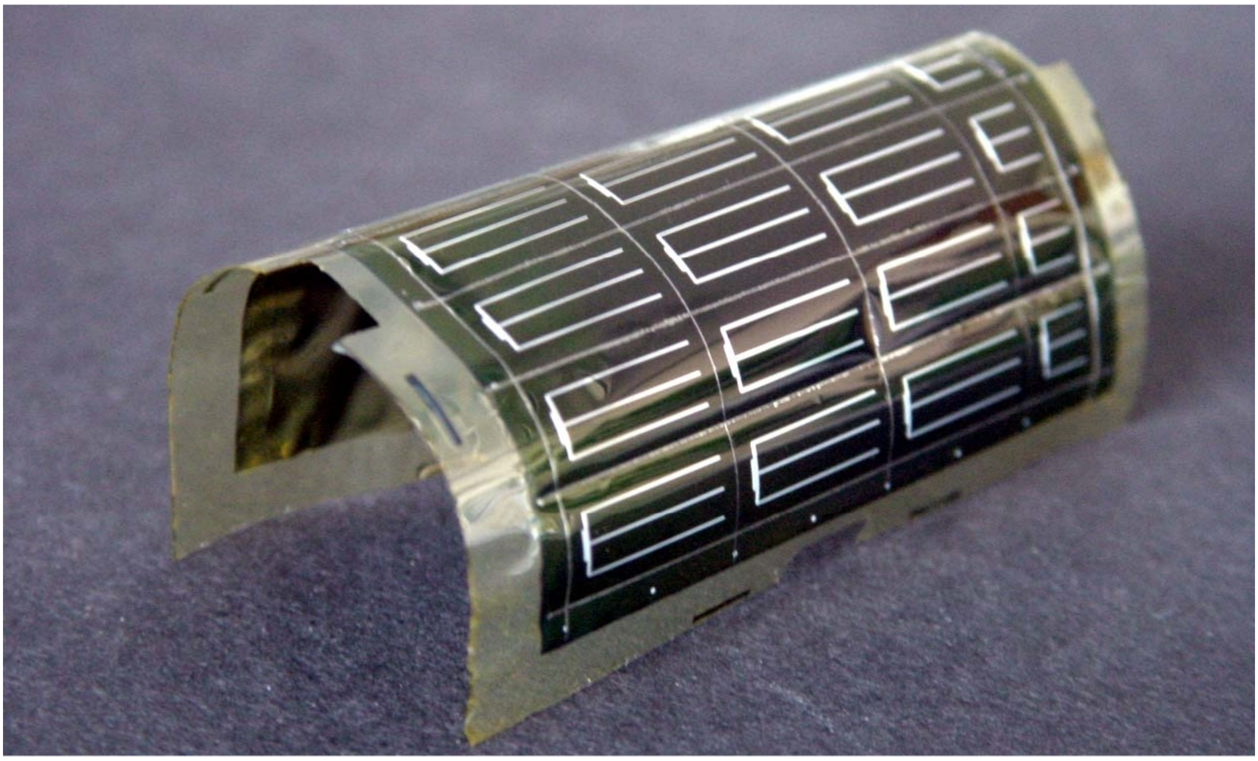
Band 1: Forschung, Mai 2005

Programm Photovoltaik Ausgabe 2005

Überblicksbericht, Liste der Projekte
Jahresberichte der Beauftragten 2004

ausgearbeitet durch:
NET Nowak Energie & Technologie AG



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Programm Photovoltaik Ausgabe 2005

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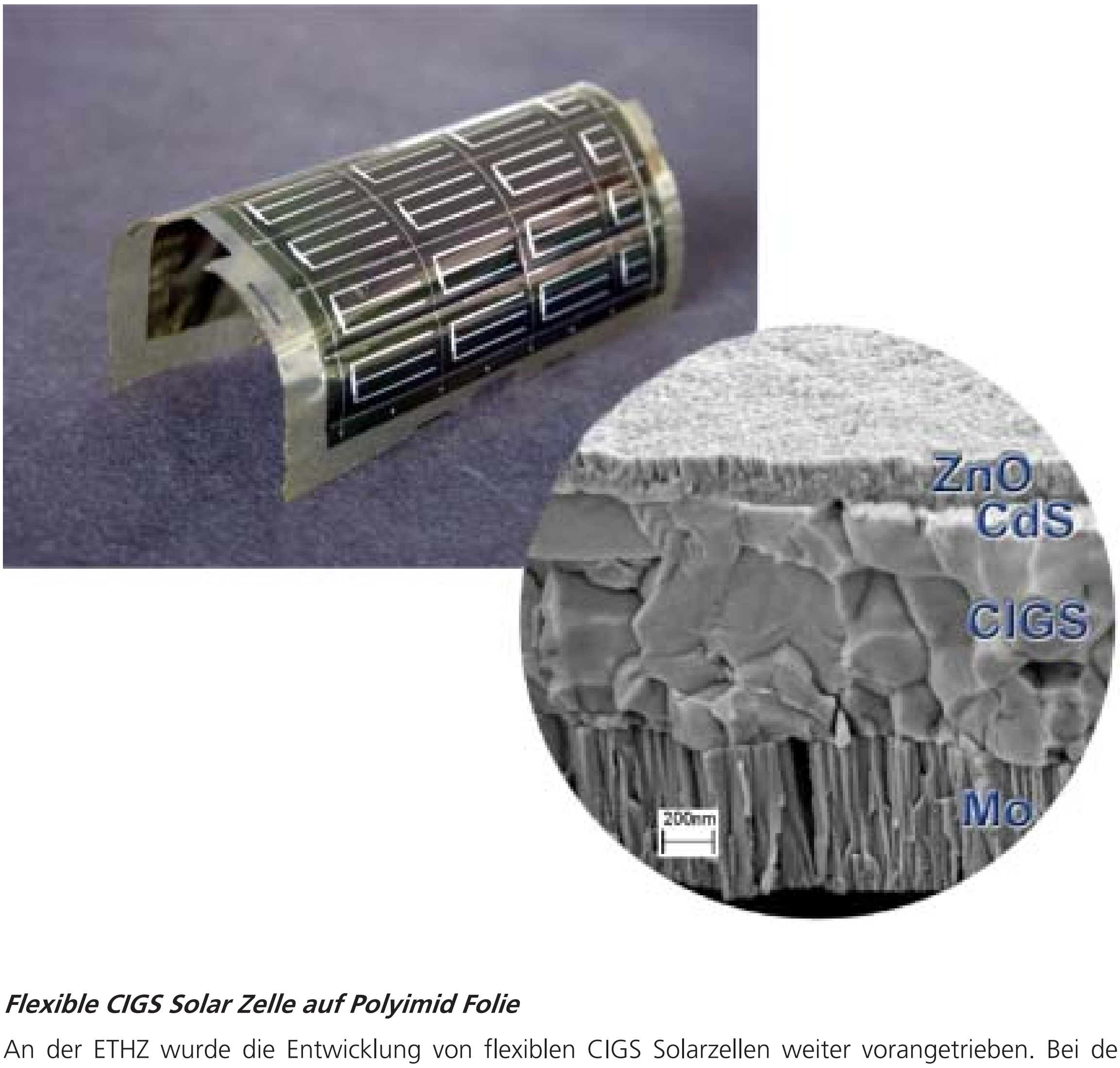

Flexible CIGS Solar Zelle auf Polyimid Folie

An der ETHZ wurde die Entwicklung von flexiblen CIGS Solarzellen weiter vorangetrieben. Bei den Flexiblen Solarzellen auf Polyimid konnte aufgrund von optimierter Prozessführung ein neuer Weltrekord für den Wirkungsgrad von flexiblen Solarzellen auf Kunststoff von 14.1% erzielt werden.

(Bildquelle ETHZ)

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1. Programmschwerpunkte und anvisierte Ziele 2004

Das Jahr 2004 stand für das Programm Photovoltaik (PV) unter dem Zeichen der im Entlastungsprogramm 2003 des Bundes beschlossenen Sparmassnahmen. Während der Einfluss dieser Massnahmen im Bereich der Forschung bisher in Grenzen gehalten und durch eine breite Abstützung des Programms zum Teil aufgefangen werden konnte, mussten im Bereich der P+D-Projekte empfindliche Einschnitte hingenommen werden. Dies erfolgt zu einem Zeitpunkt, wo die industrielle Umsetzung und die Anwendung neuer Lösungen an Schwung gewonnen hat und gefährdet damit die nachhaltige Wirkung der langjährigen Entwicklung. Angesichts dieser Ausgangslage galt es im Berichtsjahr um so mehr, für einige der vielversprechenden Entwicklungen im Bereich der Solarzellen konsequent nach Wegen zur industriellen Umsetzung zu suchen. Das bedeutende Wachstum des internationalen Photovoltaik Marktes bildet denn auch – trotz des stagnierenden nationalen Markts – die Grundlage für den weiteren Ausbau einer wachsenden Photovoltaik Industriebasis in der Schweiz.

Dementsprechend verfolgte das Programm Photovoltaik weiterhin eine ausgeprägte internationale Ausrichtung. Laufende Aktivitäten in Forschung und Entwicklung sowie noch bestehende Projekte im Bereich von Pilot- und Demonstrationsanlagen umfassen im Berichtsjahr 2004 rund 76 Projekte, wobei alle bekannten Projekte mit einer Förderung der öffentlichen Hand berücksichtigt sind. Entsprechend dem von der Eidgenössischen Energieforschungskommission CORE genehmigten Forschungskonzept Photovoltaik 2004 – 2007 [76] ist das Programm Photovoltaik in folgende Bereiche gegliedert:

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**. Neue Produktionsprozesse stehen besonders bei den Silizium Dünnschicht Solarzellen im Vordergrund. Solarzellen auf flexiblen Substraten gewinnen zunehmend an Bedeutung. Die industrielle Umsetzung wurde im Bereich der Solarzellen mit besonderem Nachdruck verfolgt.

Module und Gebäudeintegration

Die **Integration der Photovoltaik** im bebauten Raum bildet nach wie vor 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. 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. Die bessere Vorhersage des **Energieertrags** von Solarmodulen ist dabei ein Teilziel, welches in 2004 mit Nachdruck verfolgt wurde. Die Überarbeitung der **Normen** für die Installation von netzgekoppelten PV Anlagen an Gebäuden sollte im Berichtsjahr abgeschlossen werden. Für **Inselanlagen** wächst die Bedeutung der Kombination mit anderen Energietechnologien in Hybridanlagen.

Ergänzende Projekte und Studien

In diesem Bereich werden u.a. Fragen im Zusammenhang mit **Umweltaspekten** der Photovoltaik behandelt. Im Weiteren werden hier Projekte verfolgt, welche für allgemeine Konzepte, die Planung und den Anlagenbetrieb moderne **Hilfsmittel** bereitstellen. Neuste Technologien des Internets, Computermodelle und Bildverarbeitung bis hin zur Satellitenkommunikation gelangen dabei zum Einsatz. Für Anwendungen in **Entwicklungsländern** sind dagegen nicht-technische Aspekte von grösster Bedeutung.

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 besonderem Interesse waren im Berichtsjahr die Vorbereitungen für eine europäische Photovoltaik Technologie Plattform.

2. Durchgeführte Arbeiten und erreichte Ergebnisse

ZELL-TECHNOLOGIE

Die **grosse Bandbreite der Schweizer Solarzellenforschung** konnte im Berichtsjahr 2004 dank der breiten Abstützung dieser Forschung mit Erfolg fortgesetzt werden. Im Berichtsjahr gewannen insbesondere Industrie-Projekte mit Unterstützung der KTI an weiterer Bedeutung. Die Beteiligung an EU-Projekten bildete eine weitere wichtige Komponente, wobei hier bei den Dünnschichtsolarzellen ein durch die Europäische Kommission bedingter, momentaner Rückgang zu verzeichnen ist.

Dünnschicht Silizium

Die Entwicklungen im Bereich des Dünnschicht Siliziums finden an der Universität Neuchâtel (IMT), an der EPFL (CRPP), der EIAJ (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 schloss beim Projekt zu **Silizium Dünnschichtsolarzellen** [1] im Berichtsjahr eine weitere, durch wichtige Änderungen gekennzeichnete Projektphase ab: seit Herbst 2004 hat Prof. Christophe Ballif die Nachfolge von Prof. Arvind Shah angetreten; Prof. Shah bleibt dem IMT seinerseits mit seiner langjährigen Erfahrung auch im Jahr 2005 erhalten. Damit war das Jahr 2004 einerseits durch die Sicherung der Kontinuität und des Know-hows in wissenschaftlich-technischen Fragen gekennzeichnet, andererseits durch die Definition der künftigen Forschungsausrichtung und letztlich durch die zielgerichteten Arbeiten zur industriellen Umsetzung der bisherigen Forschung geprägt. Letztere war auf die Zusammenarbeit mit den Unternehmen Unaxis und VHF-Technologies konzentriert. Im Vordergrund der Arbeiten im Rahmen des BFE-Projektes stehen die Schlüsselfaktoren, welche die Führungsposition des IMT im wissenschaftlichen Umfeld des Dünnschichtsiliziums auszeichnen. Dies betrifft den Wirkungsgrad der Solarzellen, die Depositionsgeschwindigkeiten und die optische Absorption dieses Materials, sowie die transparenten Oxydschichten (TCO) zur optimalen Lichtstreuung. Die Resultate in den einzelnen Arbeitsbereichen können wie folgt zusammengefasst werden: Für mikrokristalline (σc-Si:H) Solarzellen in p-i-n Schichtabfolge konnte das TCO für den Front-Kontakt in Hinsicht auf den Kurzschlussstrom der Solarzelle optimiert werden. Für mikrokristalline Solarzellen in n-i-p Schichtabfolge wurde auf Glas ein Anfangswirkungsgrad von 9%, auf texturiertem Kunststoff PET ein solcher von 7% erreicht. Mikromorphe Tandemzellen erreichten in der n-i-p Konfiguration auf Glas 9.2%. Weitere Arbeiten konzentrierten sich auf ZnO als TCO-Material sowie auf neue spektroskopische Messmethoden zur Charakterisierung von Solarzellen.

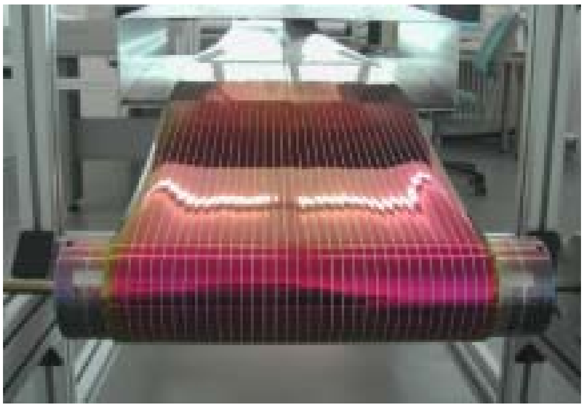
In einem neuen KTI-Projekt wird in Zusammenarbeit mit Unaxis auf der Grundlage der KAI Plasmadepositionsanlagen dieses Unternehmens der ***Prozess*** **der schnellen Abscheidung von mikrokristallinem Silizium** [2] entwickelt. Damit wird die Grundlage für den grossflächigen (1.4m²), industriellen Prozess für mikromorphe Solarzellen gelegt. Auf der Versuchsanlage konnten bereits mikrokristalline Silizium Solarzellen mit 5.5% Wirkungsgrad bzw. mikromorphe Solarzellen mit einem solchen von 9.2% hergestellt werden. In einem verwandten neuen KTI-Projekt erarbeitet das CRPP an der EPFL zusammen mit Unaxis einen neuen, grossflächigen ***VHF-Reaktor*** **für die Abscheidung von amorphen und mikrokristallinen Siliziumsolarzellen** [3]. Es werden Plasmaanregungsfrequenzen bis 100 MHz untersucht, was eine schnelle Abscheidung (∅4 Å/s) erlaubt, jedoch für die Homogenität der Schichten auf einer Fläche von ∅ 1 m² besondere Herausforderungen darstellt. Erste Arbeiten betreffen das Design des Reaktors, insbesondere die Form der Hochfrequenzelektroden, sowie die Prozessparameter. Mehr in die analytische Richtung orientiert, entwickelt das NTB in Buchs in einem weiteren neuen KTI-Projekt zusammen mit Unaxis ein auf die industrielle Produktion ausgerichtetes, spektral aufgelöstes **Photostrom Messgerät** (*Spectral Response Measurement System SRMS*) [4]. Erste Arbeiten betreffen das Hardware Design und die PC Steuerung. Diese verschiedenen KTI-Projekte bilden zusammen mit dem laufenden BFE-Projekt die Grundlage für die industrielle Umsetzung in Hinsicht auf Produktionsanlagen für Silizium Dünnschichtsolarzellen durch Unaxis (Fig. 1).

