely due to the calculation of the irradiance from the horizontal irradiance, while the SSE suffers from a lack of data cleaning. Furthermore, SSE is based on the name-plate efficiency and the module under test might have very different efficiencies. This was to be investigated further in the second round robin.

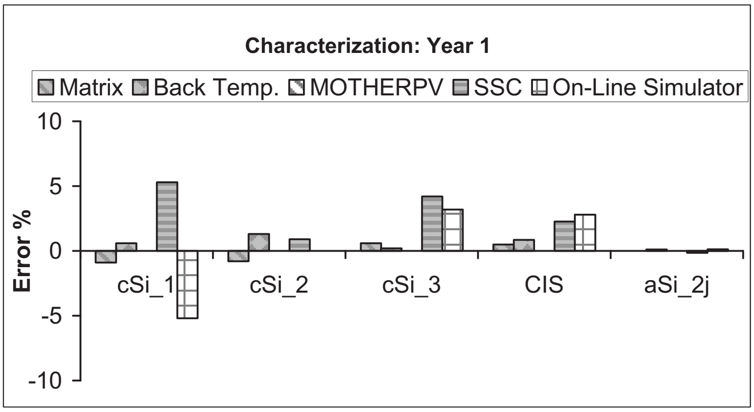

Figure 1: Shows the error between the measured and modeled energy yield for year 1 dataset from the difference centres.

The a-Si_2j device had been operating for more than 6 months prior to the data used here, hence initial degradation had already occurred and relatively stable performance is observed in the data used for the RR. The matrix method was not applied to this module, as this specific module has not yet been characterised through the required laboratory measurements.

Surprisingly, the highest errors occur for the c-Si devices. Again, SSE and online calculator methods have noticeable deviations, for different reasons. The On-line Simulator is based on ambient temperature and horizontal irradiance, while the other models are based on module temperature and in-plane irradiance. This introduces further steps in the modelling, which will result in larger error margins. Furthermore, the calculations introduce some approximation (e.g. thermal mass of a module), which will introduce further complications. Given these additional steps, the results of the simulations are actually very close to the measured energy production.

The reasons for the over-prediction of SSE is in the difference in data cleaning and the reliance on STC efficiency, which is demonstrated in the second RR. In the other models, these effects are masked because the required parameters are calculated directly from the outdoor measurements the normalisation is built into the process.

The methods MOTHERPV, Module Back Temperature and Matrix handle all modules well. The MOTHERPV model specifically has virtually no error, which is largely due to the input data being identical to the one used for the calculation of the energy output.

In the second step, a temporal translation was carried out, i.e. the year to year variation. Only the environmental data supplied from the second year of data was supplied to the modelling teams, with the measured electrical data held back to validate the blind modelling results. Typically, the error doubled for most methods. This is still within reasonable accepted errors as seen in Figure 2. It is apparent that the easiest module to predict in the same-year calculations, the aSi_2j module, exhibits significant overestimation of energy production for all the approaches. This illustrates the difficulties in predicting energy yields for thin film devices. The error obtained for the c-Si devices is typically less than 8%. This module is particularly easy to predict because its performance experiences a very limited impact of elevated temperatures and variations in the irradiance. The On-line Simulator experienced some difficulties with the module data from Wroclaw, Poland. The reason for this is that the horizontal irradiance does not translate well into the inclined irradiance and a constant tilt was assumed over the year while the tilt actual changed twice over the year. For this reason no results are presented here.

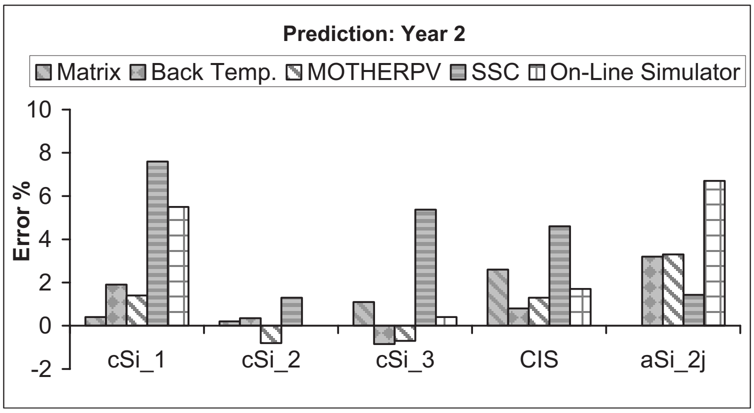

Figure 2: Shows the error between the measured and the predicted energy yield for year 2 dataset from the difference centers.

As in the previous example, the SSE model over-predicts the energy production for all devices, for the reasons explained above. The three methods Matrix, Online Simulator and SSE are consistently overestimating the yield, indicating that some losses are not considered. Matrix, MOTHERPV and Module Back Temperature can predict the output with an accuracy of better than 3%.

3. Second Round Robin 'The Realistic Situation'

In this round robin the module-to-module and site to site translation of the different performance methodologies were investigated. This was done in two stages using data from the Pythagoras project and the PV-Catapult measurement RR. The predicted Energy Yield kWh was compared with the actual values.

Stage 1: PV-Catapult Measurement RR

The data used for this was the data generated as part of the outdoor measurement RR. This allows to investigate the effect of different environments on one and the same module.
Within this test, four different modules were investigated as outlined in Table 4 It was originally planned to have five modules in the test, but one of the modules had to be replaced during the outdoor RR, because of mechanical problems.

Module Type	Area/m2	Pmax/W	Vmax/V	Voc/V	Isc/A	Efficiency/%
US32 aSi_3-J	0.52	32	16.5	23.8	2.4	6.1
A60 sc-Si	0.52	60	16.9	21	3.85	11.6
KC60 mc-Si	0.49	60	16.9	21.5	3.73	12.2
WS11007 CIS	0.72	75.0	40.0	51.0	2.00	10.4

Table 4: Modules in the RR

The modules given in Table 4 present standard technology (e.g. KC-60), modules with wide band-gaps (US-32), devices which degrade (US32) or improve (WS11007) with outdoor exposure and a device with high capacitance (A60).

The first set of data, measured at CEA was taken as the base for the module characterisation. The required modelling input was calculated and the energy yield for the same module at the different sites (SolarLab, ECN, CREST) was predicted for the measured data of the in-plane irradiance and module temperature. This is outlined in Figure 3.

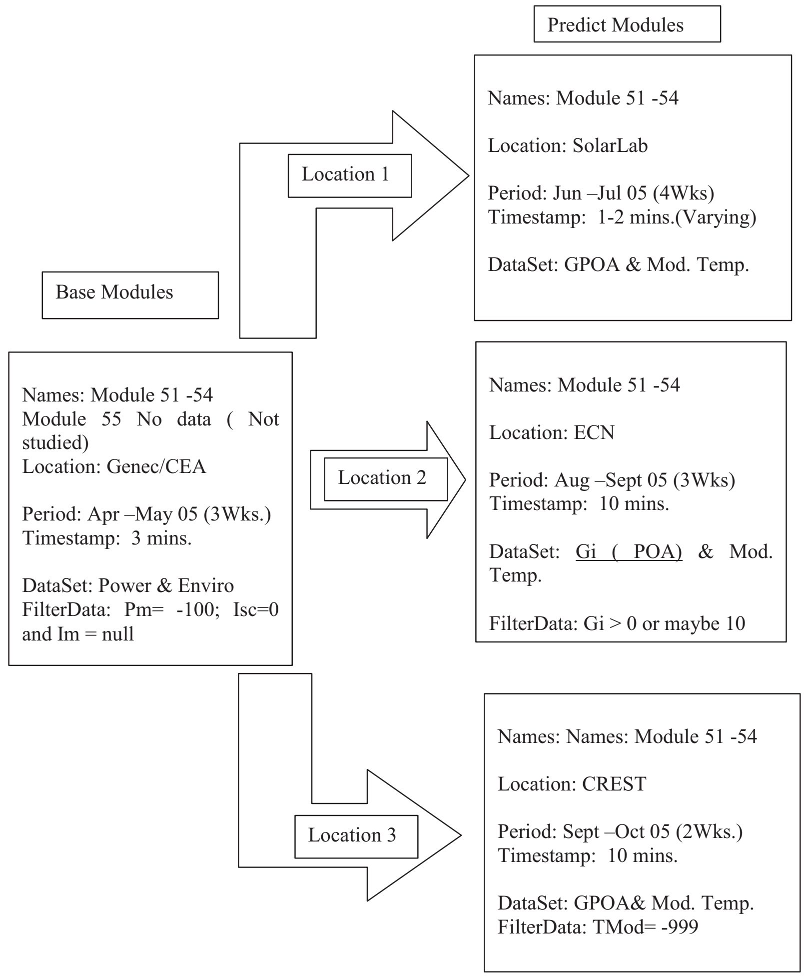

Figure 3: Block diagram with overview of datasets for Data from PV-Catapult Measurement RR

Stage 2: Thin Film Devices at Different Locations

The aims of this stage were:

- Module to module variation was investigated with similar modules at the same location
- Site to site variation of similar module (use one set of modules for CdTe and CIGS to predict either itself or the second of its kind using ZSW Widderstall data predict the Helsinki energy yield)

The block diagram of the approach is given in Figure 4. The "base modules" were used for the module characterisation and the "predict modules" indicate the modules with measured data of the in-plane irradiance and module temperature at the specific location and time period. The main aim of this test is expected to be the difference between modules and of course the difference of these modules to variations in the operating environment.