Eine weitere, unabhängige Gruppe von Projekten befasst sich mit der Entwicklung und Herstellung von Silizium Dünnschichtsolarzellen auf Kunststoffsubstraten; auf Seite der Industrie wird dies durch das IMT spin-off Unternehmen VHF-Technologies in Yverdon unter der Marke flexcell® verfolgt. Die gesamte Fabrikationskette konnte inzwischen aufgebaut und erste kommerzielle Produkte (Ladegerät) am Markt vertrieben werden. Das BFE-Projekt zur Verbesserung der **Zuverlässigkeit von amorphen Solarzellen auf Polymer Substraten** konnte im Berichtsjahr erfolgreich abgeschlossen werden [5]. Für die aktuelle Produktionstechnologie wurden im Berichtsjahr in einem ergänzenden BFE-Projekt die Prozessgrundlagen für eine **Pilotproduktion** von 40 kWp/Jahr erarbeitet [6], in dem die wesentlichen Engpässe in der Produktion durch Erhöhung der Kapazität in den einzelnen Fabrikationsschritten erfolgreich beseitigt werden konnten (Fig. 2). Die Resultate der abgeschlossenen Arbeiten legten die Grundlage für eine weitere Investitionsrunde und die Erhöhung der Produktionskapazität. Ausserdem sollen die Eigenschaften dieser Solarzellen in Hinsicht auf Energieanwendungen weiter entwickelt werden.

Das IMT entwickelt dazu in einem neuen KTI-Projekt zusammen mit VHF-Technologies und weiteren Partnern die Verwendung von **nanostrukturierten optischen Gittern** zur Verbesserung der Eigenschaften von flexiblen Solarzellen auf Kunststoffsubstraten [7]. Die nanostrukturierten Kunststoffsubstrate (PET, PEN) wurden durch OVD-Kinegram vorbereitet. Am IMT wurden auf texturierten PET Substraten amorphe Solarzellen mit 7% stabilem Wirkungsgrad hergestellt.

Ein früheres KTI-Projekt zwischen der EIAJ in Le Locle und VHF-Technologies untersuchte ebenfalls die Verwendung von **Nanostrukturen** [8], wobei diese durch Ätzprozesse auf Polyimidsubstraten hergestellt wurden. Dieses Projekt wurde im Berichtsjahr abgeschlossen. Während die beabsichtigten Strukturen erfolgreich hergestellt werden konnten, resultierte daraus noch nicht die erhoffte Erhöhung des Wirkungsgrades der Solarzellen.

Figur 1: *Industrielle Plasma KAI-Depositionsanlage (Bildquelle Unaxis)*



Figur 2: *Roll-to-roll Produktion von amorphen Silizium Dünnschichtsolarzellen (Bildquelle VHF)*

Kristallines Silizium

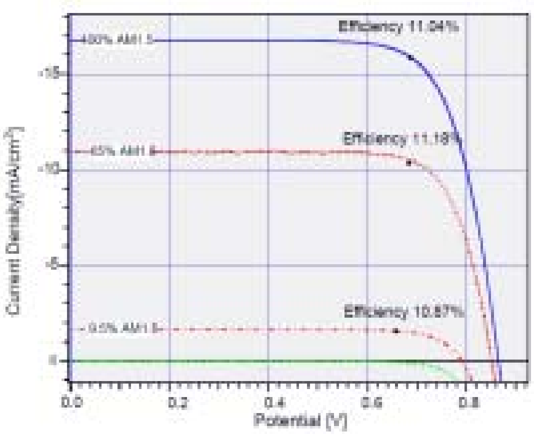
HCT Shaping Systems beteiligte sich am EU-Projekt **RE-SI-CLE** [9] zur Erarbeitung von neuen Prozessen, welche die Rezylierung von Rohsilizium aus Siliziumabfällen der Verarbeitungskette für die Wiederverwendung im Produktionsprozess anstrebte. Dies erfolgt vor dem Hintergrund des im knapper werdenden Rohmaterials für kristalline Silizium Solarzellen. Das Projekt wurde im Berichtsjahr abgeschlossen.

Am PSI wurde im Berichtsjahr in Zusammenarbeit mit HOVAL das KTI-Projekt **HEAT** [10] abgeschlossen. Es hatte zum Ziel, die Verwendung von Siliziumsolarzellen in einer Thermophotovoltaik-Anwendung für autonom betriebene Heizkessel zu entwickeln. Das PSI beteiligt sich zudem im Rahmen des neuen EU-Projektes **FULLSPECTRUM** [11] auch an internationalen Arbeiten zum Thema der Thermophotovoltaik (TPV). FULLSPECTRUM ist eines der neuen Integrierten Projekten im Bereich der Photovoltaik und führt ganz unterschiedliche Ansätze zur besseren Nutzung des Strahlungsspektrums in einem Projekt zusammen (III-V *multijunctions*, TPV, *intermediate band cells*, molekulare Konzepte); dabei werden Wirkungsgrade bis zu 40% angestrebt.

II-VI Verbindungen (CIGS)

Die Gruppe Dünnschichtphysik an der ETHZ hat über Jahre EU-Projekte zum Thema Solarzellen auf der Basis von Verbindungshalbleitern (CIGS, CdTe) durchgeführt. Im Berichtsjahr wurde im BFE-Projekt **FLEXCIM** [12] die Entwicklung von flexiblen CIGS Solarzellen weiter vorangetrieben. Diese flexiblen, 5 x 5 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. Auf Polyimid konnte aufgrund von optimierter Prozessführung ein neuer Weltrekord für den Wirkungsgrad von flexiblen Solarzellen auf Kunststoff von 14.1% erzielt werden; dieser Wert wurde durch unabhängige Messungen am Fraunhofer Institut für Solarenergieforschung (FhG-ISE) in Freiburg (D) ermittelt (Fig. 3). Durch eine Antireflexbeschichtung wird eine weitere Erhöhung auf 15% erwartet. Die Abscheidung der flexiblen CIGS Solarzellen auf Substraten von 30 x 30 cm^2 befindet sich im Entwicklungsstadium. Das EU-Projekt **METAFLEX** [13] zur Entwicklung eines *roll-to-roll* Prozesses wurde im Berichtsjahr abgeschlossen. Dabei konzentrierte sich die ETHZ Gruppe auf die CIGS Deposition auf Polyimid, Minimodule und die CIGS Abscheidung bei Temperaturen unter 450 °C. Im Berichtsjahr betrafen die Arbeiten insbesondere die Verwendung von Natrium im Depositionsprozess; dazu wurde eine spezielle Methode der *Post-Deposition* erfolgreich entwickelt und charakterisiert. Im EU-Projekt **NEBULES** [14] wird das Thema neuer Pufferschichten für CIGS Solarzellen weiter entwickelt. Hier konzentriert sich die ETHZ Gruppe auf die strukturelle und elektronische Charakterisierung der Solarzellen in Abhängigkeit von verschieden hergestellten CdS Pufferschichten. Im Berichtsjahr wurden die Grenzflächen dieser Schichten in Hinsicht auf Struktur und Zusammensetzung eingehend analysiert.

Figur 3: *Flexible CIGS Solar Zelle auf Polyimid Folie (Bildquelle ETHZ)*



Figur 4: *I-V Kennlinien von Farbstoffsolarzellen (Bildquelle EPFL)*

Farbstoffzellen

Die Entwicklung von farbstoffsensibilisierten, **nanokristallinen Solarzellen** [15] wurde am ISIC der EPFL fortgesetzt. Im Berichtsjahr wurde die Farbstoffsynthese in Hinsicht auf die optischen Eigenschaften und den möglichen Temperaturbereich vorangetrieben. Im EU-Projekt **NANOMAX** [16] sollten alternative Wege für die Farbstoff Solarzelle untersucht werden, insbesondere mittels neuen Photoelektroden Konzepten und Materialien, neuen Farbstoffen, verbesserten Transporteigenschaften und reduzierter Rekombination der Ladungsträger. Das Projekt wurde im Berichtsjahr abgeschlossen. Während für das in der Vergangenheit immer wieder erwähnte Thema der Stabilität (über 1000 h, 60°C) dieser Solarzellen ermutigende Resultate erarbeitet wurden, konnte der Wirkungsgrad noch nicht im erwünschten Ausmass (12 - 15%) erhöht werden. An der EPFL wurden dazu im Rahmen dieses Vorhabens unter einer AM 1.5 Referenzstrahlung Werte von 11% erreicht (Fig. 4).

Zusammen mit Greatcell Solar wird in einem KTI-Projekt aufgrund von Vorarbeiten innerhalb des *TOP NANO 21* Programms die **technische Hochskalierung** der Farbstoffzelle angestrebt [17]. Mittels Nanotechnologie wird TiO_2 als halbleitender Film auf transparenten leitenden Substraten hergestellt. Die Leerlaufspannung und die Betriebstemperatur der Solarzelle sollen erhöht werden. Ein früheres *TOP NANO 21* Projekt, welches sich mit **flexiblen Farbstoffzellen** [18] befasste, wurde im Berichtsjahr abgeschlossen. Im Vordergrund standen dabei als Substrat rostfreie Stahlfolien, auf welchen Farbstoffzellen als feste Heteroübergänge realisiert wurden. Dabei wurden Wirkungsgrade um die 3% erreicht. Das neue EU-Projekt **MOLYCELL** [19] befasst sich mit flexiblen organischen Solarzellen, wobei sowohl vollständig organische wie hybride nanokristallin–organische Solarzellen untersucht werden. An der EPFL stehen letztere im Vordergrund, wobei dies auf der Grundlage von nanokristallinen Metalloxydfilmen auf Kunststoffsubstraten erfolgt. Die Solarzelle basiert auf einem festen Heteroübergang, dessen Lichtabsorption einerseits durch molekulare Farbstoffe, andererseits durch Polymere beeinflusst werden soll.

Das LTC an der EPFL entwickelt auf der Grundlage der Farbstoffzellen in einem neuen KTI-Projekt zusammen mit Konarka **photovoltaisch aktive Textilien** [20]. Von dieser Entwicklung werden neuartige Photovoltaik Anwendungen erwartet.

Antennen-Solarzellen

An der Universität Bern wurden die grundlegenden Arbeiten zu **Antennen-Solarzellen** [21] 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 in Hinsicht auf die elektronische Energieübertragung. Im Berichtsjahr wurden bezüglich der Funktionalität der Zeolith-Kristalle an ihren Enden und für die Herstellung dünner Zeolith-Kristalle Fortschritte erzielt.

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. Im Berichtsjahr wurde auf die Entwicklungen für die Integration von Dünnschicht Solarzellen und deren Bedingungen weiteres Gewicht gelegt.

Swiss Sustainable Systems (3S) untersuchte in einem BFE-Projekt die durch die Verwendung von geätztem **Antireflexglas** [22] mögliche Leistungssteigerung von kristallinen Solarmodulen. Um die möglichen Effekte zu quantifizieren, wurden die Gläser wahlweise vor wie 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%, was nicht ganz den Erwartungen von 3% entspricht. Zusätzliche Effekte sind bei flachen Einstrahlungswinkeln möglich. Das EU-Projekt

AFRODITE [23] wurde im Berichtsjahr abgeschlossen. Dabei wurden unter Verwendung von rückkontaktierten, kristallinen Solarzellen neue ästhetisch ansprechende Lösungen für die PV Gebäudeintegration erfolgreich entwickelt und früher als erwartet kommerzialisiert [77]. Dadurch reduzierten sich auch die vorgesehenen Aufgaben von 3S. Im neuen EU-Projekt **BIPV-CIS** [24] 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.

Alcan Packaging beteiligte sich weiter am EU-Projekt **HIPROLOCO** [25], in welchem neue kostengünstigere Verfahren zur Einkapselung von Dünnschichtsolarzellen in Modulen entwickelt werden. Dieses Projekt wurde im Berichtsjahr abgeschlossen.

Telsonic beteiligt sich am EU-Projekt **CONSOL** [26], 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.

Der minimale Betrieb des Projektes **DEMOSITE** [27] an der EPFL wurde im Berichtsjahr durch das LESO abgeschlossen. Es zeigt nebeneinander zahlreiche Varianten der Photovoltaik-Gebäudeintegration auf Flachdächern, Schrägdächern und Fassaden. Die website http://www.demosite.ch erlaubt deren virtuellen Besuch und bietet zudem Weiterbildungsunterlagen für interessierte Architekten und andere Fachleute. Die weitere Verwendung dieser Demonstrationsanlagen ist seitens der EPFL noch nicht entschieden.

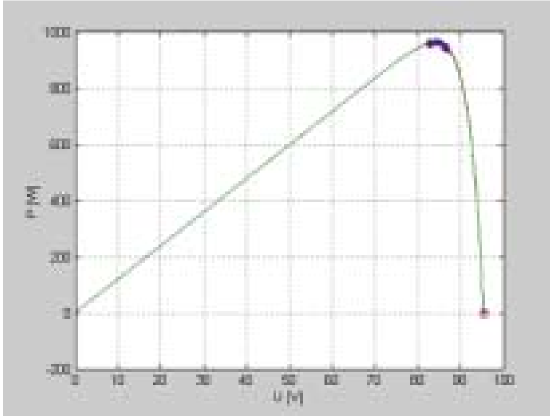
Verschiedene weitere neue Konzepte und Produkte zur Photovoltaik Gebäudeintegration wurden im Rahmen von P+D-Projekten erprobt (siehe Abschnitt *Pilot- und Demonstrationsprojekte*).

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 die Sicherheit und Zuverlässigkeit künftiger Anlagen wie auch für die Standardisierung der Produkte von grosser Bedeutung. Besonders bei aktuellen Normen für Photovoltaiksysteme und der damit einhergehenden Qualitätssicherung war akuter Handlungsbedarf gegeben. Dieser Bedarf betrifft auch Komponenten für die Gebäudeintegration, für welche trotz wachsendem Markt noch keine verbindlichen Normen vorliegen.

Das LEEE-TISO an der SUPSI hat im Berichtsjahr seine Testmessungen an Solarmodulen in einem neuen Projekt **Centrale LEEE-TISO 2003-2006** [28] 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 2100 I-V Kennlinien (Blitztests) gemessen, davon 270 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 Resultate dazu werden im Verlauf von 2005 erwartet. Weitere Untersuchungen betrafen den Temperaturkoeffizienten einzelner Solarmodule, die Messung bei unterschiedlicher Einstrahlungsintensität sowie die Messung von I-V Kennlinien im Fall von Solarzellen mit kapazitiven Eigenschaften. Für die Aussenmessungen der Solarmodule wird die Messelektronik neu konzipiert (Fig. 5). Entsprechend der Strategie des LEEE soll in Zukunft als neues Thema verstärkt auch die Photovoltaik Gebäudeintegration bearbeitet werden.

__Figur 5:__ TISO PV Modulteststand (Bildquelle LEEE TISO)



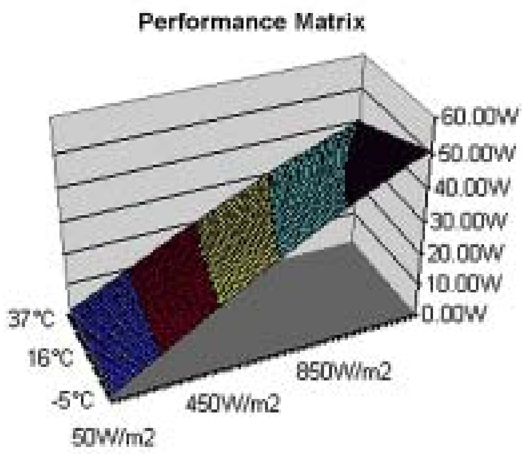
__Figur 6:__ Automatisierte Bestimmung des Wechselrichter Maximum Power Points MPP (Bildquelle HTI Burgdorf)

Das LEEE-TISO ist ferner Partner im EU-Projekt **PV Enlargement** [29], welches ein europaweites Demonstrationsprojekt in 10 Ländern, 5 davon in Osteuropa, mit 32 Anlagen von insgesamt 1.14 MWp Leistung darstellt. Ende 2004 waren davon insgesamt 12 Anlagen mit 712 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 dazu 97 Solarmodule verschiedener Technologien (c-Si, a-Si, CIS, CdTe) und Hersteller geprüft. Bei den kristallinen Zellen wiesen rund die Hälfte der 53 Module Abweichungen von der Nennleistung auf. Die grösste negative Abweichung betrug –9.4%; andererseits wies ein speziell für die Gebäudeintegration bestimmtes Modul eine positive Abweichung von +9.6% auf. Bei den Dünnschichtmodulen wurden unterschiedliche Verhalten festgestellt, die Toleranzen bei der Nennleistung aber im Allgemeinen eingehalten.

Am Photovoltaiklabor an der HTI Burgdorf wurde das Projekt **Photovoltaik-Systemtechnik PVSYTE** [30] fortgesetzt. Die Steuer- und Mess-Software für den Solargenerator-Simulator wurde in den Jahren 2003 und 2004 für halbautomatische Tests stark verbessert (Fig. 6). Zur Gewinnung von Testresultaten von neueren Wechselrichtern erfolgten 2004 ausgedehnte Tests an einigen neuen Geräten (Sunways NT4000, Fronius IG 30 und IG 40 sowie Sunny Mini Central 6000 von SMA). Dabei wurden auf nunmehr 23 Leistungsstufen alle U, I und P auf der DC- und AC-Seite, der DC-AC-Umwandlungswirkungsgrad ξ, der statische MPP-Tracking-Wirkungsgrad ξ_{MPPT}, die Oberschwingungsströme und der cos π auf der entsprechenden Leistungsstufe gemessen. Im Laufe von 2004 wurde zudem die neue Grösse „totaler Wirkungsgrad ξ_{tot}“ eingeführt, die eine noch bessere Charakterisierung des Verhaltens von Netzwechselrichtern ermöglicht. Einige der getesteten Wechselrichter weisen gegenüber früheren Geräten eine deutliche Steigerung des Umwandlungswirkungsgrades auf, der zudem oft deutlich von der verwendeten DC-Spannung abhängt. Um für zukünftige Tests zwei computersteuerbare Simulatoren zur Verfügung zu haben, wurde im Jahre 2004 auch die Steuerelektronik des kleinen Simulators (7,5 kW / 12 A) komplett überarbeitet und der Arbeitsspannungsbereich von 75 V bis 750 V auf 20 V bis 800 V erweitert. Im Rahmen dieses Projektes wurde auch das Langzeit-Monitoring der im vorangegangenen Projekt gemessenen Anlagen mit insgesamt 55 Wechselrichtern fortgesetzt.

Enecolo schloss im Berichtsjahr das Projekt **Energy Rating von Solarmodulen** [31] zusammen mit Partnern im In- und Ausland weitgehend ab. Als Basis dient die Performance-Matrix eines Solarmoduls (Fig. 7). Die Perfomance-Matrix wurde aus verschiedenen experimentellen Methoden ermittelt und in ihren Eigenschaften analysiert und verglichen. Dabei ist die hohe Qualität und breite Verteilung der Messdaten für eine aussagekräftige Performance-Matrix von Bedeutung. Während damit die für die Erstellung der Performance-Matrix notwendigen Erkenntnisse vorliegen, ist die Präzision der Aussagen in Hinsicht auf das Energierating der Solarmodule noch nicht zufriedenstellend und eindeutig.

Solaronix ist am EU-Projekt **EURO-PSB** [32] zur Entwicklung einer Polymer Solar Batterie beteiligt. Es handelt sich dabei um eine kleine, selbstaufladende Batterie für mobile Anwendungen (Fig. 8). 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. Es wurden dazu im Berichtsjahr entsprechende Lösungen erarbeitetet und ein Niederspannungskonverter mit kombinierter Ladereglerfunktion entwickelt. Amorphe Siliziumsolarzellen erwiesen sich dabei als besonders geeignet.



Figur 7: *Performance Matrix eines Solarmoduls (Bildquelle Enecolo)*

Figur 8: *Beispiel einer Anwendung der Polymer Solar Batterie (Bildquelle Varta)*

ERGÄNZENDE PROJEKTE UND STUDIEN

Das LESO an der EPFL beteiligt sich am EU-Projekt **SUNtool** [33], 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 zum Teil bereits validiert. Die Gemeinden Lausanne und Morges nehmen dazu auch als Lieferant von Informationen und Daten teil.

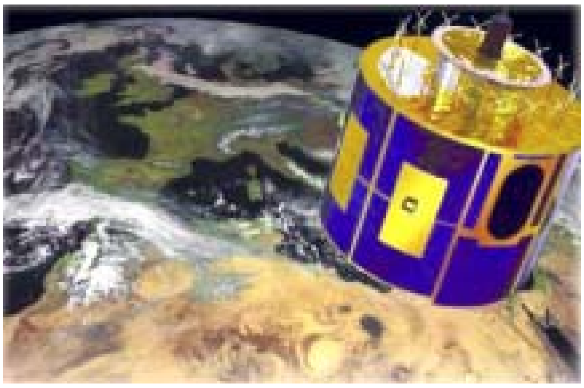
Enecolo ist am EU-Projekt **PVSAT2** beteiligt [34]. In diesem Projekt soll die satellitengestützte Performance Überwachung weiterentwickelt werden, indem einerseits präzisere Satellitendaten verwendet werden und andererseits die Produktionsdaten der PV Anlagen zentral erfasst werden. Insgesamt soll dadurch ein zuverlässiges und kosteneffizientes System zur Überwachung von kleinen Photovoltaik Anlagen entstehen, für welche eine Messdatenerfassung vor Ort zu aufwendig wäre. Im Berichtsjahr wurde vor allem die Strahlungsumrechnung verbessert und ein Entscheidungssystem entwickelt, welches allfällige Fehler beim Betrieb der Photovoltaik Anlagen detektieren kann. Enecolo ist auch am verwandten Projekt der esa **ENVISOLAR** [35] 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** [36] 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). Es konnte gezeigt werden, dass ab einer Distanz von ca. 20-25 km zur nächsten Meteostation die aus den Satellitendaten errechnete Solarstrahlung präziser ist. Das Projekt wird anfangs 2005 mit einem Workshop abgeschlossen(Fig. 9).

Das LEEE-TISO und Solstis sind Partner im neuen EU-Projekt **PV-Catapult** [37]. 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 soll dazu eine SWOT-Analyse der europäischen Photovoltaik durchgeführt werden. 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.

Ein symbolträchtiges Projekt stellt das von Bertrand Piccard und verschiedenen Partnern getragene Vorhaben **Solarimpulse** [38] dar. Das Ziel dieses speziellen Projekts ist die ununterbrochene Weltumrundung mit einem photovoltaisch betriebenen Flugzeug (Fig. 10). 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. In diesem Projekt nimmt die EPFL die Rolle des wissenschaftlichen Beraters wahr und arbeitet dazu mit weiteren Stellen im In- und Ausland zusammen.



Figur 9: *Heliosat 3*
(Bildquelle Eumetsat)

Figur 10: *Photovoltaisch betriebenes Flugzeug*
(Bildquelle: Oxyde.ch – Saprisiti / ©EPFL Solar Impulse)

INTERNATIONALE ZUSAMMENARBEIT IEA, IEC, PV-GAP

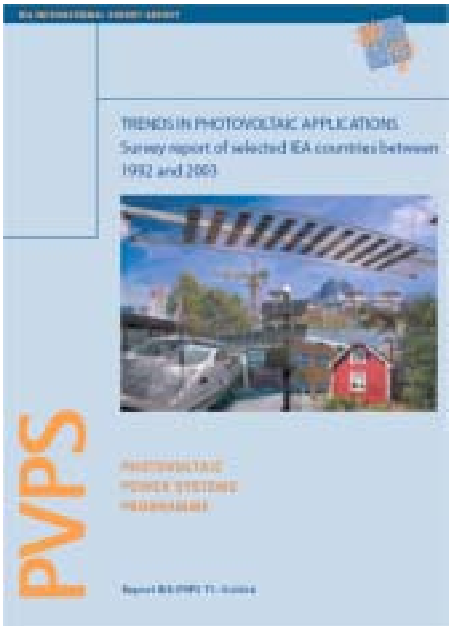
Die Beteiligung am Photovoltaikprogramm der IEA (IEA PVPS) wurde im Berichtsjahr mit Kontinuität fortgesetzt, sowohl auf der Projektebene wie im *Executive Committee* (ExCo) [78]. Die Schweiz setzte im Berichtsjahr den Vorsitz dieses weltweiten Programms fort. Im Berichtsjahr wurde die Zusammenarbeit mit der Industrie verstärkt und die Europäische Photovoltaik Industrie Vereinigung EPIA konnte neu als Sponsormitglied gewonnen werden. Ausführliche Informationen zu den Aktivitäten und Resultaten von IEA PVPS sind auf der website http://www.iea-pvps.org zu finden.

Nova Energie vertritt die Schweiz in Task 1 von IEA PVPS, welcher allgemeine **Informationsaktivitäten** [39] zur Aufgabe hat. Im Berichtsjahr wurde ein weiterer nationaler Bericht über die Photovoltaik in der Schweiz bis 2003 [79] erstellt; auf dieser Grundlage wurde die 9. Ausgabe des jährlichen internationalen Berichtes (Fig. 11) 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 (Bank Sarasin, Credit Lyonais) verwendet [81, 82]. Im Berichtsjahr wurde anlässlich der 19. Europäischen Photovoltaik Konferenz in Paris unter Schweizer Führung ein

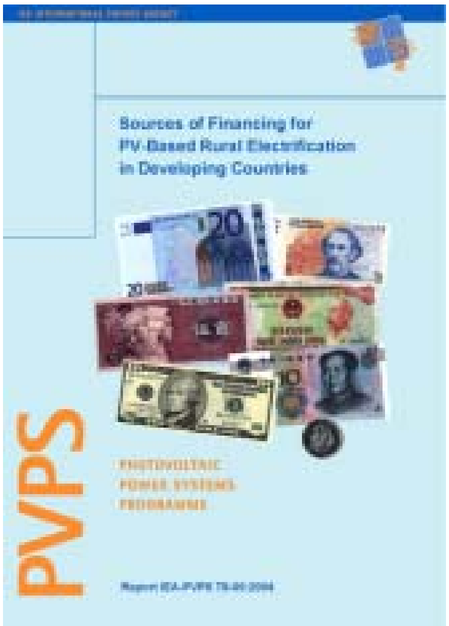
Workshop mit der Industrie organisiert. Der *IEA PVPS-Newsletter* [83] informiert regelmässig über die Arbeiten in und rund um das IEA-Programm.

In IEA PVPS Task 2 über **Betriebserfahrungen** [40] stellt TNC den Schweizer Beitrag. Im Berichtsjahr wurde dieses Projekt unter der Führung Deutschlands für eine weitere Arbeitsphase 2004-2007 verlängert und umfasst nun 11 teilnehmende Länder (inkl. Europäische Kommission, Polen ist neu permanenter Beobachter). Als wichtiges neues Thema figurieren wirtschaftliche Aspekte der Photovoltaik. Die PVPS-Datenbank *Performance Database* [84] wurde mit neuen Daten ergänzt und umfasst nun 414 Photovoltaik-Anlagen aus 21 Ländern mit insgesamt rund 15'000 Monats-Betriebsdaten und 12 MWp Anlagenleistung. Aus der Schweiz sind 64 Anlagen in der Datenbank enthalten. Im Jahr 2004 wurden zwei neue Berichte zu Performanz und Einstrahlungsdaten fertiggestellt [85, 86].

Dynatex beteiligt sich an den Arbeiten in IEA PVPS Task 3 über **Inselanlagen** [41]. Schwerpunkte der Aktivitäten dieses Projektes bilden die Qualitätsverbesserung und die Zuverlässigkeit von autonomen Photovoltaik-Anlagen sowie technische Fragen in hybriden Systemen und Batterien. Das Projekt wurde im Berichtsjahr abgeschlossen. Im Jahr 2004 wurden die letzten Berichte zur Auswahl von Bleibatterien sowie zu alternativen Speichersystemen publiziert [87-89].



Figur 11: *IEA PVPS International Survey Report*



Figur 12: *IEA PVPS Task 9 Bericht zur Finanzierung ländlicher Elektrifizierung mit Photovoltaik*

Im Rahmen der interdepartementalen Plattform (seco, DEZA, BUWAL, BFE) zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit REPIC (http://www.repic.ch) leistet entec den Schweizer Beitrag zu IEA PVPS Task 9 über die **Photovoltaik-Entwicklungszusammenarbeit** [42]. Dieses Projekt trat im Berichtsjahr in eine neue Arbeitsphase 2004-2008. Die Schweiz ist in diesem Projekt für die Koordination der Arbeiten mit multilateralen und bilateralen Organisationen verantwortlich. Im Berichtsjahr wurde im Rahmen dieses Projektes ein Bericht zur Finanzierung ländlicher Elektrifizierung mit Photovoltaik publiziert [90] (Fig. 12).

Alpha Real vertritt die Schweiz im TC 82 der IEC und leitet die Arbeitsgruppe, welche internationale **Normenvorschläge** [67] für Photovoltaiksysteme vorbereitet und verabschiedet. Alpha Real beteiligt sich ausserdem an *PV-GAP* (PV Global Approval Program), einem weltweiten Programm zur Qualitätssicherung und Zertifizierung von Photovoltaik-Systemen.

Das EU-Projekt **PV-EC-NET** [43] ist ein Netzwerk von nationalen Photovoltaik Programmkoordinationsstellen, an welchem sich 14 Länder beteiligten (http://www.pv-ec.net). Das Projekt wurde 2004 mit einer Roadmap abgeschlossen. Das ergänzende EU-Projekt **PV-NAS-NET** [44] befasst sich mit der

Analyse der Situation der Photovoltaik in den neuen Mitgliedländern der EU und führt ähnliche Arbeiten wie das Projekt PV-EC-NET durch (http://www.pv-nas.net). Im Berichtsjahr wurde dazu ein Überblicksbericht publiziert, welcher Photovoltaik Forschungsaktivitäten und die Marktsituation in diesen Ländern darstellt. Durch diese Projekte entsteht eine ausgezeichnete Übersicht über die verschiedenen Ansätze und Aktivitäten, aber auch über Probleme und Verbesserungsmöglichkeiten. 2004 begann das neue EU-Projekt **PV-ERA-NET** [45], welches Programmkoordinationsstellen und verantwortliche Ministerien aus 11 Ländern unter dem era-net Schema zusammenführt (http://www.pv-era.net). Im Verlauf dieses Projektes soll die Zusammenarbeit zwischen den Europäischen Photovoltaikprogrammen verstärkt und in ausgewählten Gebieten gemeinsame Aktivitäten ausgelöst werden.

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 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 BBW bzw. dem neuen Staatssekretariat für Bildung und Forschung SBF, der KTI, dem BUWAL, der DEZA und dem seco sowie aus der Elektrizitätswirtschaft dem VSE, dem PSEL und der Gesellschaft Mont Soleil. Diese vielfältigen Kontakte erlauben die anhaltend wichtige breite Abstützung des Programms.

4. Internationale Zusammenarbeit

Die traditionsreiche internationale Zusammenarbeit wurde auch im Berichtsjahr fortgesetzt: Die institutionelle Zusammenarbeit innerhalb der IEA, der IEC, PVGAP und den Europäischen Netzwerkprojekten wurde bereits oben beschrieben. Auf der Projektebene konnte die erfolgreiche Zusammenarbeit innerhalb der EU in bestehenden und neuen Projekten fortgesetzt werden: Im Jahr 2004 waren es 20 Projekte im 5. bzw. 6. Rahmenforschungsprogramm der EU. Ein weiteres Projekt fand mit der esa statt. Die Schweizer Photovoltaik konnte sich relativ erfolgreich an den ersten 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.