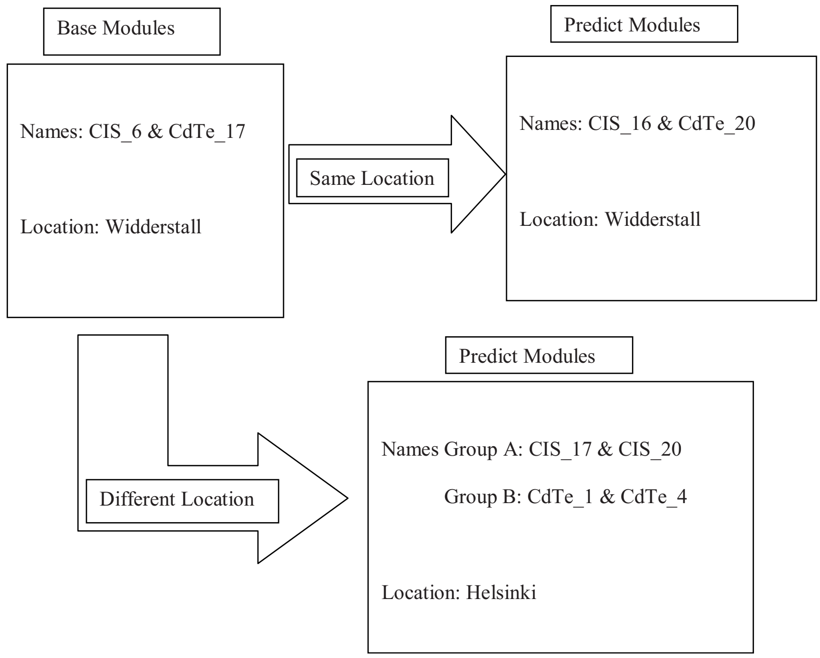

Figure 4: Block diagram with overview of datasets for Data from ZSW.

Results Stage 1

The first translation was the translation from the CEA data to the SolarLab data, which was measured relatively close in time to each other, which means that at least seasonal variations should not be too significant. The SSE method was implemented in two ways: firstly, as indicated by an NP in brackets after the method in the legends below, using the name-plate efficiency of the modules under test and secondly, given without any further descriptor, using the efficiency of the module as determined from the CEA data.

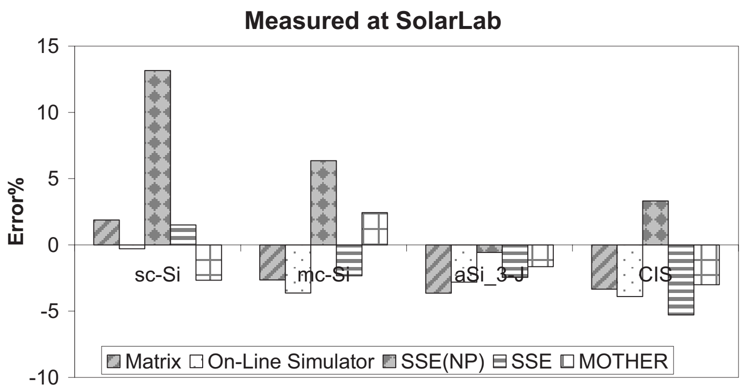

Figure 5: Prediction of the Energy Yield at SolarLab

The results of this translation demonstrate clearly the importance of the nameplate efficiency. Using the name plate efficiency in all cases except for the a-Si triple junction and the CIGS module added a significant error to the accuracy of the energy prediction. All methods were able to predict the energy production of the modules to an accuracy of better then four percent, with only SSE having one outlier. Mostly the energy prediction is slightly under-predicted, with only the sc-Si module showing an overestimation. The other cases of overestimation come from differences in the name-plate efficiency and the real rating. Looking at how the modules moved, the temperatures and intensities in Wroclaw will not have been so different to that at CEA, as we are later in the year and thus average solar elevation is similar.

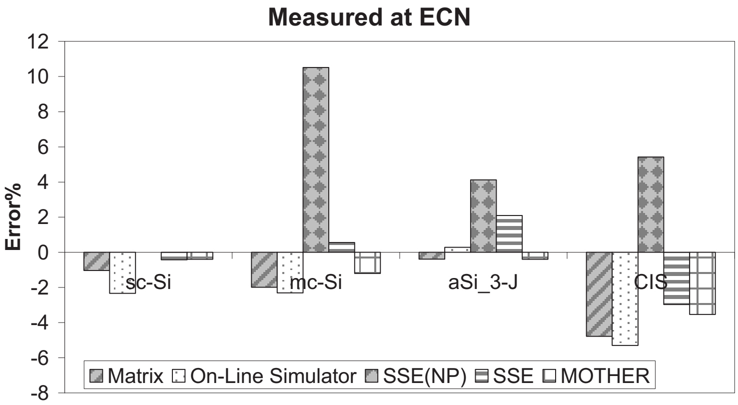

Figure 6: Prediction of the Energy Yield at ECN

The translation to ECN is of even better quality than that to the SolarLab, but still there are no serious changes in the environment. No prediction for the sc-Si is depicted for name-plate data, as this would have rendered the graph unreadable. The online-simulator and the matrix method seem to have a significant increase in error for the CIGS, while still being close to the desired 5% mark. The accuracy is not too astonishing as the module went further north with the year and are still very close to CEA in solar elevation and the operating temperatures are still very similar as the ambient temperatures are not too dissimilar from the CEA measurements. This similarity of the environment was broken when the modules went further north and the autumn arrived. The energy prediction of the measurements at CREST showed a more significant error, as illustrated in Figure 7. SSE, which assumes independence of effects of each other seems to struggle with the wide band gap material, although this is expected as here a spectral correction needs to be applied. Overall, the accuracy of all models is still within the desired 5% margin.

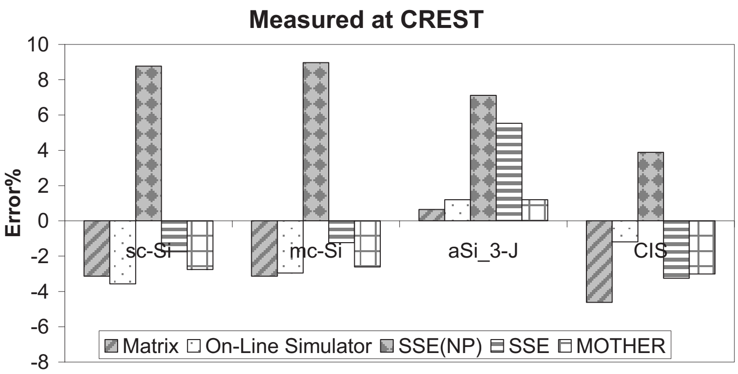

Figure 7: Prediction of the Energy Yield at CREST

This first stage of the RR shows that all methods are able to predict the energy production of known modules in different environments very well. The comparison of name-plate and real rating carried out by CREST shows that the dominant factor in the energy prediction is the rating. The calculation of the energy production at different sites can then be carried out safely, as long as the input parameters are correct. One should also highlight, that very short measurement campaigns were used, only several weeks worth of data, to characterise the modules. This seems to be sufficient, but also the target data-sets are very short and random errors would be reduced in longer term calculations. , like annual energy predictions Generally the CIS module showed the largest average error. The reason for it has still to be investigated.

Future round robins should carry out tests by starting with test meteorological data, in order to see how well the energy production can be predicted using this input.

Generally the CIS module showed the largest average error. The reason for it has still to be investigated.

Results Stage 2

The second stage of the RR highlighted that in more detail. Here data was taken from one module and translated to another module at the same site (Widderstall) and to two modules at another site with very different climatic conditions (Helsinki) for two thin film technologies. The results of the translation for the CIGS modules is shown in Figure 8.

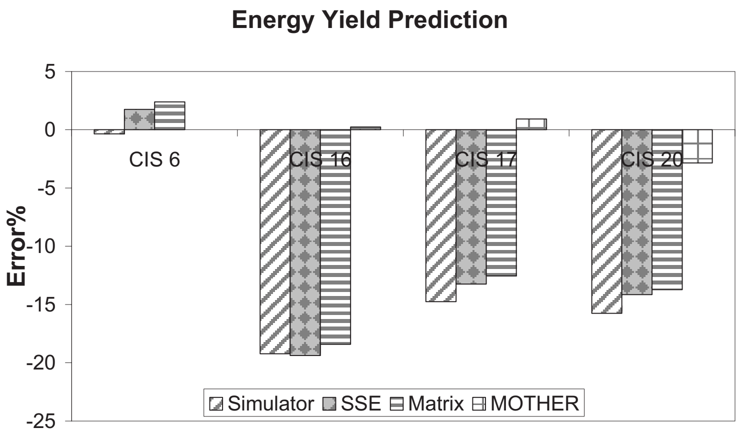

Figure 8: Accuracy of site-to-site (Widderstall/Helsinki) and module-to-module prediction of similar modules but with different power ratings

Using any translation procedure without knowledge of the new module seems to be very problematic. The average prediction error was in the order of 15%, but the general trend is under-prediction. The only method not having a large error in this case is the MotherPV method, which we attribute to prior knowledge of the elctrical data of the target modules. The initial theory was to attribute the underestimation to the slight improvements of CIGS after installation. A slight improvement in efficiency is typically observed, but it is not in the given order of magnitude. Also there were was some occurrence of snow on the modules, especially in Helsinki. However, this would have resulted in an overprediction of the energy yield, rather than the underestimation.