Eine neue, wichtige Entwicklung fand mit den Vorarbeiten in Hinsicht auf eine Europäische Photovoltaik Technologie Plattform statt. Technologie Plattformen sind ein neues Instrument der EU, mit welcher Forschung, Industrie und weitere Kreise in strategisch wichtigen Gebieten in einer gemeinsam getragenen Initiative eingebunden sind und stärker zusammenarbeiten sollen. Der Programmleiter Photovoltaik konnte in der Eigenschaft als Vorsitzender des IEA PVPS Programms an den Arbeiten des *Photovoltaic Technology Research Advisory Council* (PV-TRAC) teilnehmen. Dieser Beirat der Europäischen Kommission erarbeitete im Verlauf von 2004 einen Bericht mit einer Vision für die Photovoltaik im Jahr 2030 [91], welche im September 2004 vorgestellt wurde. Es wird erwartet, dass die Photovoltaik Technologie Plattform 2005 operativ wird und insbesondere in Hinsicht auf das 7. Rahmenforschungsprogramm der EU Wirkung entfalten kann.

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

5. Pilot- und Demonstrationsprojekte

EINLEITUNG

Das Entlastungsprogramm 2003 des Bundes hatte auf das Photovoltaik P+D Programm einschneidende Auswirkungen. Stieg die Anzahl der aktiven Projekte im Jahr 2003 im Photovoltaik P+D Bereich leicht auf gut 45 Projekte an, wurden im Berichtsjahr insgesamt rund 35 Projekte begleitet. Anfang 2005 betrug die Zahl der aktiven Projekte noch 25. Aufgrund der aktuellen Budgetsituation im PV P+D Bereich ist die Unterstützung neuer Projekte vorderhand nicht mehr möglich.

Die P+D Aktivitäten verteilten sich im Berichtsjahr auf die Sektoren Pilotanlagen, Studien und Hilfsmittel, Messkampagnen und Komponentenentwicklung. Die pilotmässige Erprobung neuer Komponenten bei P+D Anlagen im Massstab 1:1 bildete auch dieses Jahr einen klaren Schwerpunkt. Thematisch hauptsächlich vertreten bleibt weiterhin die **Photovoltaik Gebäudeintegration**.

Aktuell befassen sich diverse PV P+D Projekte mit den Einsatz- und Anwendungsmöglichkeiten verschiedener Dünnschichtzellentechnologien. Bei mehreren Projekten wird die Eignung neuer Module dieses Typs für die Photovoltaik Gebäudeintegration untersucht. Die bisherigen Erfahrungen belegen die positiven Eigenschaften einiger PV Elemente mit Dünnschichtzellen für die direkte Integration in thermisch isolierte Dächer und Fassaden ohne Hinterlüftung der Module.

P+D PROJEKTE

Neue P+D Projekte

Im Berichtsjahr 2004 konnten im P+D Programm aufgrund des Entlastungsprogramms 03 des Bundes **keine neuen P+D Projekte** mehr begonnen werden. Damit wird es verschiedenen Schweizer Firmen zunehmend erschwert, Erfahrungen mit neuen Produkten im Ersteinsatz zu sammeln, oder neue Entwicklungen anzugehen, die zum Erhalt der internationalen Konkurrenzfähigkeit im Photovoltaikbereich beitragen. Während sich der PV Weltmarkt seit Jahren mit Wachstumsraten von jährlich 30 bis 40% entwickelt, stagniert der Schweizer Markt seit über 5 Jahren. Diversen Schweizer Firmen fehlen damit einerseits mindestens teilweise die Erfahrungen mit neuen Produkten, und andrerseits die Erfahrungen im Massengeschäft. Damit besteht für diverse in der Schweiz ansässige Firmen die Gefahr, gegenüber der ausländischen Konkurrenz ins Hintertreffen zu geraten. Ausgenommen sind dabei all jene Unternehmen, die sich frühzeitig in internationalen Wachstumsmärkten etablieren konnten.

Laufende P+D Projekte

Bei den laufenden Projekten konnten mit dem Bau der dachintegrierten 15 kWp Flachdachanlage CPT Solar mit amorphen Dünnschichtzellen in Trevano [49], Fig. 13 wertvolle Erfahrungen gesammelt werden. Der über den Erwartungen liegende Ertrag von 1070 kWh/kWp belegt die optimale Planung und Auslegung dieser Installation.

Mit dem Projekt PV DünnFilmTest [61] Fig. 18 wird nach der zweijährigen Messphase die gute Eignung einiger Dünnschichtmodule für die Gebäudeintegration in Kombination mit einer thermischen Isolation aufgezeigt. Im Schlussbericht werden die detaillierten Auswertungen nachzulesen sein.

Interessant sind auch die Resultate der 62 kWp Flachdachanlage mit PowerGuard Modulen [52] Fig. 14. Neben der einfachen Montage überzeugt diese Anlage auch mit einem guten optischen Erscheinungsbild und einem hohen Ertrag.

Figur 13: *15.4 kWp Flachdachintegration mit Sarnasol Photovoltaik Elementen (Bildquelle: Sarnafil)*

Figur 14: *62 kWp Anlage mit PowerGuard Modulen (Bildquelle: Zagsolar)*

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) [46]

Anlagen

↓ 15.4 kWp Flachdachintegration CPT Solar (Pilotmässiger Einsatz einer neu entwickelten Kombination von amorphen Dünnschichtzellenmodulen mit einer dichten Kunststofffolie; Leitung: LEEE-TISO) [49] Fig. 13

↓ 23.5 kWp PV Anlage Zollhof Kreuzlingen (Flachdach Demonstrationsanlage mit Grossanzeige an gut frequentierter Lage; Leitung: Böhni Energie und Umwelt) [50] Fig. 15

↓ Autonome 5.7 kWp Photovoltaik Anlage in Kombination mit einem BHKW (Ganzjährige autonome Energieversorgung von 2 Jurahäusern mittels Photovoltaik, BHKW, thermischen Kollektoren und Holz; Leitung: A. Reinhard) [75]

↓ 17.6 kWp Flachdachanlage mit Dünnschichtzellenmodulen ETHZ (Optisch diskrete Flachdachanlage mit amorphen Zellen; Leitung: BE Netz) [51]

↓ 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) [52] Fig. 14

↓ 12 kWp Solight Pilotanlage (Pilotmässige Umsetzung von zwei verschiedenen Solight Varianten; Leitung: Energiebüro) [53]

↓ 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) [56]

- 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) [71]
- 27 kWp Anlage AluStand Hünenberg (Demonstrationsanlage mit Verwendung der Flachdachvariante des Modulhaltesystems AluTec (AluStand); Leitung: Urs Bühler Energy Systems and Engineering) [54] Fig. 16
- 25 kWp Gründachintegration Solgreen Kraftwerk 1, Zürich (Piloteinsatz einer neu entwickelten Modul Haltekonstruktion für den Gründachbereich; Leitung: Enecolo) [55] Fig. 17
- 3 kWp Anlage Ferme Amburnex (Inselanlage mit Hilfs-Dieselaggregat zur elektrischen Versorgung einer Alp, autonome Anlage; Leitung: Services Industriels Lausanne) [73]
- 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) [58]

Figur 15: *PV Anlage Zollhof Kreuzlingen (Bildquelle NET)*

Figur 16: *27 kWp Alustand Hünenberg (Bildquelle Urs Bühler Energy Systems)*

Messkampagnen

- Messkampagne Wittigkofen (Detaillierte Messungen und Auswertungen mit Visualisierung der Daten zur 80 kWp Fassade Wittigkofen; Leitung: Ingenieurbüro Hostettler) [60]
- 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) [62]
- PV DünnFilmTest Migros Zürich (18 Testanlagen mit PV Dünnschichtzellen-Modulen im direkten Vergleich, Gesamtleistung: 24.5 kWp; Leitung: Energiebüro) [61] Fig. 18
- Messkampagne 100 kWp Anlage A 13 (Leitung: TNC Consulting) [63]

Figur 17: *Gründachanlage Solgreen Kraftwerk 1 Zürich (Bildquelle NET)*

Figur 18: *PV DünnFilmTest (Bildquelle NET)*

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) [64]

↓ 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) [65]

↓ *Solar Electri City Guide* - Schweizer Solarstromführer für die Gemeinden (Leitung: NET) [66]

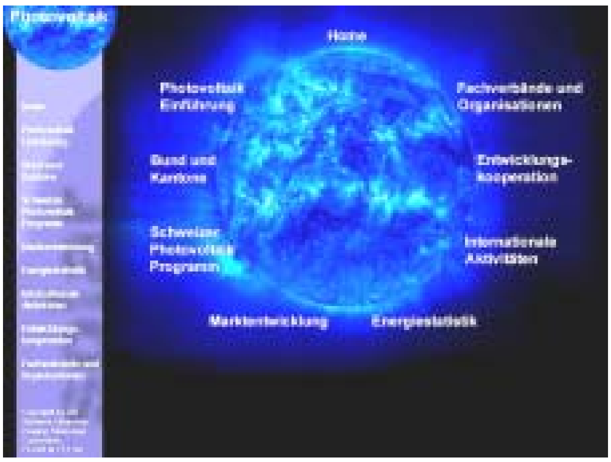
↓ IEC Normenarbeit PV Systeme (Leitung: Alpha Real) [67]

↓ Internetportal Photovoltaik Schweiz http://www.photovoltaic.ch (Realisierung eines umfassenden Schweizer Internetauftritts mit umfangreichen Informationen zu nationalen und internationalen PV Aktivitäten; Leitung: NET) [A]

↓ Photovoltaikstatistik der Schweiz 2004 (Leitung: Ing. Büro Hostettler, Energiebüro, VSE) [B]

↓ Solarstrom vom EW (Leitung: Linder Kommunikation) [C]

Figur 19: *Ausschnitt Titelblatt neue NIN Norm (Bildquelle SEV)*



Figur 20: *Schweizer Photovoltaik Internetportal (http://www.photovoltaic.ch)*

Im Jahr 2004 abgeschlossene Projekte

Im Jahr 2004 wurden die folgenden P+D Projekte abgeschlossen (in chronologischer Reihenfolge):

Komponentenentwicklung

↓ Photovoltaik-Alpur-Dach (Photovoltaik Dach mit thermischer Isolation; Gebäudeintegration; Leitung: ZAGSOLAR) [47]

Anlagen

↓ 5.5 kWp Dachintegration mit dem Integrationsystem Freestyle® in Lutry (Vollflächige Photovoltaik Dachintegration mit Modulen mit amorphen Tripelzellen, Pilotanlage; Leitung: Solstis) [48] Fig. 21

↓ 15 kWp Photovoltaik Dachintegration Pfadiheim Weiermatt Köniz (Vollflächige Photovoltaik Integration mit dem MegaSlate® Solardachsystem ins Dach des energietechnisch optimierten Pfadiheims Weiermatt; Leitung: 3S - Swiss Sustainable Systems) [68] Fig. 22

↓ Photovoltaik Obelisk (Pilotmässige Realisierung von Informationssäulen mit modernem Design für den öffentlichen Raum mit integrierter PV Anlage zur Energieversorgung; Leitung: Enecolo) [72] Fig. 23

↓ 3.9 kWp Photovoltaik Beschattungsanlage mit CIS Modulen (Piloteinsatz von multifunktionalen teiltransparenten Modulen mit CIS Zellen für die gleichzeitige Beschattung eines Atriums und die Stromproduktion; Leitung: Enecolo) [57] Fig. 24

↓ 70 kWp Flachdachanlage Palexpo Genf (Netzgekoppelte Photovoltaik Dachanlage an gut frequentierter Lage, kombiniert mit 2 Ladestationen für Elektromobile; Leitung: SSES - Société Suisse pour l'Energie Solaire) [70] Fig. 25

↓ 16 kWp Dachintegration Sunny Woods (Dachintegrierte PV Pilotanlage mit amorphen Tripelzellen in einem Mehrfamilien-Passivhaus; Leitung: Architekturbüro Kämpfen, Naef Energietechnik) [69]

Figur 21: *5.5 kWp Dachintegration Freestyle (Bildquelle Solstis)*

Figur 22: *15 kWp Dachintegration Weiermatt (Bildquelle NET)*

Figur 23: *PV Obelisk (Bildquelle NET)*

Figur 24: *PV Beschattungsanlage Würth Chur (Bildquelle NET)*

Figur 25: *70 kWp Flachdachanlage Palexpo (Bildquelle NET)*

Figur 26: *Autonome 3 kWp Dachintegration Soyhières (Bildquelle NET)*

Messkampagnen

↓ Messkampagne Soyhières (Detaillierte Messungen und Auswertungen zur autonomen 3 kWp PV Dachintegration in Soyhières; Leitung: SGI / Solstis) [59] Fig. 26

↓ 47 kWp Anlage IBM (Detaillierte Messkampagne zu schmutzabweisenden Oberflächenbeschichtungen von PV Modulen; Leitung: awtec, Zürich) [74]

6. Bewertung 2004 und Ausblick 2005

Der weltweite Photovoltaikmarkt boomt aufgrund grossangelegter Förderprogramme bzw. Einspeisevergütungen einzelner Länder weiterhin mit Wachstumsraten zwischen 30 und 40%. 2004 wurde in der Modulproduktion erstmals die 1000 MW Schwelle überschritten. Von diesem Wachstumsmarkt konnte die Schweizer Photovoltaik Industrie auch im Export profitieren; aufgrund von Umfragen wird das jährliche Photovoltaik Exportvolumen auf mindestens 50 Mio. CHF geschätzt. Demgegenüber stagniert der schweizerische Photovoltaik-Markt und konnte im Jahr 2004 den Vorjahreswert dank den Solarstrom- bzw. Ökostrombörsen leicht übertreffen. Die länderspezifischen Photovoltaik Marktdaten von IEA PVPS zeigen, dass die Schweiz relativ und gegenüber den Entwicklungen in den gegenwärtig grössten Märkten, insbesondere Deutschland, Japan und USA, weiter zurückfällt, und sich nun in absoluten Zahlen im Mittelfeld bewegt.

Die aufgrund des Entlastungsprogramms 2003 des Bundes beschlossenen Kürzungen sind inzwischen vorab für die Mittel für P+D-Vorhaben wirksam geworden und haben damit eine einschneidende Wirkung auf die Ausgestaltung und die Möglichkeiten im Programm Photovoltaik. Im Berichtsjahr 2004 konnten mit BFE-Mitteln keine neuen P+D Projekte unterstützt werden. Diese Entwicklung ist sehr zu bedauern, da damit ein wesentliches Glied in der Umsetzung von Forschung und Entwicklung hin zu industriellen Produkten und Verfahren und damit zum Markt geschwächt wird. Dies trifft die Photovoltaik zu einem Zeitpunkt, in dem sich nach langem Aufbau eine verstärkte Umsetzung im Programm Photovoltaik abzeichnet. P+D Projekte sind ein wesentliches Bindeglied zwischen Forschung / Entwicklung und der Umsetzung der Resultate in industrielle Prozesse, Produkte und Anlagen.

Durch die breite Abstützung des Programms Photovoltaik konnte der Rückgang der zur Verfügung stehenden Mittel im Bereich der Forschung bisher in Grenzen gehalten werden. Dazu haben EU-Projekte mit Unterstützung des Bundesamtes für Bildung und Wissenschaft BBW (ab 2005 Staatssekretariat für Bildung und Forschung SBF) sowie seit 2004 auch durch die Europäische Kommission direkt beigetragen, ebenso die Kommission für Technologie und Innovation KTI (seit kurzem die Förderagentur für Innovation). Die gute Vernetzung des Programms und seiner Akteure, sowohl national wie international, ist dabei eine wichtige Voraussetzung, welcher weiterhin grosse Beachtung geschenkt wird. Es ist von zentraler Bedeutung, dass für die P+D-Vorhaben auch in Zukunft eine Substitution der ansonsten nicht vorhandenen Mittel gefunden werden kann.

An der ETHZ fand im März 2004 die gut besuchte 5. Nationale Photovoltaik Tagung statt. Die Schweizer Photovoltaik war auch an der 19. europäischen Photovoltaik Konferenz im Juni in Paris mit ihren Beiträgen gut vertreten [92]. Der Informationsaustausch bleibt in der Schweiz weiterhin ein wichtiges Thema. Die Photovoltaik website http://www.photovoltaic.ch beinhaltet alle wesentlichen Informationen sowie Berichte und dient damit als wichtiges Informationsinstrument, das laufend unterhalten wird. Dies ist ab 2005 besonders wichtig, da der frühere ENET-Publikationsdienst in seiner bisherigen Form nicht fortgeführt werden kann und in Zukunft nur noch mit reduziertem Umfang (http://www.energieforschung.ch) betrieben wird.

Am 12. April 2005 findet an der EMPA ein Fachseminar im Bereich der Solarzellenforschung statt. Als wichtigste nationale Veranstaltung findet im Jahr 2005 die 6. Nationale Photovoltaik Tagung in Genf statt (24./25. November 2005). Ausserdem finden die 20. Europäische Photovoltaik Konferenz in Barcelona (6.-10. Juni 2005, http://www.photovoltaic-conference.com), die Fachmesse Intersolar in Freiburg (23.-25. Juni 2005, http://www.intersolar.de) und das 20. Symposium für Photovoltaische Solarenergie in Staffelstein (9.-11. März 2005) statt.

7. Liste der F+E – Projekte

(JB) Jahresbericht 2004 vorhanden
(SB) Schlussbericht vorhanden
Einzelne Jahresberichte und Schlussberichte können von www.photovoltaic.ch heruntergeladen werden
Unter den aufgeführten Internet-Adressen können weiter Informationen heruntergeladen werden

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[44] S. Nowak, (stefan.nowak@netenergy.ch), NET, *St. Ursen:* ***PV-NAS-NET: Co-ordination of Newly Associated States and EU RTD Programmes on Photovoltaic Solar Energy*** (JB) / http://www.photovoltaic.ch http://www.netenergy.ch

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8. Liste der P+D – Projekte

(JB) Jahresbericht 2004 vorhanden
(SB) Schlussbericht vorhanden
Einzelne Jahresberichte und Schlussberichte können von www.photovoltaic.ch heruntergeladen werden
Unter den aufgeführten Internet-Adressen können weiter Informationen heruntergeladen werden

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11. Verwendete Abkürzungen (inkl. Internetlinks)

Allgemeine Begriffe

ETH	Eidgenössische Technische Hochschule	
HES	Haute Ecole Spécialisée	
PV EZA	Photovoltaik Entwicklungszusammenarbeit	http://www.photovoltaic.ch

Finanzierende Institutionen

PSEL	Projekt- und Studienfonds der Elektrizitätswirtschaft	http://www.psel.ch

Nationale Institutionen

BBT	Bundesamt für Berufsbildung und Technologie	http://www.bbt.admin.ch
BBW	Bundesamt für Bildung und Wissenschaft - heisst neu Staatssekretariat für Bildung und Forschung SBF	http://www.sbf.admin.ch
BFE	Bundesamt für Energie	http://www.energie-schweiz.ch
BUWAL	Bundesamt für Umwelt, Wald und Landschaft	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
EIAJ	Ecole d'Ingénieurs de l'Arc jurassien	http://www.eiaj.ch
EMPA	Eidgenössische Materialprüfungs- und Forschungsanstalt	http://www.empa.ch
ENET	Netzwerk für Informationen und Technologie-Transfer im Energiebereich	http://www.energieforschung.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
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

SECO	Staatssekretariat für Wirtschaft	http://www.seco-admin.ch
SBF	Staatssekretariat für Bildung und Forschung	http://www.sbf.admin.ch
SUPSI	Scuola universitaria professionale della Svizzera Italiana	http://www.leee.supsi.ch
VSE	Verband Schweizerischer Elektrizitätsunternehmen	http://www.strom.ch

Internationale Organisationen

EU	Europäische Union (RTD-Programme)	http://www.cordis.lu
(RTD)	Forschungs- und Entwicklungsinformationsdienst der Europäischen Gemeinschaft	
ECN	Energy research Centre of the Netherlands	http://www.ecn.nl
EESD	Energy, Environment and Sustainable Development	http://www.cordis.lu/eesd/
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 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
UNDP	United Nations Development Programme	http://www.undp.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.statistik.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	Arbeitsgemeinschaft Swissolar	http://www.swissolar.ch
SOLAR	Schweizerischer Fachverband für Solarenergie	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 2004

Thin film silicon modules: Contributions to low cost industrial production

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ABSTRACT

IMT has done significant work on the joint optimisation of p-i-n microcrystalline silicon (µc-Si:H) solar cells and underlying rough LP-CVD ZnO layers. The effect of ZnO layer roughness on the contribution to J_{sc} from the red and near infrared light was clearly evidenced.

Work for improvement of µc-Si:H p-i-n cells is under way, both for low-rate and high-rate deposition.

New records were achieved for n-i-p solar cells intended for use within flexible plastic-based modules: 9 % on glass substrates and 7 % on PET (V_{oc} = 509 mV, FF = 68 %, J_{sc} = 20.4 mA/cm^2).

The factors influencing the optical and electrical performance of ZnO layers deposited by LP-CVD were identified. Several novel schemes for improved ZnO layers were started.

Various new diagnostic tools for µc-Si:H layers and cells were introduced. Above all, Fourier-transform photoconductive spectroscopy (FTPS) was built up at IMT and shown to be a powerful tool for evaluating the quality of intrinsic µc-Si:H layers.

Introduction

During 2004, IMT has started intensive and specific collaborations for technology transfer and development within 3 CTI-funded projects with Swiss industrial firms. These 3 projects are all concerned with large-area production of thin film silicon modules; 2 of them have already started in the beginning of the year and are described in separate reports.

This report presents the work done at IMT in preparing for a further increase in the performance of small-size laboratory cells based on IMT's micromorph (amorphous/microcrystalline silicon) tandem cell concept.

Project goals

The project goals were fourfold:

1. Revamping of IMT's laboratory cell technology for p-i-n solar cells on glass substrates after the departure of 2 senior and 2 junior IMT staff members from this sector to join Unaxis Solar.
2. Bringing up IMT's laboratory cell technology for n-i-p solar cells on plastic substrates to a high level.
3. Consolidating IMT's transparent conductive oxide (TCO) technology, especially Zinc oxide deposited by low-pressure chemical vapour deposition (LP-CVD ZnO) and implementation of novel ideas to improve further TCO performance in connection with pin solar cells.
4. Developing diagnostic tools for microcrystalline silicon solar cells. Improving the understanding of growth mechanisms for microcrystalline silicon layers and solar cells and gaining further knowledge on their stability with respect to light-induced degradation.

Work done and results

1. p-i-n solar cells on glass substrates

Optimisation of the front contact layer (TCO) and the microcrystalline solar cell

In the reporting year, the two research sections involved in p-i-n cell manufacturing, on one hand, and TCO development, on the other hand, established intense exchange. The motivation was to combine our best TCO (growth-textured LP-CVD ZnO) with our best μc-Si:H silicon solar cell. In fact, our surface-textured ZnO front contact of the solar cell is known to increase the short-circuit current density (J_{SC}) of the device.

We report here on devices with various front-contact layers, whereas the same type of solar cell and transparent back-contact is applied without any back-reflector. The reason for this is our interest to evaluate first the influence of the **front-contact** on the cell performance. (Note: the terms 'front' and 'back' are always used here to describe the way in which the light passes through the device).

In a first study, the thickness of the ZnO layer is varied between 0.8 μm and 2.5 μm by an increase of deposition time of the LP-CVD process. The result is shown in Fig. 1: the steady increase of the ZnO film thickness results in a steady increase of the diffuse transmittance, as measured by photo spectrometry.

To simplify further interpretations, the optical measurement of the diffuse transmittance is quantified by a single figure of merit, called here 'scattering capability'; this is the average of the data points of the diffuse transmittance within the spectral interval of interest, in our case, the red and near-infrared part comprising wavelengths from 550 nm up to 1000 nm.

After the co-deposition of μc-Si:H solar cells onto these ZnO samples, I-V characterisation revealed a satisfying overall production yield (>75%) on all substrates i.e. on all sub cells, with open-circuit voltages exceeding 0.5 V and Fill-Factors (FF) larger than 63% (which can be expressed also by the product V_{OC} * FF > 0.3). A reasonable yield is important for further comparison of cells fabricated on various front-contact samples.

The devices are then measured for their Quantum Efficiency (QE): By integration of the spectral response as a function of wavelength, multiplied with standard AM1.5 solar spectrum data, one obtains the short-circuit current density J_{SC} of the device.

Only the red and near-infrared spectral region comprising from 550 nm up to 1000 nm is taken into account for further interpretation. With the optical data of the front-contact (as measured by photo-spectrometry, see Fig. 1) and the QE data within our region of interest, we are able to correlate the scattering properties of the bare front-contact with the J_{SC} generated in the device. We can then plot the J_{SC} values as a function of the scattering capability; this is shown in Fig. 2. The hypothesis of a correlation of surface texture (expressed in the scattering capability) and the integrated J_{SC}-value can be confirmed for this specific series, where the thickness of the ZnO layer is varied.

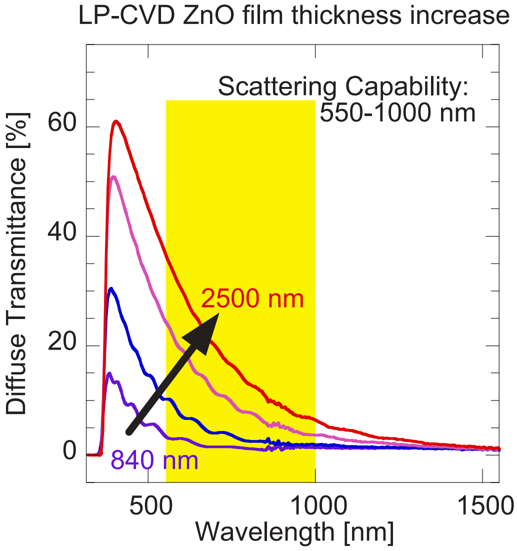

Fig.1: Diffuse transmittance measured by photo-spectrometry increases steadily for an increasing thickness of the ZnO film.

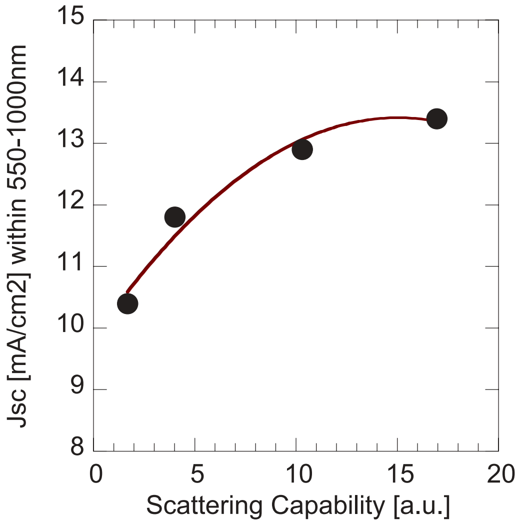

Fig. 2: Correlation between the scattering capability, obtained from optical diffuse transmittance data and the integrated J_{SC} value (550-1000 nm) of μc-Si:H solar cells deposited onto ZnO layers (0.8 to 2.5 μm thickness).

In the presented study, samples of various ZnO film thicknesses are incorporated in the same type of μc-Si:H thin-film solar cell. A direct correlation between high surface roughness of this front-contact layer and high J_{SC}-values on the resulting devices could be shown. The "scattering capability" deduced from optical transmittance data scales well with the short-circuit current density J_{SC} of the solar cells.

These first results are an encouraging signal for further investigations in the same direction: in fact, the optical and electrical properties of LP-CVD ZnO films can be varied easily by changing other film parameters. Therefore, additional cell depositions on different ZnO films should be carried out.

Further investigations will be necessary as well. The introduction of a back-reflector should further increase the J_{SC} values of μc-Si:H devices. And finally, the combination of high-quality TCO with high-efficiency micromorph tandem solar cells has to be studied.

2. n-i-p solar cells on low-cost substrates

One of the advantages of solar cells in the n-i-p configuration, compared to cells in the p-i-n configuration, is the possibility to use cheap and flexible substrates instead of glass substrates. The Swiss company VHF-Technologies S.A. in Yverdon is currently developing a roll-to-roll production line for thin film silicon solar cells on flexible and low-cost plastic substrates like Poly Ethylene Terephtalate (PET). At the same time, IMT aims at transferring its pioneering results (regarding microcrystalline and micromorph solar cells) on these PET substrates. During the reporting period, significant progress was achieved in this sector.

Textured substrates for n-i-p solar cells

IMT studied the possibility to enhance light-trapping within cells deposited on PET. Therefore, textured substrates obtained by a replication process, which is compatible with PET substrates as well as with a continuous roll-to-roll fabrication process, have been tested. Random and periodic textures, with different dimensions and shapes, were fabricated on glass and on PET and incorporated into cells.

µc-Si:H solar cells

n-i-p µc-Si:H solar cells have been developed on different textured substrates including periodically textured PET substrates. For all cells, as-grown textured LPCVD-ZnO was used as top contact.

∉ On glass/flat Ag/sputtered ZnO, 7.1 % initial efficiency was achieved.

∉ On glass/as-grown textured Ag/sputtered ZnO, up to 9% initial efficiency was achieved (V_{oc} = 0.52 V, FF = 73 %, J_{sc} = 24.2 mA/cm^2).

∉ On **periodically textured PET substrate/flat Ag/sputtered ZnO, 7% initial efficiency has been achieved so far** (V_{oc} = 0.51 V, FF = 68 %, J_{sc} = 20.4 mA/cm^2).

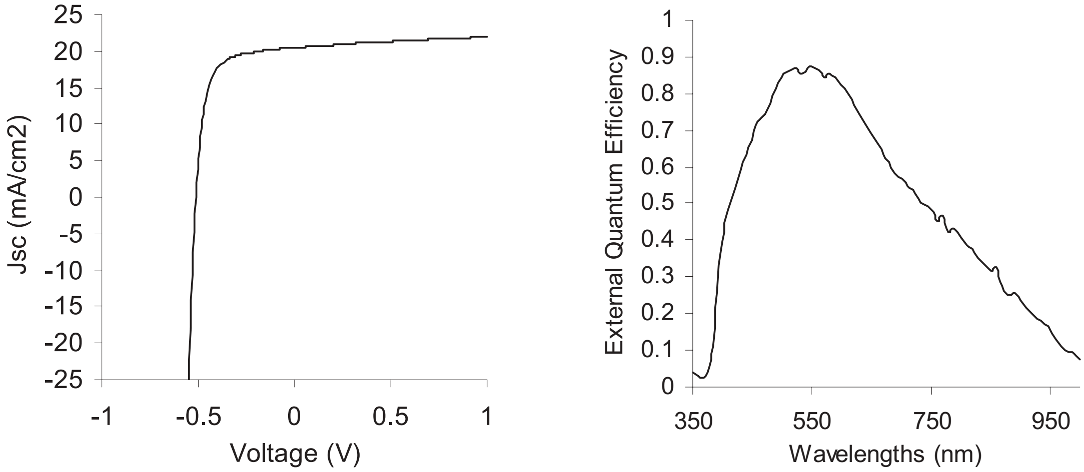

Figure 3: IV and (external) quantum efficiency curves of microcrystalline n-i-p silicon solar cells deposited on low-cost textured PET substrates.

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µc-Si:H/a-Si:H tandem cells

n-i-p tandem solar cells have been extensively studied on glass. The best performances have been obtained using as-grown textured hot silver as scattering back reflector. Typical initial efficiency is 9.2% (V_{oc} = 1.384 V, FF = 66.4 %, J_{sc} = 10 mA/cm^2).

Preliminary work has been done for deposition of micromorph tandem cells on PET substrates; promising first results have already been obtained.

3. Transparent conducting oxides

Transparent Conductive Oxides (TCO) are an essential part of thin-film solar cells, both cost-wise and performance-wise. Amongst these TCO’s, doped Zinc Oxide (ZnO) is a very promising candidate for future thin-film technology, especially because of its low cost and because of the wide availability of its constituent raw materials.

Doped ZnO layers deposited by the Low Pressure Chemical Vapour Deposition (LP-CVD) technique have been studied at IMT for their use as transparent contact layers for thin-film silicon solar cells. This LP-CVD technique allows us to obtain ZnO films that are not only transparent and electrically conductive, but also possess a pronounced light-scattering capability. The light-scattering capability increases the path of the light within the solar cell, and, hence, enhances also its probability to be absorbed in the cell. This aspect is especially important in the case of amorphous and microcrystalline silicon (a-Si:H and µc-Si:H) thin-film solar cells, because of their relatively low optical absorption coefficient in the red and near infra-red (NIR) spectral range

The light-scattering property is linked to the surface roughness of the TCO layer used in the cell. Indeed, a rough surface allows one to scatter efficiently the light that enters into the solar cells through the TCO layer.