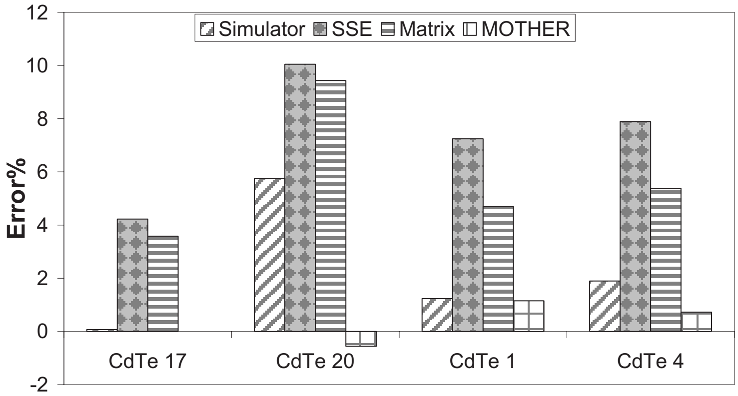

Figure 9: Accuracy of site-to-site (Widderstall/Helsinki) and module-to-module prediction of similar CdTe modules but with different power ratings

The prediction of the CdTe is of similar quality of the CIGS, but typically reulsting in overpredictions.. The error margin is ten percent or better. Again the differences are found in the differences between the different modules (and again MOTHERPV, does use electrical data for improving the performance). The difference in prediction accuracy is so astonishing, is dominated by the different rating of devices, as demonstrated in Figure 10.

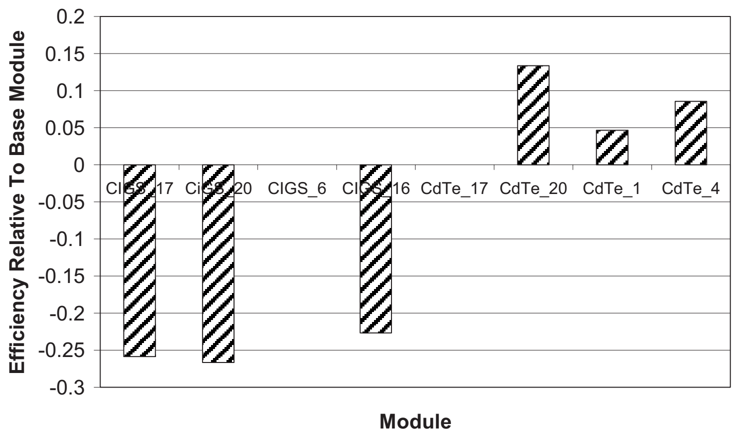

Figure 10: Efficiency of the different modules relative to the base module.

The data used for this test is taken from a project concerned with the development of modules, and the modules were installed at different stages in the project (which is not known to this project for reasons of confidentiality). The base modules were chosen arbitrarily. During the project responsible for the collection of the data, the module quality was improved significantly which is then seen in the module-to-module variations. The variations between the different modules are in the order of magnitude of 25% for CIGS and about 12.5% for CdTe. It should be emphasised that these numbers are not indications of the quality of the modules; they are representatives of the progress in the module efficiencies achieved within the Pythagoras project. However, this clearly explains why all the CIGS modules were underestimated.

Applying this correction factor of the rating, brings the measurement error very close to the other results (i.e. to a magnitude of 3% deviation between measurement and prediction). The prediction Widderstall -> Helsinki still poses significant problems (>10%) but this can be attributed to further device improvements being incorporated and thus the devices might behave differently.

4. CONCLUSIONS

The conclusions from this work can be split into the number of steps involved in the prediction of the energy output of PV-modules, which could be summarised as:

1. Calculation of the input parameters for the site and period of prediction (translation of the available meteo-parameters as horizontal irradiance, ambient temperature to the input parameters such as in-plane irradiance, module temperature, spectrum).
2. Characterization of the module (efficiency of the module as a function of input parameters such as in-plane irradiance, module temperature, spectrum).
3. Translation of these parameters to a similar module (same type, manufacturer, model). In practice one assumes that the characteristics of a certain module applies also for a "similar" module.

Conclusion for step 1:
Comparing the "on-line simulator" results of the first and the second round robin shows that the first step introduces a significant uncertainty in the predicted energy. This step was not addressed in full detail in the project, but appears to be crucial for any further development..

Conclusion for step 2:
The results of stage 1 of the second round robin shows that the characterisation of the modules and the calculation of the energy output of the very same modules for a set of measured input parameters is achievable as long as certain quality assurance measures are in place. The uncertainty in the calculated energy output is in the order of 3% when using the same dataset as used for the extraction of the device characteristics. These 3% can be attributed to unpredictable things such as moving clouds or similar non-standard measurements, which have an impact on the overall accuracy but cannot be handled by models without significant effort and are not considered here. However, if the characterisation is based on the nominal nameplate rating, the uncertainty becomes much larger. Overall the prediction accuracy for thin films is much lower than for crystalline devices, largely due to the often more pronounced inpact of the environment on the device performance, which often works actually in favour of such devices. It is clearly demonstrated that these newer device-categories have a significant need for research to improve the accuracy of this prediction.

Conclusion for step 3:
The adoption of the measured module characteristics for another, similar, module introduces large uncertainties in the predicted energy output due to module-to-module variations. The adoption of the measured module characteristics for exactly the same module, but at another time, can also introduce uncertainties (time effect).

Internationale Koordination

Annual Report 2005

Schweizer Beitrag zum IEA PVPS Programm Task 1

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Project- / Contract Number	11427 / 151471
Duration of the Project (from – to)	01.01.2005 – 31.12. 2005

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 to 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 June and November
- 1 **Task 1 meetings** in Lyon, France
- 2 Workshops in Barcelona (June) and Shanghai (October)

Work still to be done:

- Organize a Workshop at the PV conference in Dresden (Sept. 2006)

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:

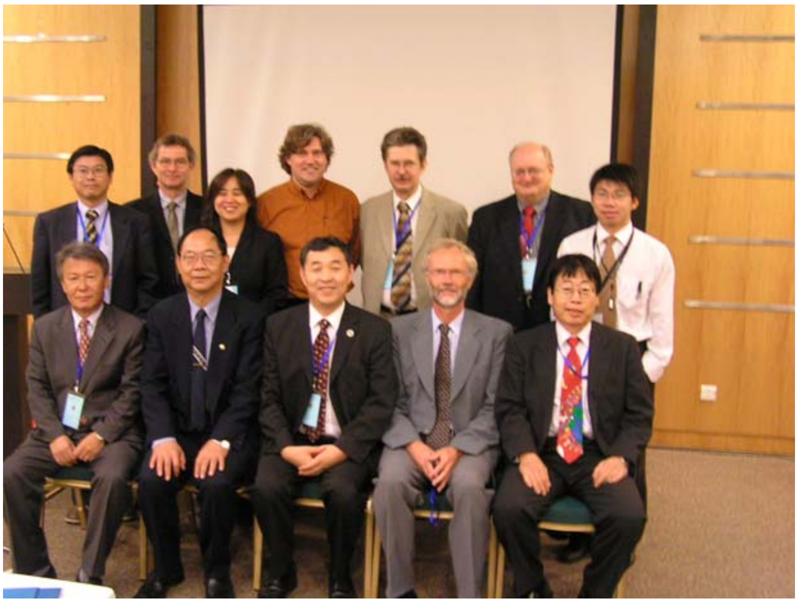
- **PV POWER**, ein zweimal jährlich erscheinender Newsletter
- **Trends Report** (Trends in Photovoltaic Applications, Survey report of selected IEA countries between 1992 and 2004), ein Jahresbericht zur Markt- und Technologieentwicklung der dem Programm angeschlossenen Ländern
- Reports und Workshops 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**
- 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
- Medienarbeit in der Schweiz: Hinweise auf internationale Publikationen des Programms, Publizieren von Marktstatistiken.

Referenten des PVPS-Workshops in Shanghai, Okt. 2005



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 einerseits die jährlichen Erhebungen des Sonnenenergie Fachverbandes SOLAR, andererseits die VSE-Statistik zu den netzgekoppelten PV-Anlagen. Die nachfolgende Tabelle gibt einen Überblick über die erhobenen Marktzahlen.

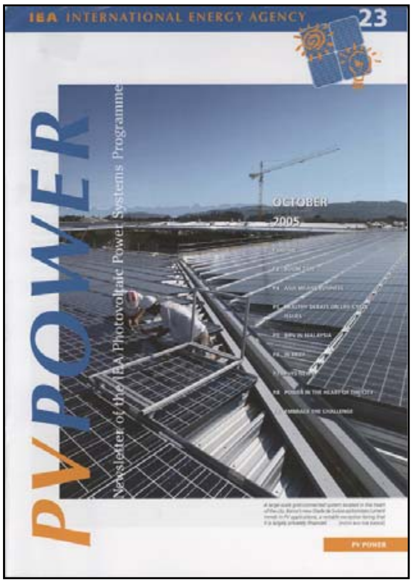
Sub-market / application	31 Dec. 1992 kW	31 Dec. 1993 kW	31 Dec. 1994 kW	31 Dec. 1995 kW	31 Dec. 1996 kW	31 Dec. 1997 kW	31 Dec. 1998 kW	31 Dec. 1999 kW	31 Dec. 2000 kW	31 Dec. 2001 kW	31 Dec. 2002 kW	31 Dec. 2003 kW	31 Dec. 2004 kW
off-grid domestic	1 540	1 675	1 780	1 940	2 030	2 140	2 210	2 300*	2 390*	2 480*	2 570*	2 740*	2 810*
off-grid non-domestic	70	100	112	143	162	184	190	200*	210*	220*	230*	260*	290*
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**
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
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

* Author's estimates. Exact figures for the proportion of off-grid power for domestic and non-domestic applications are not available.
**** This figure includes part of the new installation on the Stade de Suisse Stadium in Bern, which was installed in Winter 2004 / 2005

PV Power

PV Power wurde im Berichtsjahr 2 mal ausgeliefert (Juni und Oktober).