Research at IMT in the ZnO field during this year has consisted first in the continuation of the material analysis of IMT's LP-CVD ZnO layers. The various deposition parameters (gas flows, pressure, temperature, doping level etc.) have been tuned over a large range of values. The optical properties (transparency and light-scattering capability) and electrical properties (resistivity, free electron concentration and mobility) of the obtained ZnO layers have been systematically studied [1-2].

The second part of the research at IMT in the ZnO field during this year has been dedicated to the specific optimization of the ZnO layers when they act as efficient rough TCO for p-i-n microcrystalline solar cells. Surface roughness has been tuned over a large range of values, by varying thickness and/or doping concentration of the ZnO layers (see Fig. 4 which illustrates the roughness variation of ZnO layers due to a variation in the doping level).

A series has also been implemented, for which the doping level has been varied while keeping the square resistance of all the ZnO layers equal to 10 T_{sq} (thereby, the thickness of the ZnO layer has been adjusted, in order to compensate the high resistivity of poorly doped ZnO layers). The constant resistivity allows one to maintain the series resistance of the whole solar cell device, deposited on this front TCO, in order to observe only the "optical" influence of the front ZnO roughness on the solar cell performance.

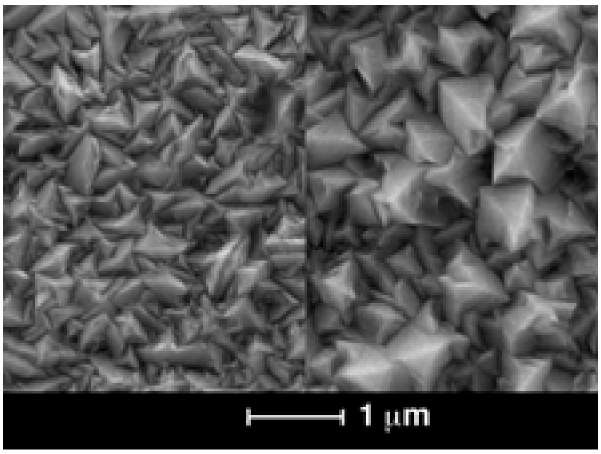

Fig.4: SEM micrographs of the surface of (a) a highly doped ZnO layer, and (b) a non-doped ZnO layer. Both layers have the same thickness. A variation in the surface roughness (and therefore in the light-scattering capability) of the ZnO layer is still observed in function of the doping level, i.e. the more the layer is doped, the less it scatters the light. But a minimum doping level is necessary to assure sufficient electrical conductivity for the TCO.

Identical p-i-n microcrystalline solar cells have then been deposited on all these front ZnO substrates developed at IMT. In all cases, a clear increase of the photo-generated current has been observed in the red and NIR spectral range for rougher ZnO substrates. Increasing three times the grain size of the front ZnO leads to an increase of ~ 20% of the photo-generated current in microcrystalline p-i-n solar cell, and this without any back reflector as yet [3-4].

However, if the ZnO layer becomes too rough, this has so far resulted in a negative impact on the Voc and FF values of the solar cell. To avoid this drawback, the solar cell deposition on these very rough ZnO substrates has to be newly optimized.

All these results highlight the major advantage of our LPCVD ZnO layers where we can actually "tune" the surface roughness of the substrate over a wide range of values: this will allow us to optimize the whole solar cell structure for the highest photo-generated current without negative impact on the electrical behaviour of the solar cell.

4. Characterisation of solar cells

Thanks to the study of the material microstructure by Transmission Electron Microscopy (TEM), the importance of the substrate's chemical nature on the nucleation and growth of microcrystalline silicon has been evidenced. The influence of the spatial distribution of the amorphous and nanocrystalline phases within microcrystalline silicon layers has been shown to be determinant for the measurement of the Raman crystallinity value. These results will soon be published [E. Vallat et al, Thin Solid Films, 2005].

A simple numerical growth model rendering most of the features within the complex microstructure of µc-Si:H has been further developed and details have been published [3].

Micro-Raman and Fourier Transform Photo-spectroscopy (FTPS) have been established as valuable measurement techniques for the evaluation of the material crystallinity and of the electronic defect density, respectively. The FTPS measurement technique which has recently been set-up in our laboratory, is already extensively used for the characterization of µc-Si:H solar cells. Deep-defect density as well as bandtail-related absorbance can be rapidly measured with this technique, as demonstrated by a degradation study on microcrystalline silicon solar cells.

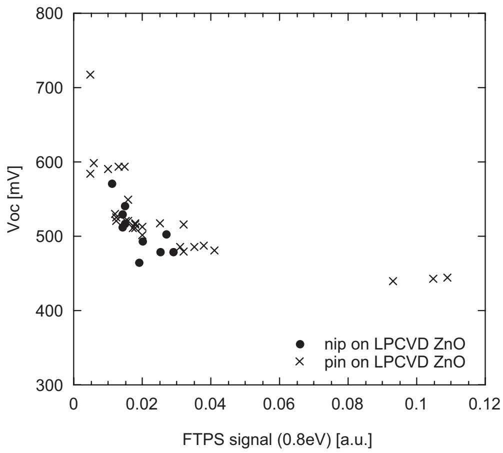

Fig. 5: V_{oc} values of p-i-n and n-i-p solar cells as a function of defect-related absorbance at 0.8 eV, measured by FTPS

Furthermore, the open circuit-voltage V_{oc} of the device is clearly shown to decrease with increasing defect-related absorbance. This has been observed for irradiated cells as well as for cells with an active layer deposited with increasing hydrogen content in the plasma. From these observations, one can conclude that defect passivation in microcrystalline silicon is the key for increasing open-circuit voltage. Study of defect density of active i-layer material with this technique will be developed as a standardized quality control tool for material incorporated into solar cells.

National and international collaboration

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

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

European collaboration was only possible on an informal level because of lack of continuation in our European PV project. However, this is expected to be remedied in the coming year 2005.

Evaluation of progress in 2004 and perspectives for 2005

Joint optimisation of p-i-n solar cells and rough TCO layers, carried out for the first time at IMT, has given interesting results, but also shown some unexpected problems (decrease of FF and V_{oc} on highly rough TCO).

Due to several practical problems, the general progress of p-i-n solar cells on glass/TCO substrates has not been as fast as hoped for. This sector is at present also understaffed and will need reinforcement in 2005 in order to live up to the high industrial expectations of UNAXIS. The probable start of an European Integrated Project within 2005 should allow to at least partly alleviate the shortfall in staff.

In sector of n-i-p solar cells on plastic substrates, progress has been excellent; the bottleneck here so far was the capability of the industry to take over the results obtained in microcrystalline silicon.

The TCO/ZnO sector has been consolidated and is set out for significant progress in 2005.

Finally, the sector of materials and device characterisation is now well established. A new Fond National project has been submitted; this should allow us to finance again independently this sector.

With the establishment of the new leadership of Professor C. Ballif, who has joined IMT in October, also ends a long period of transition (programme uncertainity, delayed project acceptance, reduced financing etc.). A more straightforward progress can indeed be expected for 2005.

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Annual Report 2004

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

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Project- / Contract Number	6928.1 IWS-IW
Duration of the Project (from – to)	1. March 2004 – 28. February 2006

ABSTRACT

The successful tandem solar cell concept as proposed by IMT Neuchâtel is industrialised in this CTI project. Note that the laboratory scale micromorph solar cells, combining an amorphous silicon (a-Si:H) absorber with a microcrystalline silicon (µc-Si:H) absorber, reach stable conversation efficiencies up to almost 12%.
This research project is based on three key issues: First, the deposition time of the µc-Si:H absorber has to be reduced, second, the device has to perform reasonably well and third, the process has to be executed in a single-chamber PECVD reactor. The development of a fabrication process for high performance thin-film (TF) silicon solar cell on industrial mass-production equipment is, thus, the aim of this project; this requires thereby a single–chamber deposition of all doped and intrinsic microcrystalline silicon layers at high deposition rates. UNAXIS KAI PECVD reactors developed for active-matrix LCD technology have already shown to possess a high potential for cost-effective manufacturing of thin-film silicon solar cells based on amorphous silicon, as shown in a preceding CTI project between IMT, CRPP and Unaxis. This technology is presently transferred by Unaxis to KAI type PECVD systems larger than the KAI-S system at IMT.
In the present project, specific issues relating to microcrystalline devices are developed now on the small KAI–S reactor (deposition area: 0.15m^2) at IMT Neuchâtel. A successful conclusion of the project will allow for production in large size KAI reactors (area 1.4m^2) and the cost-effective production of TF micromorph modules in the future.
First cells and modules could already be fabricated in the single-chamber KAI reactors where conversion efficiencies of first microcrystalline silicon and micromorph tandem test cells of 5.5 % and 9.16 % respectively were obtained.

Introduction / Project goals

Without doubt, thin-film solar cells have the potential for a substantial cost reduction of photovoltaic (PV) modules compared to crystalline wafer-based silicon technology. However, the main reason why thin-film solar cells did not reach commercial breakthrough, lies in the problem of up-scaling of laboratory research results to large-area mass products of high performance. Up-scaling of thin film solar cells to areas of 1 m^2 is a much more difficult task compared to the implementation of crystalline wafer technology, as there is not yet state-of-the art production equipment available for thin-film solar modules. Conversely, thin-film solar modules are associated with a higher risk of uncertainty and investment with respect to the development of production equipment, as compared to crystalline silicon where small well-known production units can be added to increase the production volume.

The success of today's crystalline silicon solar cell technology is based on many results drawn from the semiconductor industry. In the case of the thin-film solar cell technology, synergies with other types of mass production technologies have to be considered and adapted. One possibility is the synergy with the strong and growing market of flat panel displays. In this industrial segment, the need for ever larger deposition systems to meet the growing demand of flat panel screens based on the amorphous silicon thin film transistor (TFT) is driven by the market itself. The development in the display sector involves investments in production equipments of increasing size. In Fig. 1 Unaxis' most recent reactor generation of 5 m^2 size, as used for the deposition of amorphous silicon TFTs is shown. Due to the coming market of flat panel TV screens larger and larger mother glasses are used here.

The Institut de Microtechnique (IMT) Neuchâtel has focused its research on the development of future thin-film silicon solar cells. In 1987 IMT introduced the VHFGD (Very High Frequency Glow Discharge) technique for the increase of the deposition rate of silicon films, and it has pioneered microcrystalline silicon as a new thin film absorber material. IMT's concept of combining amorphous silicon (high bandgap) and microcrystalline silicon (low bandgap) cells, the so-called "micromorph" concept, is considered one of the most promising thin-film solar cell concepts, as it has the potential of absorbing and converting a wide range of the solar spectrum.

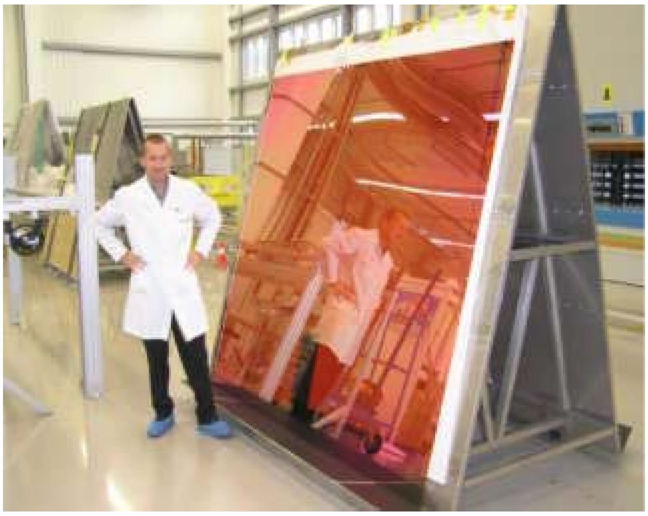

Fig. 1: a-Si:H film deposited on glass of 5 m^2 area of Unaxis' most recent generation of KAI reactor.

Brief description of the project and installation

The radio-frequency (RF) glow discharge deposition system used in 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 of dimensions 47 cm x 57 cm (width x length). The plasma excitation frequency employed by us is 40.68 MHz. The KAI-S reactor is equipped with a load-lock which allows for shorter deposition cycles and better vacuum conditions in the deposition chamber. The process gases are introduced through a showerhead incorporated within the RF-powered electrode, see Fig. 2.

Thin µc-Si:H films are deposited onto glass samples for further characterisation: the thickness of the deposited film is measured, then the crystalline volume fraction is determined by Raman spectroscopy. Optical absorption measurements by Fourier Transform Photocurrent Spectroscopy (FTPS) as well as by the conventional Constant Photocurrent Method (CPM) are then performed. Dark-resistance behaviour are measured in order to know the electrical characteristics of the doped (p-type and n-type) and the intrinsic (undoped) films. Then devices are deposited onto Zinc Oxide (ZnO)-coated glass samples, rear contacts are sputtered onto the silicon devices and these solar cells are then measured under the standard AM1.5 sun simulator and in the spectrally dependent Quantum Efficiency (QE) set-up.

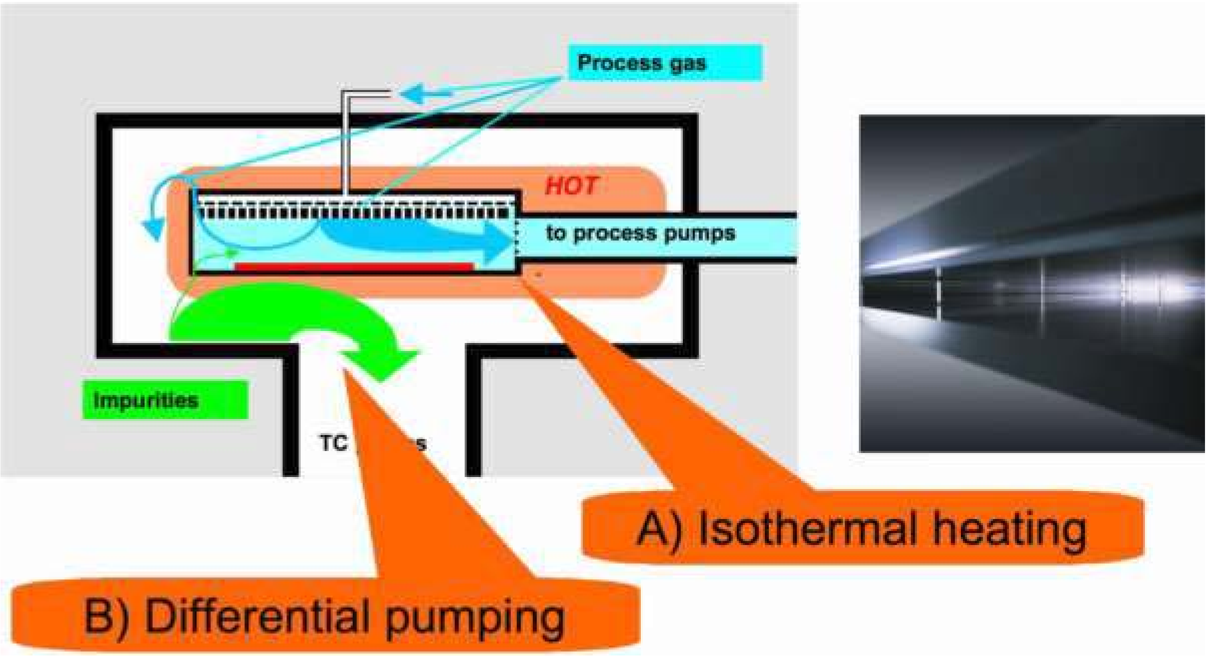

Fig. 2: KAI PECVD: The concept of Plasma Box high performance batch-processing reactors.

The project is aimed at mastering the applications of KAI-type PECVD reactors for processing of µc–Si:H thin-film solar cells in the VHF plasma domain. For this reason, a cross-fertilisation of the Unaxis PV-research labs and the IMT lab are of vital importance, where the industrial partner brings in the economical point of view, whereas more fundamental considerations of device fabrication are contributed from the IMT side.

Work done and results

The project started with a kick-off meeting on 2nd March 2004 with all project partners in Trübbach. From the first day on of the project, the KAI deposition equipment at IMT was fully operational and could be used intensively.

The CTI research project partners agreed to meet every three months.

The first task was to explore the working regimes for microcrystalline (µc-Si:H) film deposition with an equipment which was never used before in such conditions. In a preceding CTI project, amorphous (a–Si:H) films and devices could successfully be deposited (test cells of initial conversion efficiency of 10% and light-soaked stabilised efficiency over 8%). But the parameter space necessary for solar grade AND fast µc–Si:H thin-film deposition is known to extend into more extreme conditions, as indicated by the work of other research groups in Germany and Japan, i.e. one needs high plasma power, high working pressure and high deposition gas flow. These results have to be confirmed for the case of the KAI-type PECVD reactor, for which the set-up differs considerably from the plasma reactors of these other research groups.

At the first review meeting in June 2004 in Neuchatel, initial results indicated a technical limitation of the reactor that prevented us to explore this wide parameter space, i.e. the total gas flow as well as the maximum gas flow of individual mass-flow controllers needed to be increased. In consequence, the KAI reactor at IMT was upgraded in the second half of June 2004.

As shown at the second review meeting in September 2004 these hardware modifications on the deposition reactor proved to be the right choice: The p-type and n-type doped µc-Si:H films fabricated in the KAI reactor are comparable to state of the art layers made on the small-sized laboratory PECVD reactors at IMT. With this result, the first milestone of the project was successfully achieved.

Complementary technological meetings and discussions, besides the quarterly review meetings, facilitate the exchange of late-braking results and new know-how and are organised on an irregular basis. These discussions reinforce the mutual progress, where the leading role is sometimes taken up by the Unaxis research labs and sometimes by the IMT lab.

In order to fabricate first microcrystalline p-i-n solar cells, p-doped µc-Si:H window layers have been carefully developed. Entirely microcrystalline cells have been optimised. The I(V) curve of the sofar best cell is given in Fig. 3. Starting from low V_{OC} and FF values, values of 440mV and 69%, respectively, could be reached. Further improvement can be achieved by a detailed study of all deposition conditions. The cell in Fig. 3 was deposited at a rate of 3 Å/sec on LP-CVD ZnO as front TCO.

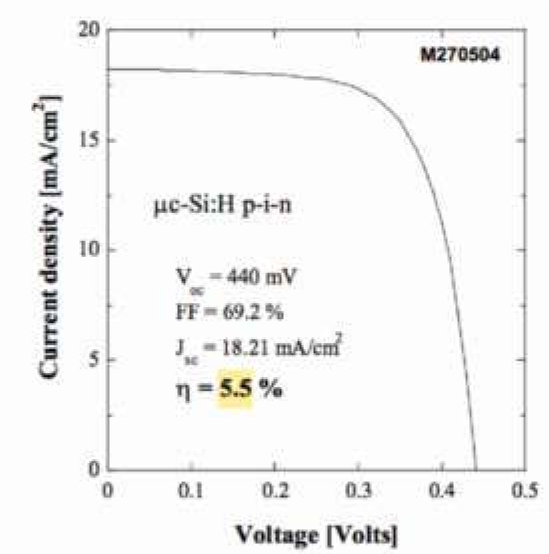

Fig. 3: AM 1.5 I(V) characteristics of sofar best µc-Si:H p-i-n solar cell deposited in a KAI reactor in the Unaxis research lab, cell thickness 0.8 µm.

The systematic exploration of the parameter space for high-rate µc-Si:H absorber films of solar grade quality is still under way. The variation of key-parameters, like the deposition pressure, silane concentration and injected plasma power signifies an impressive work effort at a high level of complexity. It is at present not possible to predict where approximately one will find the best working conditions to combining solar grade µc-Si:H material and high deposition rates.

At the time of writing this annual report, 9 out of 24 months of the whole project duration have evolved. First results from the Unaxis labs could be presented at the 19th Photovoltaic Solar Energy Conference in Paris [1,2]. For the moment, no preliminary results of this project on the side of the IMT lab have been published in a journal or on a conference. The authors wish, for confidentiality reasons, not to present more than the present comments at this place.

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 of specialised researchers at the *Ecole d'ingénieurs de l'arc Jurassien – University of applied Sciences* (EIAJ) in Le Locle, the *Interstaatliche Hochschule für Technik Buchs* and the *Centre de Recherche en Physique des Plasmas* (CRPP) of EPFL in Lausanne.

Evaluation of progress in 2004 and perspectives for 2005

In 2004 excellent progress was made in this project and it was confirmed that the KAI type PECVD reactor is indeed a versatile deposition tool: the reactor is satisfactorily equipped for the moment, the down-time could be kept very low and the deposition of µc-Si:H films is a reliable and reproducible process. Confronted with the complexity of the deposition parameter space, the pioneering work done sofar should be just considered as a first series of trials, sketching some regions, where reasonable devices could be made.

A systematic approach will have to continue and lead to a mapping of the parameter space showing which parameter combinations lead to high-rate deposition of decent solar cell devices. Thereby, we also expect to gain a better understanding of the plasma processes involved. Sofar, however, no simple rules for explanation of the process parameter regions could be found.

This exploration work has to be continued until about project mid-term, i.e. until the end of February 2005. From then on (during the rest of 2005), the main accent will be on the fabrication of full solar cell devices which combine a high deposition rate and good device performance.

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Annual Report 2004

A new large area VHF reactor for high rate deposition of micro-crystalline 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 a high pressure, high rate process window. 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 investigated the physical basis for two principal causes of plasma non-uniformity: the standing wave effect and the telegraph effect. The standing wave non-uniformity occurs when the vacuum wavelength of the rf excitation is one tenth, or less, of the reactor dimensions. This effect can be suppressed by using a special, lens-shaped electrode. The theory [1] and experimental proof [2] have been published, and Unaxis currently employs a stepped lens design in a KAI 1200 reactor at 40 MHz operation for industrial testing. The stepped lens is incorporated into the rf showerhead electrode, because a lens in the ground electrode would be electrically screened by the TCO-coated substrate used for solar cell manuracture. Higher plasma excitation frequencies have been shown to be a better choice since high device quality at industrially interesting deposition rates can be obtained with this process. In addition, since the sheath voltage decreases rapidly with increasing excitation frequency, the possibility to couple much higher RF power into the plasma exists while keeping a moderate sheath voltage thus preventing the substrate from damage.

The second source of non-uniformity is due to an asymmetric electrode construction. This asymmetry is intrinsic to the plasma-box design where the planar RF electrode is surrounded by a grounded sidewall. It was shown analytically [3] that the RF plasma potential, and therefore the plasma, is more intense near these walls, extending into the plasma by a damping length given by the telegraph equation. This gives rise to circulating DC currents which have been measured using surface probes [4], thereby confirming the model. The influence of the side walls can therefore be predicted, and it was shown that a symmetric electrode design would eliminate this source of plasma and film non-uniformity. During this fist year of the current project, the film thickness on the both the rf and ground electrodes were shown to be influenced by the telegraph effect [5]. It is therefore proven that sidewall asymmetry can be responsible for deposition non-uniformity of up to 30% near the substrate edge.

By means of a lens-shaped, symmetric electrode design, two major sources of deposition non-uniformity can be suppressed.

Process parameters. The CRPP has a KAI-Small reactor with load lock which is used to study micro-crystalline silicon deposition at high pressures and small gap to investigate a possible process window at high deposition rate (> 0.4 nm/s) and good uniformity (better than 8%) for simultaneous deposition of mixed phase material (micro-crystalline silicon in an amorphous matrix). First results at the standard gap of 25 mm show that large quantities of silicon powder are produced during micro-crystalline silicon deposition. Experiments are underway to investigate whether high pressure processes have a viable process window for reactors with a smaller inter-electrode gap of 10 mm. 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 2004 and perspectives for 2005

The work proposed in the project proposal has been performed to schedule. Experiments on reactor design for plasma and film uniformity have been completed successfully. Initial experiments for extending the process window to a high pressure domain have been carried out at standard inter-electrode gap, and this work will be continued in the reactor and loadlock modified for small gap. During 2005, the aim is to define process parameters for improved rate and uniformity of mixed phase microcrystalline and amorphous silicon deposition with material quality suitable for large-scale solar cell production.

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Annual Report 2004

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 to September 2006

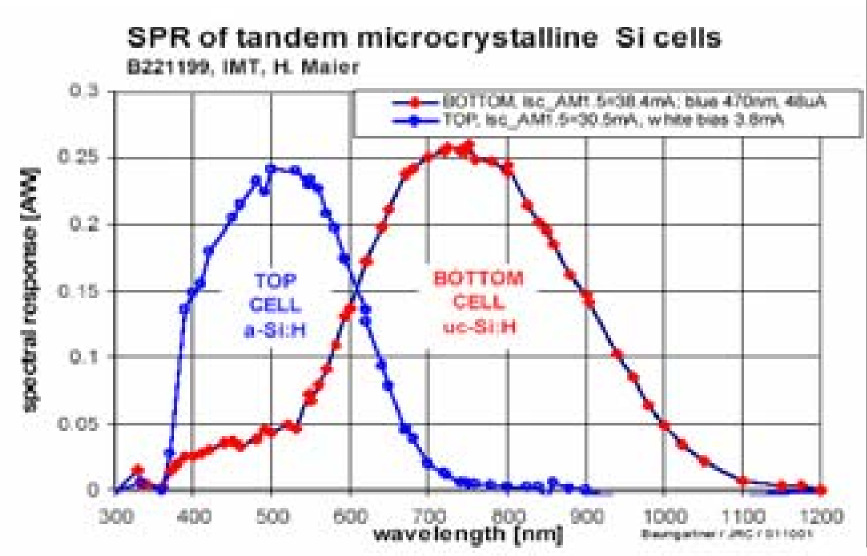
ABSTRACT

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 tool. Today, there are 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 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.

Introduction and project objectives

The fingerprint of a solar cell is given in the current voltage characteristics (I-V curve) while the current is the integral value of the ability to convert the different photons of the solar spectra. A more detailed analysis of the short-circuit-current (J_{sc}) can be found in the spectral photocurrent characteristics. The so-called spectral response characteristics of a tandem a-Si/µc-Si solar cell are shown in Fig. 1.



Spectral Response Equation:

$$J_{sc} = \int SR(\lambda) \cdot P(\lambda) \cdot d\lambda$$

J_{sc} short circuit current

SR(λ) Spectral Response characteristic of the cell

P(λ) spectral characteristic of the light source (number of photons per wavelength interval)

if P(λ) is given in W/nm than SR(λ) is given in A/W both values given per square

Figure 1: Spectral response characteristics of an a-Si amorphous silicon / µc-Si microcrystalline silicon tandem cell produced at IMT Neuchâtel and measured at the European JRC Labs in Ispra [1].

During the optimization of a solar cell the individual deposition process parameters are varied and the performance of the cell device has to be analyzed. The spectral response measurement may give important insight to problems related to

- the quality of the internal electric field of a p-i-n device for the collection of the photo generated electron-hole pairs (fill factor)
- cross contaminations into and contaminations in the i-layer
- the quality of light-trapping by front side (glass-TCO) and back side (back reflector) of the solar cell
- the thicknesses of the p-type window and n-type back layers
- the thickness and quality of the intrinsic absorber layer
- the quality of the tunnel-junction (interface recombination) in a tandem junction
- the independent determination of the short-circuit-current (J_{sc}) for AM1.5 standard illumination (for comparison with indoor and outdoor AM1.5 I-V measurements) and for other spectra
- Optimizing top and bottom photocurrent to match AM1.5 standard illumination conditions (very important to reduce process time of the thicker µc-Si:H bottom cells)

Due to the fact that the today's share of thin film modules on worldwide PV sales is very low, less information on the above stated interrelation is documented for a-Si compared to standard crystalline cell technology.

Therefore, this special analyzing method is essential and obligatory for the optimization of solar cells.
Of course there exist several unique SR measurement setups at university research labs but not a industrial oriented analyzing tool. Most of them are suited to measure the spectral photocurrent of silicon single cells at a fixed position and flexible to changes in research interests. Measuring a tandem cell configuration is not standard also at university labs.

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

The principle of the SRM method is well known (see figure 2).[4] A lamp serves as light source; a monochromator with 5 nm interval is chopped. Two lenses focus the light to the Device Under Test DUT. The generated photocurrent is amplified.

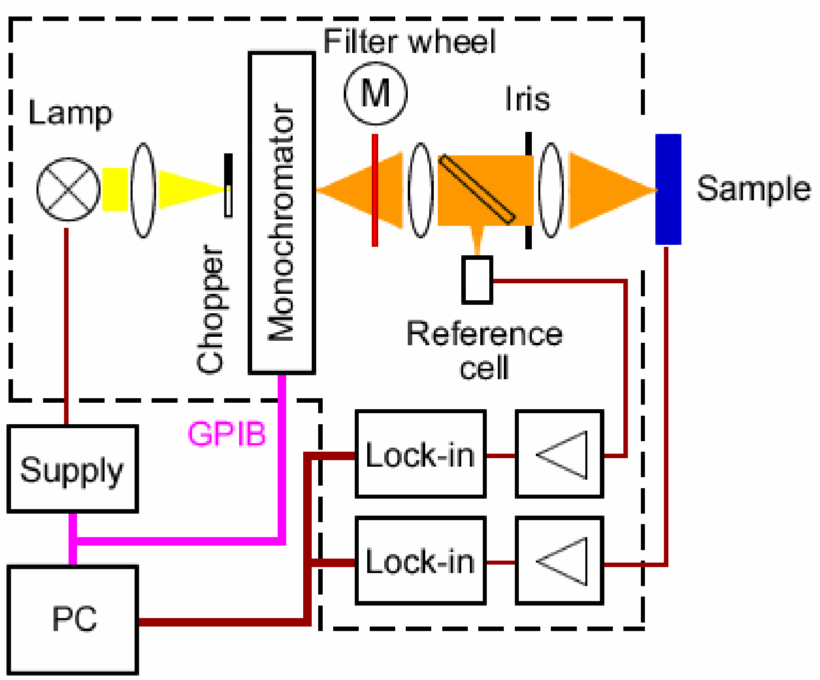


Figure 2: Principle diagram of SRMS.

To measure the small currents in the DUT, the lock-in amplifiers technique with the reference of the optical chopper signal is used. To analyse the SR and guarantee the long-term stability, the reference a stable reference cell in the optical path measures light intensity after the beam splitter (see Fig. 2). For grating-monochromators, a filter wheel is needed to block higher orders of the wavelength. The halogen lamp is driven with constant current from a DC-supply.

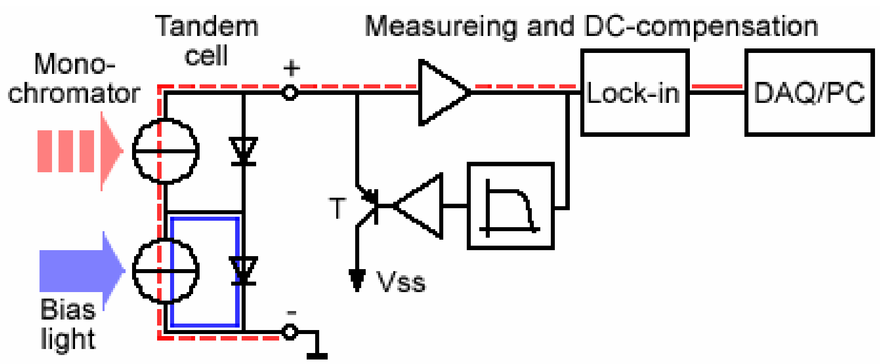


Figure 3: Electrical diagram, spectral current measuring and DC-compensation of tandem cells.

The electrical equipment is designed to measure single-junction and tandem cells based on amorphous (a-Si:H) and microcrystalline silicon (σc-Si:H). Optionally white, red or blue bias-light will be applied to the DUT.

The chopped light beam from the monochromator generates a chopped photocurrent in cell. These chopped currents are preamplified by a transimpedance operational amplifier and feed into the Lock-in amplifier (see broken line in Fig. 3). The output of the Lock-in is read out by use of a PC based data acquisition-card (DAQ). To measure the SR characteristics of a tandem structure, the second cell has do be illuminated in such a way, that the second photocurrent have to exceed the first one (see Fig. 3). The additional DC-photocurrent generated by the bias light (especially at white bias light) will be compensated by a transistor (T) and, thus, will not be pre-amplified. To control this compensation circuit, a low-pass filter reads the DC-content of the preamplified signal and controls the transistor.