In der Herbstausgabe ist die PV-Anlage auf dem Stade de Suisse auf der Titelseite abgebildet. Schwerpunkt bildete der neuste Trends Report 2004 sowie ein kleiner Schwerpunkt Asien im Hinblick auf die Asiatische Photovoltaik-Konferenz PVSEC 15 in Shangai.

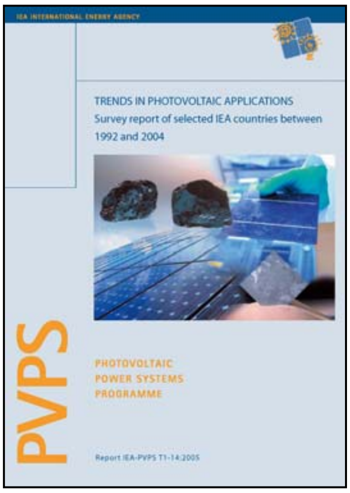


Trends Report

Basierend auf den Daten der "National Survey Reports" wurde Mitte September der Trends Report publiziert. Dieser Bericht ist international sehr anerkannt, da er unabhängig von der Industrie Daten zu Produktion und Markt in 20 Ländern liefert.

Die wichtigsten Daten aus dem Bericht sind auch im Internet unter www.iea-pvps.org [3] einsehbar. Der ganze Bericht wie auch einzelne Tabellen können als PDF - Dokumente heruntergeladen werden.

Die aktuellen Zahlen sind in der nachfolgenden Tabelle aufgeführt.



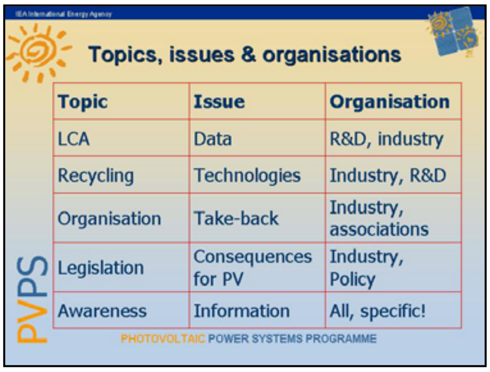
Country	Cumulative off-grid PV capacity (kW)		Cumulative grid-connected PV capacity (kW)		Total installed PV power (kW)	Total installed per capita (W/Capita)	PV power installed in 2004 (kW)	Grid-connected PV power installed in 2004 (kW)
	domestic	non-domestic	distributed	centralized				
AUS	15 900	29 640	5 410	1 350	52 300	2,60	6 670	780
AUT	2 687		15 340	1 153	19 180	2,37	2 347	1 833
CAN	5291	8 061	476	36	13 884	0,44	2 054	107
CHE	2 810	290	18 440	1 560	23 100	3,12	2 100	2 000
DNK	65	190	2 035	0	2 290	0,43	400	360
DEU	26 000		768 000		794 000	9,62	363 000	360 000
ESP	14 000		23 000		37 000	0,87	10 000	8460
FRA	12 500	5 800	8 000	0	26 300	0,44	5 228	4 183
GBR	193	585	7 386	0	8 164	0,14	2 261	2 197
ISR	653	210	9	14	886	0,13	353	3
ITA	5 300	6 700	12 000	6 700	30 700	0,53	4 700	4 400
JPN	1 136	83 109	1 044 846	2 900	1 131 991	8,87	272 368	267 016
KOR	461	4 898	4 533	0	9 892	0,21	3 454	3 106
MEX	14 169	4 003	10	0	18 182	0,17	1 041	0
NLD	4 769		41 830	2 480	49 079	3,01	3 162	3 071
NOR	6 438	375	75	0	6 888	1,50	273	0
PRT	1 657	569	417	0	2 643	0,25	574	20
SWE	3 070	602	194	0	3 866	0,43	285	0
USA	77 900	111 700	153 600	22 000	365 200	1,24	90 000	62 000
Estimated total	**170 730**	**281 021**	**2 064 201**	**79 593**	**2 595 545**		**770 270**	**719 536**

Notes: 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.

Workshop PV systems - meeting the sustainability challenge, 8. Juni 2005, Barcelona

Anlässlich der Europäischen Photovoltaik-Konferenz in Barcelona organisierte Task1 einen Workshop zu Thema Umweltaspekte der Photovoltaik.
Namhafte Referenten aus Europa, Asien und USA stellten Ihre Forschungsarbeiten zu Lebenszyklusanalysen und Konzepte zum Recycling von PV-Modulen vor (siehe auch www.iea-pvps.org -> Task1 -> Special Information Activities).

Innerhalb Task 1 und zusammen mit dem ExCo laufen jetzt die Vorbereitungsarbeiten für eine evtl. neue Task zum Thema „Environment, Safety & Health".



Topic	Issue	Organisation
LCA	Data	R&D, industry
Recycling	Technologies	Industry, R&D
Organisation	Take-back	Industry, associations
Legislation	Consequences for PV	Industry, Policy
Awareness	Information	All, specific!

Joint workshop on international PV collaboration and market developments, 14. Oktober 2005, Shanghai

Task 1 ist es gelungen, zusammen mit den Organisatoren der PVSEC 15 in Shanghai einen gemeinsamen Workshop zu organisieren. Die Initiative für diesen Workshop kam von der Schweiz und Japan. Mit einem schlussendlich ganztägigen Programm konnten wir die PVPS - Aktivitäten unseren asiatischen Partnern näher bringen. Die nicht-Asiatischen Teilnehmer erhielten einen hervorragenden Überblick über die Marktentwicklung insbesondere in China, Thailand und Südkorea.

Nationale / internationale Zusammenarbeit

Im Berichtsjahr fand 1 Task 1 Meeting statt:

Juni 2005	Lyon 1/2 Tag Joint Meeting mit Task 10 Feinplanung für den ES&H-Workshop in Barcelona (Juni 05) und den Joint-Workshop PVPS@PVSEC15 in Shanghai Status des Trends Reports 2004
Konferenzen	Europäische Photovoltaik-Konferenz in Barcelona Juni 2005, Poster-Beitrag zum Trends Report 2004 PVSEC15, Shanghai, Oktober 2005 Konferenzbeitrag (oral presentation) zum Trends Report 2004
Workshops	Die Schweiz war zusammen mit Japan vor allem in der Initialisierungsphase federführend und damit hauptverantwortlich, dass die beiden oben erwähnten Workshops in Barcelona und Shanghai zustande kamen.
Solarpreis 2005	Anlässlich der Solarpreis Verleihung wurde in einem Kurzreferat die Entwicklung des Schweizer PV-Marktes im vergleich zum Rest der Welt aufgezeigt.
Sarasin Report	Für den durch die Bank Sarasin erstellten jährlichen Report zum Status der Solarenergienutzung lieferte Task 1 zum frühestmöglichen Zeitpunkt die Marktzahlen 2004 sowie eine kurze Zusammenfassung des ES&H-Workshops in Barcelona.

Bewertung 2005 und Ausblick 2006

Mit den zwei durch Task 1 organisierten Workshops parallel zu den zwei wichtigsten PV-Konferenzen 2005 konnte einerseits das Thema „Environment Safty & Health“ etwas stärker in den Vordergrund gerückt werden. Mit dem Shanghai-Workshop ist es gelungen, direkte und persönliche Beziehungen mit Exponenten aus dem asiatischen Raum zu festigen resp. neu zu knüpfen. Dies ist umso wichtiger, da China im Moment nicht Mitglied beim PVPS Programm ist.

Für 2006 ist ein Workshop zum Thema Trends Report - Daten Beschaffung, Qualität des Datenmaterials, Bedürfnisse der Zielgruppen geplant (Dresden Sept. 2006)

Referenzen / Publikationen

[1] P. Hüsser, A. Hawkins, ***National Survey Report on PV Power Applications in Switzerland 2004***, Mai 2005

[2] ***Trends in Photovoltaic Applications in selected IEA countries between 1992 and 2004,*** IEA, PVPS, Task I – 14:2005

[3] ***Internet site www.iea-pvps.org***

[4] P. Hüsser, P. Cowley, G. Watt, ***GLOBAL ASPECTS OF PV DEVELOPMENT***
Results from the latest surveys in selected IEA PVPS countries
Poster an der Europ. PV-Konferenz, Juni 20054, Barcelona

[5] P. Hüsser, Izumi KAIZUKA, ***Statistics and trends in photovoltaic applications***
Results from the latest surveys in selected IEA-PVPS - and Non-IEA-PVPS countries along the PV value chain
Präsentation an der asiatischen Photovoltaikkonferenz PVSEC 15 in Shanghai, Oktober 2005

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IEA PVPS Programm Task 2 Schweizer Beitrag 2005

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Project- / Contract Number	14805 / 151472
Duration of the Project (from – to)	1. January 2005 - 31. December 2005

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 acitve Subtasks.

Subtask 1 : Performance Database (enrichment and dissemination of the performance database)
This tool has now worldwide more than 2’992 users form 90 different countries. It is beeing updated at least once a year by the expert-group.

New activities: In Phase III 2004 - 2007

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 lead Switzerland)
The global economical survey aims at gathering information on plants, technical performance, maintenance and cost of as many PV systems as possible. The Internet-based survey tool became available during the Photovotaic Conference Barcelona on 08 June 2005. It can be reached at the public website http://www.iea-pvps-task2.org.

Subtask 7 : Dissemination Activities.

BFE
OFEN
UFE
SFOE

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 2005:

• Deutschland (Taskleitung) • Frankreich • Italien • Japan • Österreich • Schweiz
neu sind: • Kanada • Schweden • USA
und • Europäische Union • Polen (als Beobachter)

Task 2 befindet sich in der dritten Phase (2004 - 2007).

Kurzbeschrieb des Projekts

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. Viele Anlage-Daten stammen aus nationalen Projekten der Task 2 Mitgliedländer. Total: 431 Anlagen.

Durchgeführte Arbeiten und erreichte Ergebnisse

Arbeiten des Task 2:

- Zwei Task Meetings
  Florida, USA, Februar/März 2005
  Hameln, Deutschland, September 2005

Subtask 1:

- Ergänzung der Performance-Database
- Unterhalt der Task 2 www-Homepage
- Aufbereitung und Analyse der Messdaten
- Vorbereitung der Veröffentlichung eines wichtiges Teils der Performance-Database im Internet

Neue Aktivitäten:

- Subtask 5: Technical Assessments and Technolgy Trends of PV Systems
- Subtask 6: PV System Cost over Time
- Subtask 7: Dissemination Acitivities

Subtask 6 „PV System cost over time“

Die Schweiz leitet den Subtask 6. Am Task-Meeeting in Florida wurde die Struktur des Erfassungsrasters für den economical survey durch die Experten verabschiedet. Anlässlich der 20. Europäischen Photovoltaik-Konferenz in Barcelona wurde der global economic survey gestartet (8. Juni 2005) [1] [2]. Bis zum 19.12.2005 haben 62 Experten aus 16 Ländern insgesamt 171 Systeme in der Datenbank ökonomisch beschrieben. Darin enthalten sind auch die Projekte, die in der Performance Database (Task 2 Subtask 1) ökonomische Daten enthalten.

Dieses Zwischenresultat ist zwar interessant aber von der Datenmenge her noch nicht ausreichend repräsentativ, um die notwendigen Untersuchungen durchzuführen. Die Bemühungen um grössere Datenstämme werden durch die Experten intensiviert und auch im ersten Viertel 2006 vorangetrieben.

TNC hat als Ergänzung zum Datenerfassungswerkzeug im Internet eine Analyse-Datenbank entwickelt und den Task 2 Experten am 15.12.2005 zur Verfügung gestellt. Diese Runtime-Version einer Datenbank ermöglicht es, die vorliegenden Projektdaten in anonymisierter Form zu selektieren, zu sortieren und in eine Excel-Darstellen zu exportieren. Dies ermöglicht individuelle Auswertungen und Analysen durch die einzelnen Task-Experten. Die Datenbank selbst kann via Internet mit Name, Passwort um weitere, zusätzlich erhaltene Projektinformationen ergänzt werden. Dieses Werkzeug wird nur intern angewendet und dient der Ausarbeitung von Analysen und vertiefenden Berichten zum Subtask 6 (Activity 63).

Nationale / internationale Zusammenarbeit

In Kombination mit dem Task-Meeting in Hameln hat die Expertengruppe ein sehr gutes, hochrangig besuchtes Industrieseminar für vor allem für die deutsche und europäische Photovotlaik-Industrie durchgeführt. Dieser, am 28. September 2005 abgewickelte, eintägige Workshop [4] erlaubte einen Dialog zwischen namenhaften Industrievertretern und den Task-Experten. Die Vorgehensweise reflektiert das zunehmende Interesse der Photovotlaikindustrie an den Arbeiten des Task 2.

Die internationale Zusammenarbeit wurde auch anlässlich der Europäischen Konferenz in Barcelona, Juni 2005 und an der Amerikanischen Solar Power Conference, Oktober 2005 in Washington DC gepflegt und vertieft [3].

Bewertung 2005 und Ausblick 2006

In der jetzt angelaufenen Phase III vom Task 2 2004 -2007 werden die Inhalte der Performance-Datenbank ergänzt und zukünftig auch übers Internet einen noch grösseren interessierten Kreis von Fachleuten vorgehalten. Die komplementären Aktivitäten „PV cost over time“ ergänzen die rein technischen Performance-Überlegungen und Analysen um den ökonomischen Teil.

Referenzen / Publikationen

[1] Thomas Nordmann: ***Feed-in tariffs and building integrated PV (BIPV) - Can we make it a winning team?,*** 20th European Photovoltaic Solar Energy Conference, 6-10 June 2005 Barcelona, Spain

[2] Ulrike Jahn: ***Operational Performance of GCS: Overview of the Task 2 Results,*** 20th European Photovoltaic Solar Energy Conference, 6-10 June 2005, Barcelona, Spain

[3] IEA PVPS Taks 2 Thomas Nordmann: ***PV System Performance Analysis,*** The Solar Power 2005 Conference and Expo, 5-9 October 2005, Washington DC, USA

[4] IEA PVPS Task 2, 1st Workshop on Quality for PV Systems***, PV System Performance, Technology, Reliabilty and Economical Factors of the PV Industry***, Hameln/Emmerthal (ISFH) 28 September 2005

[5] IEA PVPS Task 2, ***Analysis of Photovoltaic Systems***, Report IEA-PVPS T2-01: 2000.

[6] International Electrotechnical Commission (IEC), ***Photovoltaic System Performance Monitoring - Guidelines for Measurement***, ***Data Exchange and Analysis***, Standard IEC 61724.

[7] 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

[8] ***Performance Database***, Version 1.19, Edition: June 2005, auf CD-ROM für EUR 20.- erhältlich bei der Taskleitung: Ulrike Jahn, Institut für Solarenergieforschung GmbH Hameln/Emmerthal (ISFH), E-Mail: ujahn@easynet.de ,oder als Download (47 MB) von der Task 2 Homepage: http://www.iea-pvps-task2.org/

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Annual Report 2005

Swiss Interdepartmental Platform for Renewable Energy Promotion in International Co-operation (REPIC)

including Swiss contribution to IEA PVPS Task 9

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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 new 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 foreseen 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 are expected to provide for synergies between activities from the private sector and the civil society.

Under these goals, the REPIC-Platform also provides the Swiss contribution to IEA PVPS Task 9 - *Photovoltaic Services for Developing Countries.*

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 neue gemeinsame Initiative des Staatssekretariates für Wirtschaft (seco), der Direktion für Entwicklung und Zusammenarbeit (DEZA), des Bundesamtes für Umwelt, Wald, und Landschaft (BUWAL) 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, soll mit dieser Initiative ein koordinierter Ansatz zur Förderung solcher Projekte erfolgen. 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 soll insbesondere dort Wirkung entfalten, 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 2. Jahresbericht beschreibt die Aktivitäten, Resultate und Erfahrungen im 2. Jahr der REPIC-Plattform.

Kurzbeschreibung REPIC

REPIC versteht sich als marktorientiertes Dienstleistungszentrum zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit. Unter Berücksichtigung der vorhandenen Erfahrungen soll diese Plattform neue konkrete Projekte mit erneuerbaren Energien unter vermehrter Mitwirkung von Schweizer Unternehmen und Organisationen ermöglichen. Sie baut dazu ein Netzwerk zur Information und Sensibilisierung interessierter Kreise auf, pflegt den Erfahrungsaustausch zwischen verschiedenen Akteuren und fördert die Kenntnis von lokalen Rahmenbedingungen und Projektmöglichkeiten. Zur Realisierung erfolgversprechender Projekte 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 2005

Im ersten Jahr hat das Sekretariat zusammen mit der REPIC-Steuergruppe die Detailausführung der Plattform erarbeitet und umgesetzt. Dies betraf insbesondere die Prozeduren, die Kriterien, die Hilfsmittel zur Projektförderung sowie das Kommunikationskonzept. Damit bestand die Grundlage für die weiteren Arbeiten der Plattform im Jahr 2005. Besonderes Gewicht haben im Jahr 2005 die folgenden Punkte erhalten:

- die systematische Kommunikation und Berichterstattung
- die Sammlung von ersten Erfahrungen mit geförderten Projekten
- eine effiziente Gesuchsbearbeitung
- die plangemässe Projektabwicklung

Entsprechend den für REPIC definierten Elementen und aufgrund der ersten Erfahrungen wurden im Jahr 2005 die folgenden **vier** Schwerpunkte verfolgt:

1. Diskussion der REPIC Strategie;
2. Verstärkung von Information, Kommunikation und Mobilisierung;
3. Formalisierung von Projekteingaben, Stellungnahmen, und Entscheidfindungen, Unterstützung und Begleitung von Projekten, Berichterstattung;
4. Interne und externe Koordination

Durchgeführte Arbeiten und erreichte Ergebnisse

Projektarbeit

Nachdem während dem ersten Jahr das Sekretariat zusammen mit der REPIC-Steuergruppe die Detailausführung der Plattform erarbeitet und umgesetzt hatte, wurden im zweiten Jahr die ersten Erfahrungen mit geförderten Projekten gesammelt, sowie eine effiziente Gesuchsbearbeitung und Projektabwicklung umgesetzt. Besonderes Gewicht erhielten die Formalisierung von Projekteingaben, die Unterstützung und die Begleitung von Projekten, sowie die Kommunikation. Die REPIC Steuergruppe traf sich dazu zu insgesamt fünf Arbeitssitzungen.

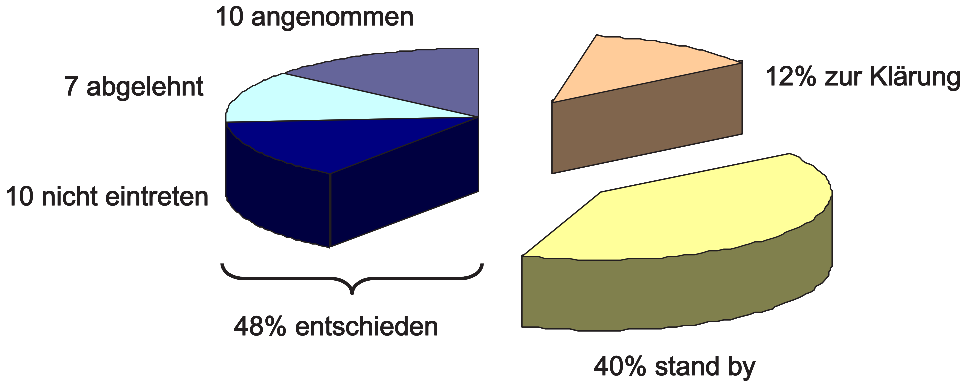
Im Verlauf von 2005 wurden 22 neue Vorschläge bearbeitet; davon wurden 10 durch die REPIC-Steuergruppe behandelt und entschieden. Von den 10 entschiedenen Vorschlägen mündeten 5 in eine direkte finanzielle Unterstützung durch die REPIC-Plattform, Ein Vorschlag wurde nach eingehender Evaluation abgelehnt und auf 4 weitere Vorschläge wurde nicht näher eingetreten. Von den restlichen 12 Vorschlägen befanden sich Ende 2005 noch 7 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 Photovoltaik, ein Projekt die Biomasse, ein Projekt den Wind und ein Projekt die Kleinwasserkraft.

Tabelle 1 : Stand der Vorschläge 2005

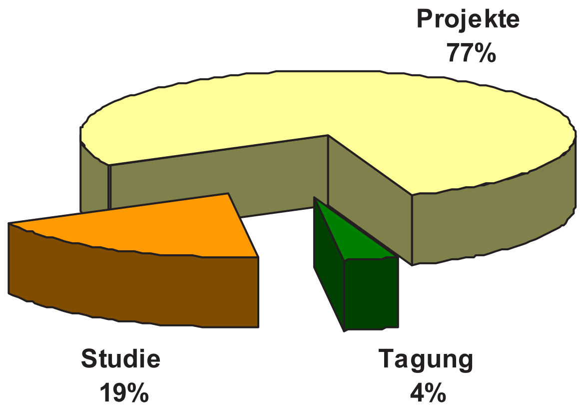
Status	angenommen	abgelehnt	zur Klärung	stand by	Total
Anzahl	5	5	7	5	22

Mit einem Total von 22 Anfragen erfolgten 2005 insgesamt weniger Anfragen als 2004 (35 Anfragen). Dieser Sachverhalt wird nicht als sinkendes Interesse sondern vielmehr als Resultat einer zielgerichteten Vorgehensweise und Kommunikation gesehen. Dies wird auch dadurch belegt, dass die Ausrichtung und Qualität der Anfragen im 2. Jahr besser geworden ist: 22% der 2005 eingereichten Anfragen wurden unterstützt (2004 waren es demgegenüber nur 14%).

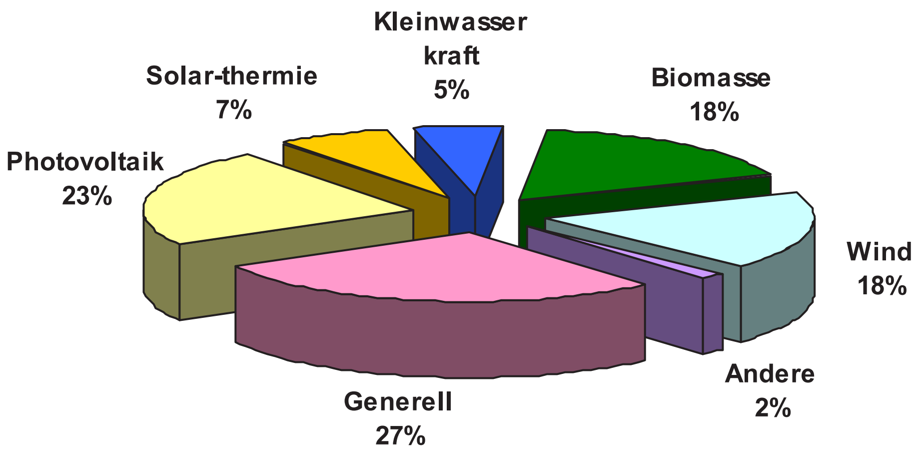
Damit wurden seit Beginn der REPIC-Plattform bis Ende 2005 insgesamt 57 Projektanfragen eingereicht. Figur 1 stellt den Stand dieser Anfragen zusammen. Allgemein entsprachen 2005 die Anfragen besser den REPIC Zielsetzungen. Bei einzelnen Projektanfragen stellen sich aber trotzdem Abgrenzungsfragen zwischen 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 - 2005)



Figur 2 : Art der Projektanfragen (Periode 2004 - 2005)
43 konkrete Projekte, 11 Studien und 2 Tagungen



Figur 3: Verteilung der Projektvorschläge auf die verschiedenen Technologien (Periode 2004-2005)

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

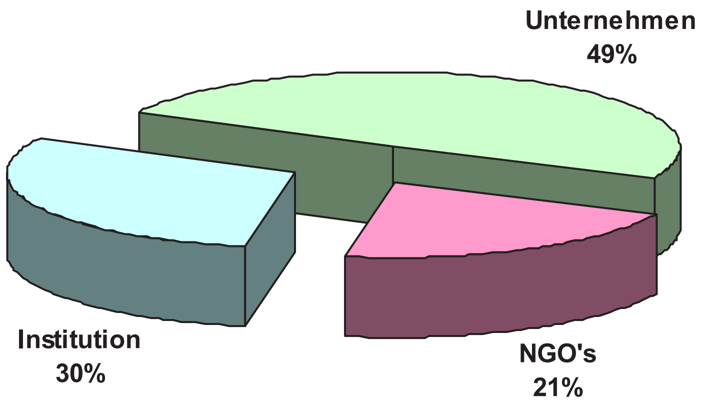
Die Kommunikation und die Information wurden durch die Inbetriebnahme der REPIC Website (www.repic.ch) verstärkt. Die Website ist in 3 Sprachen aktiv (deu/fra/eng) und enthält ausführliche Informationen zur REPIC-Plattform, allgemeine Dokumente sowie spezifische Informationen zu unterstützten Projekte. Ausserdem wurden, entsprechend dem Kommunikationskonzept, Projekt-Leitfaden [1] und Flyer [2] regelmässig verteilt.

Figur 4: Die REPIC Website www.repic.ch wurde anfangs 2005 aufgeschaltet

Ein nationales Seminar zum Thema der erneuerbaren Energien in der internationalen Zusammenarbeit fand am 21. September 2005 auf dem Gurten (Bern) statt [3]. Die Ziele des Seminars waren die Schweizer Akteure auf diesem Gebiet zusammenzuführen, Informationen und Erfahrungen aus Projekten auszutauschen sowie Bedürfnisse und Möglichkeiten in Bezug auf die künftige REPIC-Strategie zu identifizieren.

Figur 5: Eindrücke vom Nationalen REPIC Seminar

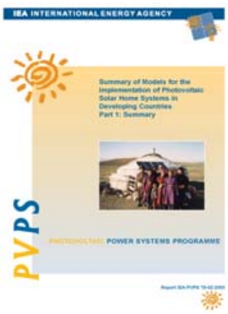
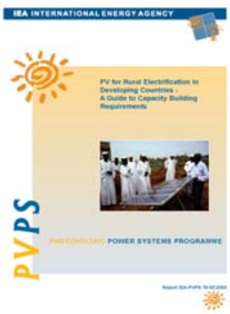
Das Seminar richtete sich im Sinn der REPIC-Zielsetzungen gleichermassen an Unternehmen, Institute, NGO's und Behörden. Mit 66 Teilnehmern war die Mehrheit der für die Thematik der erneuerbaren Energien in der internationalen Zusammenarbeit relevanten Schweizer Firmen und Organisationen anwesend.



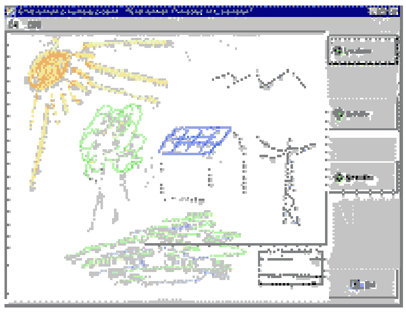
Figur 6: Aufteilung der Seminarteilnehmer

Unterstützte Projekte

Insgesamt hat die REPIC-Plattform bisher 10 Projekte unterstützt (vgl. oben). Ausführliche Informationen zum Stand und den Resultaten aller Projekte sind dem REPIC-Jahresbericht zu [4] entnehmen. Im Folgenden werden hier nur die Photovoltaik Projekte aufgeführt.

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
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.
Website	www.entec.ch www.oja-services.nl/iea-pvps/tasks/i_task09.htm
Projektstatus	laufend - IEA PV SDC, die Arbeitsgruppe der Internationalen Energie Agentur - Photovoltaik Power Systems - Photo Voltaic Services for Developing Countries blickt auf das erste Jahr der 2ten Fünfjahresphase zurück. Die Schweiz erbringt ihren Beitrag wie in der ersten Phase durch die Führung des Aufgabenbereichs Unterstützung und internationale Zusammenarbeit. Die Arbeitsgruppe setzt sich zur Zeit zusammen aus Experten der Länder Australien, Kanada, Deutschland, Japan, Schweden, Schweiz, England und Frankreich. Die Expertentätigkeit der Schweiz innerhalb der Arbeitsgruppe wird massgeblich durch die entec AG, St. Gallen wahrgenommen. Neben den zwei regulären Arbeitssitzungen (12th and 13th experts meeting): • Washington, 14. - 17. März 2005 parallel zur "energy week" der WB • Shanghai, 11. Oktober 2005 parallel zur 15ten "photovoltaic Science and Engineering Conference and Solar Energy Exhibition" fanden eine Vielzahl von Anlässen statt. Diese wurde genutzt um erarbeitetes Know-how von PV SDC im direkten Dialog der eigentlichen Zielgruppe zu vermitteln 
Dokumentation	Jahresbericht Schweizer Beitrag IEA PVPS Task 9, 1999 – 2005 [5] Publikationen IEA PVPS Task 9 [6]

Förderung der Solarenergie für eine nachhaltige Entwicklung in Timbuktu, Mali	
Projektart	Infrastrukturorientiertes Projekt
Schweizer Partner	Wirz Solar GmbH – SolSuisse GIE Mali
Technologie	Photovoltaik
Beschreibung	Das vorliegende SolSuisse Mali Pilotprojekt 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	laufend – Die Wasserprojekte in Boukayatte und Finkolo konnten vorbereitet werden sowie die Planung der Elektrifizierung des Quartiers Kabara in Timbuktu in Angriff genommen werden. Obwohl noch nicht für alle Teilmodule eine Finanzierung erreicht werden konnte, sollte es möglich sein, die Infrastrukturprojekte Boukayatte und Kabara anfangs 2006 via eine private Vor-Finanzierung in Angriff nehmen zu können. Modul 2, der Aufbau des Solsuisse-Servicecenters, ist vorbereitet und kann auf Abruf schnell in Betrieb genommen werden. Es fehlt derzeit vor allem an Material. Im Ausbildungsbereich (Modul 3) konnte der erste Kurs für die Brunnenwarte durchgeführt werden, ein zweiter Kurs für Solartechniker ist in Vorbereitung. Modul 4, Mikrofinanz, ist ebenfalls auf gutem Weg, zusammen mit dem Partner Oikocredit in Timbuktu eingeführt zu werden, dauert allerdings länger als geplant. Modul 5 wird gestartet, sobald das Material vor Ort ist. Februar 06.  

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
Technologie	Photovoltaik
Beschreibung	Dieses Projekt hat zum Ziel, eine generell verwendbare Simulations- und Optimierungsprozedur für photovoltaisch betriebene Wasserpumpen zu erarbeiten und diese im Programm 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 das bereits erfolgreich eingesetzte Programm 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.
Website	www.unige.ch/cuepe/pvsyst/pvsyst/index.php
Projektstatus	laufend – Die folgenden Resultate wurden Ende 2005 erreicht : ein Pumpen Modell mit einer benutzerdefinierten Schnittstelle; die notwendige logische Struktur für die komplette Modellierung; die generelle Form für die Prä-Dimensionierung des Systems.  

*ausführliche Informationen in separatem Bericht (Schweizer Photovoltaik Programm)

Bewertung 2005 und Ausblick 2006

Allgemeines

Die REPIC Plattform kann Ende 2005 auf die ersten zwei Jahre ihrer Existenz und Tätigkeit zurückblicken. In diesen zwei Jahren wurde wesentliche Aufbauarbeit zur Umsetzung des ursprünglichen Mandates der beteiligten 4 Bundesämter geleistet. Anhand einer ansehnlichen Anzahl von total 57 Projektanfragen konnten wertvolle Erfahrungen aus konkreten Beispielen gesammelt werden, welche laufend in die Ausrichtung der Tätigkeiten der Plattform einfliessen. Die REPIC Plattform ist damit insgesamt auf gutem Weg, die gesteckten Ziele für die ersten 3 Jahre zu erreichen.

Projektarbeit

Im Jahr 2004 wurden 35 Anfragen bearbeitet, während es 2005 22 Projekte waren. Die Anfragen waren 2005 besser auf die Zielsetzungen und Kriterien der REPIC-Plattform ausgerichtet, was sich durch eine höhere Erfolgsrate von unterstützten Projekten ausdrückte. Dieses Resultat wird auf eine systematische Kommunikation, die Verfügbarkeit von Hilfsmitteln (Leitfaden, Website) sowie die zielgerichtete persönliche Beratung und Betreuung zurückgeführt. Einzelne Projektanfragen stellen die Abgrenzung der REPIC-Aktivitäten, insbesondere in Bezug auf Technologieentwicklung in Frage.

Ende 2005 waren von den total 10 bisher durch die REPIC Plattform unterstützten Projekten vier abgeschlossen (je zwei in 2004 und 2005), die restlichen sind noch laufend. Von den drei abgeschlossenen technischen Projekten liegen ausführliche Schlussberichte vor. In allen drei Fällen sind weitere Aktivitäten in den Projekten erfolgt, welche eine viel versprechende Entwicklung dieser Vorhaben erwarten lassen. Das erste in 2004 abgeschlossene Projekt *Malaysia Building Integrated Photovoltaic MBIPV* hat in ein grosses GEF-Projekt mit Schweizer Beteiligung gemündet. Für die Windenergieprojekte in Rumänien und Nicaragua erfolgen derzeit wichtige Schritte zur weiteren Entwicklung von konkreten Anlagen.

Projekte mit multilateralen Organisationen und Mechanismen

Die bisherigen Erkenntnisse aus der REPIC-Plattform zeigen, dass für Projekte mit multilateralen Organisationen (GEF, WB, usw.) bzw. mit Kyoto-Mechanismen in der Schweiz bisher nur bei wenigen spezialisierten Firmen entsprechendes Know-how und Erfahrungen bestehen. Der grosse Aufwand zur Erarbeitung dieser Erfahrungen stellt jedoch ein wesentliches Hindernis zur weiteren Entfaltung dieser Projektmechanismen dar. Hier könnte die gezielte Unterstützung durch erfahrene Akteure eine Verbesserung der Situation bewirken.

Technologien

Mit den im Jahr 2005 neu unterstützten Projekten hat sich die Technologiebasis erweitert. Von den 9 bisher durch REPIC unterstützten technischen Projekten sind 4 aus der Photovoltaik, 3 Windenergieprojekte, sowie je eines aus mit Biomasse und Kleinwasserkraft. Bei den 57 Projektvorschlägen sind mittlerweile alle Technologien der erneuerbaren Energien vertreten.

Kommunikation

Die bisherigen Massnahmen zur Kommunikation haben bereits Wirkung entfaltet, indem die für REPIC relevanten Zielgruppen erreicht werden konnten und die Modalitäten der REPIC Plattform bei diesen besser bekannt sind. Die Kommunikationsmassnahmen sind systematisch weiter zu verfolgen und punktuell zu verstärken, z.B. durch Beiträge an Veranstaltungen sowie in spezialisierten Medien und Netzwerken.

Mobilisierung der Zielgruppen

Mit dem im September 2005 durchgeführten Nationalen Seminar zum Thema der erneuerbaren Energien in der internationalen Zusammenarbeit wurden alle wesentlichen Unternehmen, Organisationen und Netzwerke der erneuerbaren Energien in der Schweiz gezielt angesprochen. Die Teilnehmer des Seminars deckten die für die internationale Zusammenarbeit relevanten Akteure aus Firmen und Organisationen zu einem hohen Grad ab. Damit konnte das Seminar seine Zielgruppen weitgehend erreichen.

Bei den an REPIC gerichteten Projektvorschlägen sind die Zielgruppen der Unternehmen mit einschlägiger Erfahrung gut vertreten. Hingegen konnte bei den bisherigen Projekten die Organisationen der Zivilgesellschaft noch nicht im gleichen Ausmass mobilisiert werden.

Netzwerke und Organisationen

Die REPIC-Plattform ist durch ihre Vertreter auf Bundesebene und einzelne Projekte bereits in verschiedene nationale und internationale Netzwerke eingebunden; punktuell sind dabei noch Verbesserungen möglich. Häufig ist es dazu von Bedeutung, wichtige Vertreter persönlich zu kennen und diese bei Bedarf ansprechen zu können. Mit einzelnen Organisationen in der Schweiz sollen die Beziehungen noch intensiviert werden.

Für REPIC ebenfalls von Bedeutung ist der Schweizer Beitritt zur internationalen Partnerschaft für erneuerbare Energien und Energieeffizienz REEEP (Renewable Energy and Energy Efficiency Partnership – www.reeep.org) an. Mit dem Beitritt zu diesem Bündnis aus Regierungen, Unternehmen und Organisationen will die Schweiz zum Aufbau eines globalen Netzwerks beitragen, das den verstärkten Einsatz erneuerbarer Energien und eine effizientere Energienutzung zum Ziel hat.

Prozeduren

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 eine effiziente Gesuchsbearbeitung und Projektabwicklung sichergestellt und erste Erfahrungen mit geförderten Projekten gesammelt. Die Anforderungen der REPIC-Plattform sind den Zielgruppen i.A. bekannt und die Prozeduren werden durch diese eingehalten. Dies drückt sich durch eine bessere Qualität der Gesuche und eine höhere Erfolgsrate bei der Unterstützung aus. Dabei ist die REPIC-Plattform bemüht, so flexibel wie möglich auf die Anträge zu reagieren.

Koordination

Die Zusammenarbeit der 4 beteiligten Bundesämter im Rahmen der REPIC-Plattform hat sich gut entwickelt, die entsprechende Koordination hat sich bewährt und ist durch Kontinuität und Vertrauen gekennzeichnet. Damit ist es 2005 gelungen, die Zusammenarbeit auf inhaltliche und strategische Aspekte zu fokussieren, was eine wichtige Zielsetzung der REPIC-Plattform darstellt.

Ausblick

Die bisherigen Erfahrungen mit der REPIC-Plattform weisen den Weg für die nächsten Schritte und Schwerpunkte der Tätigkeiten. Auf der Projektebene wird es im Jahr 2006 besonders darum gehen, die durch die REPIC-Plattform unterstützten Projekte anzahlmässig weiter zu erhöhen, deren Wirkung abzuschätzen und die Diversifizierung der Technologien im Auge zu behalten. Von Bedeutung ist dabei auch die Zielregion der durchgeführten Projekte. Mit den für das Kyoto Protokoll relevanten Organisationen wie Swissflex und der Stiftung Klimarappen soll ein aktiver Dialog gepflegt werden. Der Informationsaustausch und gegebenenfalls die Zusammenarbeit mit weiteren zu REPIC thematisch verwandten Organisationen (OSEC, SOFI, KFPE, usw.) soll dazu ergänzend verbessert werden. Darüber hinaus wird für Ende 2006 eine erste Evaluation der REPIC-Plattform vorbereitet.

Entsprechend den für 2004 und 2005 definierten Elementen und aufgrund der bisherigen Erfahrungen in den ersten zwei Jahren werden 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)
5) **Evaluation** und **Strategiediskussion** für eine eventuelle **Verlängerung** von REPIC ab 2007

Referenzen / Publikationen

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[3] ***Seminar Erneuerbare Energien in der internationalen Zusammenarbeit,*** 21.09.2005, Gurten, Bern; Unterlagen zu beziehen bei NET Nowak Energie & Technologie AG oder http://www.repic.ch

[4] ***Jahresbericht REPIC-Plattform 2005,*** zu beziehen bei NET Nowak Energie & Technologie AG, oder http://www.repic.ch

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Annual Report 2005

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)

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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), which is considered a key technology and industry. The consortium comprises 17 participants from 11 countries with more than 20 national RTD programmes (or parts of programmes) and two 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 objectives

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 17 participants from 11 countries with more than 20 national RTD programmes (or parts of programmes) and two 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 cooperation 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.

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 also expected that links (and possibly consortium extension) can be established with other relevant national and regional RTD programmes by appropriate communication and interaction.

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.

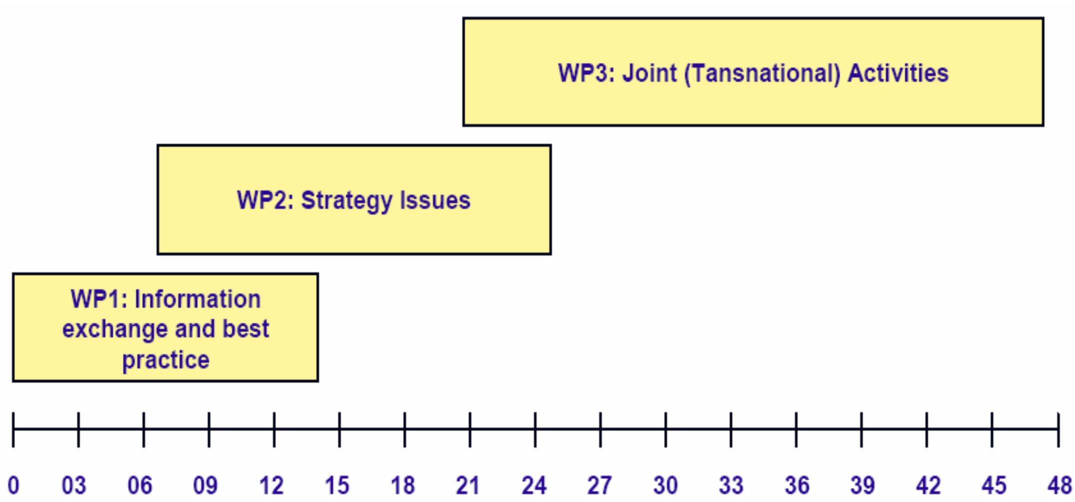

Figure 2: The set-up of the work packages of PV ERA NET reflects the stepping-up of the levels of coordination and cooperation. The scale at the bottom indicates the project duration in months (since Oct 2004).

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 following year will be 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 year and of other ERA NETs', an assessment of first common interest in programming issues and common thematic scope has been initiated in order to launch this work package.
The main goal will be 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 will be 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 will follow logically sequenced steps allowing to gain more experience and practice allowing to implement more relevant joint activities.
The main goal will be to investigate, prepare and implement joint (transnational) activities.

Work performed and results

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 (see box on the right). 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
- 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
- Lessons Learnt

Programme Context
- Community
- Interaction and Stakeholder Involvement
- Framework and Environment

International Orientation
- Current Transnational Activities
- Future Transnational Activities and Opportunities
- Barriers and Gaps

Initial findings: The structure of the country reports allows for finding the relevant information with respect to key features of the various programmes and look up interesting ways of programme design and management. For the latter, an overview “Important Elements for PV RTD Programming” is under development and will collect good examples of programming practices.
Some very general observations can be made by looking at the different programmes with respect to future transnational PV RTD activities:

i) The programmes involved cover a large share of public spend on PV RTD. Around 50 MEUR p.a. are assessed. On a very general level, it can be stated that PV RTD funding is becoming more important.
ii) Looking at priorities, the programmes’ spend indicates that more than half of the funding is oriented towards cell and module technology and a fourth goes into building integration. The priorities can vary significantly *both* between the countries *and* within the country over time.
iii) Most states and programmes do not have a budget specified for PV.
iv) Programme context: Only a few programmes are specifically dedicated to PV. PV is mostly embedded in larger RTD programmes: renewable energy, energy, technology, RTD and / or general programme.
v) Programme extent: Most programmes involved do not cover all PV RTD activities in a country. In most states, there is (often much) more PV RTD done and more public spend on PV RTD than is assessed (with)in the programmes.
vi) Context and extent both reflect different policies in the states. There are different strategies for PV RTD, sometimes there is no clear strategy specified for PV. This has consequences on how focused and comprehensive a programme is with respect to PV RTD.
vii) The scope of the programmes with respect to PV depends on the (diverse) policies and strategies. Programmes can cover all or parts of the development chain from basic R&D to demonstration, or parts of the development chain can be found in different (sub) programmes.

Networking and scope: PV presents major opportunities and challenges. On the international level, PV is seen as an important issue, which is reflected in FP6 research, the PV Technology Platform recently established 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. ERA-NET aims at networking and mutual opening with the great diversity of how research is organised in the different states. Common scope has become clear for different transnational activities, e.g. (tools for) direct information exchange between programmers, common expertise and evaluators’ pool, specific technical R&D topics.

International cooperation

According to the very mission of the ERA NET scheme, further 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. 17 organisations from 11 countries 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 mbH	• 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
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
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 Nether-lands	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-West-phalia	Research Center Jülich GmbH, Project Management Organisation Energy, Technology, Sustainability / Forschungszentrum Jülich GmbH, Projektträger Energie, Technologie, Nachhaltigkeit 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	• Efficient use of energy and of renewable energy sources – technical development and demonstration projects • Solar Energy Association NRW
Poland	Ministry of Science and Information Society Technologies / Ministerstwo Nauki i Informatyzacji	• Polish PV Network (POL-PV-NET) (set of coordinated activities)
Spain	Ministry Education and Science / Ministerio de Educación y Ciencia	• National Energy Programme (NEP)
Sweden	Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning / Forskningsradet för miljö, areela näringar och samshällsbyggande Swedish Energy Agency / Statens energimyndighet	• Long-term research energy programme • Swedish national co-financed programme for PV systems and applica-tions (SolEl) (package of RTD activities)
Switzer-land	Swiss Federal Office of Energy / Bundesamt für Energie / Office fédéral de l'énergie / Ufficio federale dell'energia NET Nowak Energy & Technology Ltd. NET Nowak Energie & Technologie AG	• Swiss Photovoltaic RTD programme
United Kingdom	Department of Trade and Industry	• Technology Programme • Engineering and Physical Sciences Research Council (EPSRC) programmes • Major Photovoltaics Demonstration Programme

Evaluation 2005 and outlook 2006

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.

Mid-September 2005 meeting in Stockholm (Sweden) marked the transition from information to action as outlined in the work plan.

Figure 3: Meeting at Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning gathering PV RTD programme managers and coordinators from twelve countries, officers from the EC as well as representatives from other ERA NETs and from the PV sector. The joint workshop organised on 14 September 2005 allowed for exchanging information and experience and bringing the different perspectives from both the photovoltaic technology and the ERA dimension together.

For the next project steps, working groups are 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.

A first ongoing example is 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.

In the international European context, EC's Seventh Framework Programme and the Strategic Research Agenda by the European Photovoltaics Technology Platform (http://www.eupvplatform.org) will be major elements for drawing the PV RTD landscape. Some of the PV ERA NET members participate in the National Programmes Mirror Group and four specific Working Groups of the PV Technology Platform.

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.

Further Information

Website

http://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.

Newsletter

A regular newsletter is published on the website:

www-pv-era.net -> News & Newsletter

Reports

Several reports are available.

Most reports are however confidential.

Public report:

Survey Report Part I: Organisation, Set-up, Strategy, Objectives and Priorities of Photovoltaic Research and Technological Development Programmes in PV ERA NET States.

October 2005

It can be found on:

www.pv-era.net -> States & Programmes or -> Publications.


PV ERA NET

Survey Report

Part I:

Organisation, Set-up, Strategy, Objectives and Priorities of Photovoltaic Research and Technological Development Programmes in PV ERA NET States

(public version)

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PV ERA NET „Green Power from Sunlight“, February 2005, Brussels