Present Status of the Project

Work was performed to construct the first measurement setup for cell spectral response measurement. (Fig. 4) The hardware components were mounted and the control via PC was successfully tested.

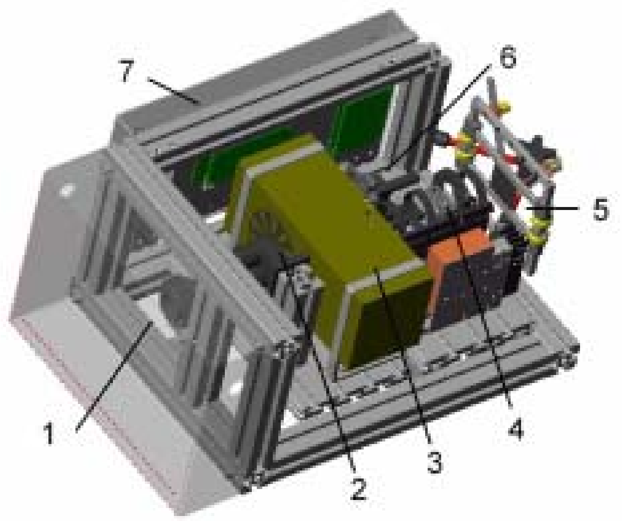


Figure 4a: Hardware setup as CAD-model: 1 housing for halogen lamp, 2 optical chopper, 3 grating-monochromator , 4 reference cr-silicon photodiode, 5 cell mounting system, 6 filter wheel, 7 electronic equipment and Lock-in amplifier

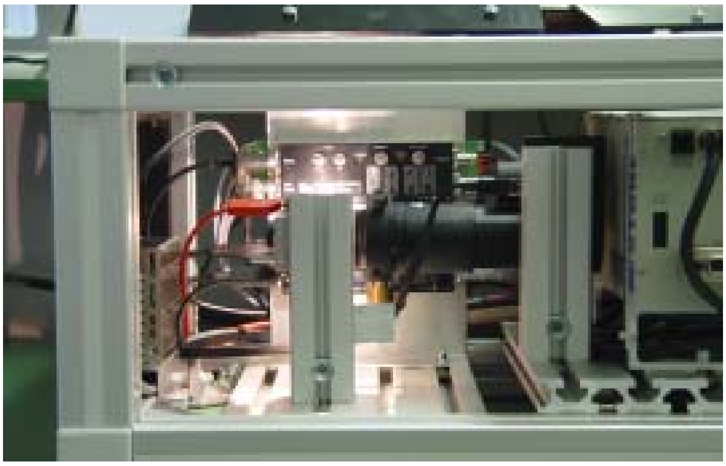


Figure 4b: Photograph of the light source feeding the input of the monochromator (right corner). In the background the lock-in amplifiers are seen.

National and international collaboration

The present collaboration of the NTB with the solar test and installation group at the European JRC Joint Research Center in Ispra [3] will be very helpful to exchange the findings on the development of spectral response measurements techniques on thin film tandem cell. The exchange of reference samples and intensive discussions and visits will be very helpful

In a future project it is planed to focus more on the outdoor validation and the energy rating at different AM spectra together with partners is Switzerland like SUPSI and PSI.

Evaluation 2004 and outlook 2005

The progress in the first 3 month is according to the project plan. By the end of 2004 first spectral photocurrent measurements will be performed and the evaluation of measurement uncertainty will be started.

Related PV projects at NTB

Since more than twenty years the University of Applied Sciences Buchs, NTB is active in developing engineering solutions of PV systems. In collaboration with industrial partners PV projects carried out in the field of grid connected PV inverter development and development of new measurement concepts. Web based online system monitoring of grid connected PV systems were developed and thus monitored performance data of overall 60kWp installed PV power is documented.[5] The laboratory of electrical measurement systems successfully developed different types of magnetic and optoelectronic sensors mainly in cooperation with industrial partners. The Labs know-how includes engineering techniques in the field of measurement electronics, lock-in amplifier techniques, optoelectronics and different instrumentation software solutions. The laboratory is also an active member of a Swiss working group on electrical measurement techniques headed by the METAS in Bern.

In a present project the development of an optical thickness sensor in collaboration with the University of Neuchatel and Unaxis Solar is performed. [6]

The head of the laboratory has experience in thin film solar cell research and measurement techniques since 1989. He is also active in European Photovoltaic collaborations for example JRC working group of the new monitoring and measurement guidelines on PV systems and components. The related present research topics are concentrated also on a method to include the DC-voltage dependence on PV-system performance and a new definition of EURO inverter efficiency. [7]

References

[1] Measurement performed by Franz Baumgartner during a sabbatical stay at the JRC Labs in 2001. The results were presented at a seminar lecture at the IMT University of Neuchatel, 2002-02-14.

[2] Catalogue of the 250 exhibitors at the 19th European Photovoltaic Solar Energy Conference and Exhibition, Paris 7-11 June 2004

[3] personal communication in June and July 2004 of Dr. Harald Muellejans (harald.muellejans@cec.eu.int) and Dr. Tony Sample; responsible scientists of PV module tests and qualification at the European Solar Test and Installation, at the European Joint Research Center Ispra, Italy.

[4] A. Götzberger; Sonnenenergie; Teubner Verlag, ISBN 3-519-03214-7.

[5] Homepage: links to PV-online monitoring of NTB projects and downloads www.ntb.ch/pv

[6] KTI Nr. 6928.1 IWS-IW project leader University Neuchatel; industrial partner Unaxis Solar.

[7] F. Baumgartner, European PV-Conference, June 2004, Paris, Plenary 5D (www.ntb.ch/pv)

Annual Report 2004

Ligne pilote de fabrication de cellules solaires flexibles en silicium amorphe

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Project- / Contract Number	100540 / 150666
Duration of the Project (from – to)	01 11 2003 – 30 11 2004

ABSTRACT

The goal of the project is to implement a balanced pilot-line facility for the production of amorphous silicon solar modules on plastic film substrate.

In order to achieve an annual capacity of 40 kWpeak, the bottleneck steps of the fabrication process are addressed and suitable improvements and capacity increases are implemented.

The following results are obtained:

- Continuous coating of a-Si n-i-p solar cells by the VHF-GD process, with a production speed of 3.3 meter/hour
- Continuous top contact (ITO) structuring at > 1 meter/minute
- Series connection speed of 4.8 meter/hour
- Parallel sputtering of back contact and ITO from 2 targets
- Integration of a large area laminator with a capacity for 4 Watt products of 25 per hour.

Based on these achievements, a balanced pilot line capacity of 40 kWpeak for flexible solar cell products is realized at Yverdon-les-Bains.

Introduction / Project goals

VHF-Technologies SA est une entreprise start-up issue de l'IMT de l'université de Neuchâtel. Grâce aux résultats de recherche de pointe du Professeur Shah, VHF-Technologies a levé plus de trois millions de francs de capitaux privés dans le but de réaliser en Suisse une production pilote de cellules photovoltaïques d'une nouvelle génération.

Après avoir commencé la commercialisation du chargeur solaire portable (www.flexcell.ch) au mois d'août 2003, la demande pour ce produit s'est rapidement confirmée pour des volumes pouvant atteindre 10'000 pièces par an.

A long terme (2007-2010), la vision de VHF-Technologies et de ses investisseurs est d'atteindre un coût de cellules proche de $1/Watt, et ceci grâce à l'utilisation de matériaux bons marchés (silicium amorphe, films plastiques), combinés à des technologies de fabrication performantes et économiques (procédés continus en roll-to-roll, dépôt rapide VHF).

Depuis sa fondation en février 2000, VHF-Technologies SA a développé la technologie pour la fabrication de cellules solaires en silicium amorphe sur substrat film plastique. A présent, la faisabilité de toutes les étapes du procédé de fabrication a été démontrée. En outre, un chargeur solaire universel et enroulable ainsi qu'une ligne de produit OEM de faible puissance ont été développés.

Depuis août 2003, VHF-Technologies occupe des locaux industriels à Yverdon dans le but d'y finaliser sa ligne pilote de production. Afin d'arriver à une véritable production pilote fiable, VHF-Technologies se lance maintenant dans un programme de développement et d'investissements sur 6 mois pour atteindre une capacité annuelle de 10'000 chargeurs solaires par an, ce qui correspond a environ 40kWc/année.

Figure 1: Cellules solaires bruts sur film polyimide 30 cm de large (état après dépôt ITO)

Figure 2: Module solaire flexible 2 Watt pour le marché OEM (après encapsulation)

Figure 3: Chargeur solaire enroulable FlexRoll (500gr / 4 Watt)

Figure 4: Première livraison de 50 chargeurs FlexRoll en août 2003

Description du projet

Capacité cible
La capacité cible à atteindre par la ligne pilote est de 10'000 modules flexibles de 30cm x 60cm par an. La largeur de production de VHF-Technologies étant de 30cm, la fabrication des 10'000 modules de 60cm de long nécessite une production de 6000 mètres de cellules solaire, correspondant à 30 mètres par jours sur 200 jours.

Avec une puissance stabilisé de 4 Wcrête par module 30cm x 60cm, le nombre de 10000 modules correspond à une capacité de production annuelle de 40 kWcrête.

Procédé de fabrication / étapes et capacités / workpackages:

Le procédé de fabrication des cellules solaires flexibles de VHF-Technologies peut être séparé en trois sections principales: la métallisation (préparation du substrat), le front-end (dépôt de la cellule), et le back-end (fabrication des modules).

La métallisation et le front-end sont installés sur le site de l'EICN au Locle. Comme ces deux sections utilisent les mêmes infrastructures (ink, PVD, lift-off), ils ne peuvent pas produire en même temps. Un bon compromis d'utilisation est réalisé si la métallisation fonctionne pendant 10% des jours de fabrication, en produisant 300m de film métallisé par jour, en alternance avec 90% des jours de production front-end avec une capacité de 30m de film par jour.

Les graphiques ci-dessous montrent l'ensemble des étapes de production, les capacités de production ciblées, et les workpackages définis pour atteindre ces cibles.

Métallisation: capacité cible de 300m par jour

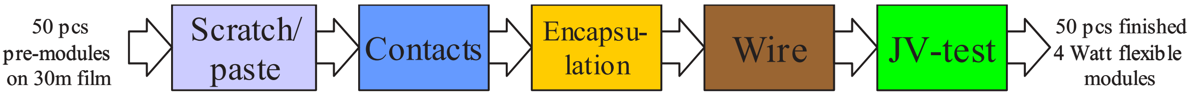
Workpackage : **WP 1**

Front-end: capacité cible de 30 m par jour

Workpackage : **WP2** **WP3** **WP4**

Back-end: capacité cible de 30m ou 50 modules par jour

Le back-end, qui comprend la mise-en série, l'encapsulation et le test final des modules, doit être capable d'absorber la production totale du front end, c'est à dire 30m / jours, soit 50 modules de 4Wc par jour.



Workpackage : **WP 5 / 6** **WP7**

Résultats

Au début du projet, VHF-Technologies possédait le know-how d'un ensemble d'étapes de fabrication qui permettait de démontrer la faisabilité de la production du produit flexcell de A à Z. Néanmoins, le parc de machines de diverses capacités empêchait la réalisation d'une production pilote linéaire.

Maintenant, grâce au soutien de ce projet, tous les goulots d'étranglement ont pu être éliminés, tout en améliorant la qualité et en diminuant grandement le travail manuel. La capacité de production de la totalité des étapes a ainsi été amenée à un même niveau (situation « équilibrée »). Ce niveau se situe vers une capacité annuelle de 40 kWcrête, ce qui était la valeur cible du présent projet.

La Figure 5 donne la capacité des étapes critiques avant et à la fin du projet en comparaison avec la valeur cible de 40 kWcrête.

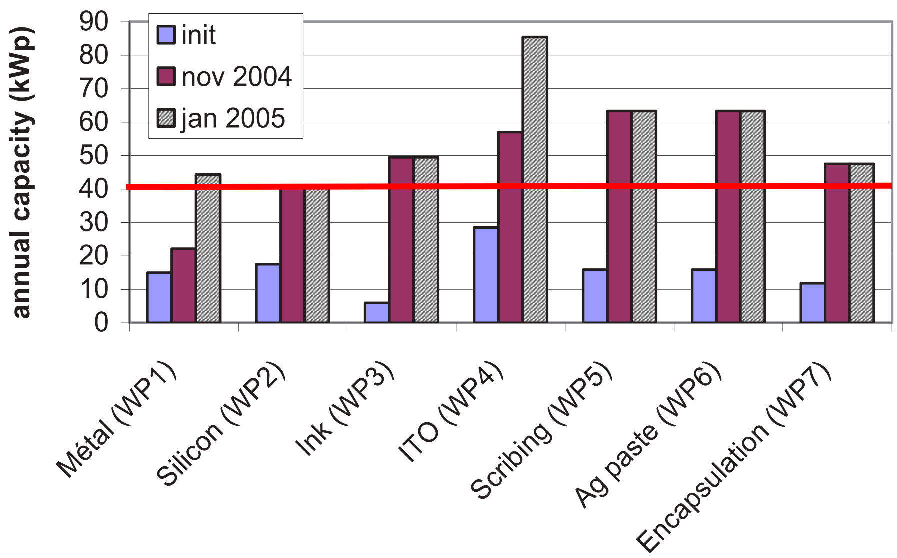


Figure 5 : Capacité annuelle des étapes de fabrications critique dans la fabrication du produit flexcell, au début du projet (octobre 2003), et à la fin du projet en novembre 2004/janvier 2005.

Les photos ci-dessous montrent les nouvelles installations back-end de VHF-Technologies SA à Yverdon-les-Bains (Figure 6).

Figure 6 : Gauche : mise en série sur table X-Y (WP5/6) ; droite : zone de lamination et mesure (WP7)

Collaborations

Depuis 2000, et encore pendant toute la durée du présent projet, l'EIAJ Le Locle (école d'ingénieurs) a hébergé la partie front-end de la fabrication de VHF-Technologies dans son laboratoire de microtechnique. Sous la direction du Prof. Herbert Keppner, une collaboration intense est conduite depuis des années au sujet d'amélioration et de l'industrialisation des procédés de fabrication des cellules solaires sur film plastique par plasma. Pendant l'année 2004, la collaboration avec l'EIAJ a été notamment soutenue par les projets TopNano 6059.1 et CTI 7013.1.

VHF-Technologies a collaboré avec l'IMT Neuchâtel (Prof. Shah), le PSI, l'EIAJ, ODV, dans le projet CTI 7013.1 dans le but d'améliorer le light-trapping des cellules solaires sur substrat plastique. La collaboration avec l'IMT permet un échange permanent et fructueux sur l'amélioration et la caractérisation des cellules en couche mince de silicium sur substrat plastique.

Pour le développement et l'évaluation des matières de production, VHF-Technologies collabore notamment avec Honeywell Specialty materials, DuPont, Bayer, St-Gobain, et Isovolta.

Pour le développement des composants de BIPV, des collaborations sont en cours avec les Services industriels de Genève (fonds SIG-NER), Axpo Naturstromfonds, les services industriels de Lausanne (SIL), Alcan, Eternit AG, Carlysle Syntec, Ernst Schweizer AG et Metecno.

Evaluation pour 2004 / perspectives pour 2005

Une ligne de production pilote est maintenant en place, ce qui permettra en 2005 de servir le marché OEM et des chargeurs portables avec des volumes encore modestes, mais réguliers.
En parallèle, cette même production pilote permettra de développer le business et de rechercher des partenariats stratégiques dans la direction du marché BIPV/énergie, à travers la mise à disposition du produit flexcell pour des projets de démonstration (field tests) et de co-développement avec des partenaires.

Cette stratégie est maintenant à nouveau soutenue par les investisseurs de VHF-Technologies, qui ont refinancé la société pour atteindre en 2005 les buts suivants :

- regroupement des activités à Yverdon-les-Bains
- élimination des dernières étapes de fabrication en batch (tout en continu)
- augmentation de la performance du produit à 4% de rendement stable
- augmentation de la capacité fabrication à 100 kW avec un rendement de fabrication de 80%
- accélération des ventes des secteurs chargeurs portables et produits OEM
- développement de nouveaux produits
- vérification du modèle de coût et du business plan pour un scénario de 5 MW annuel
- conclusion d’un partenariat stratégique dans la distribution d’élément PV pour les bâtiments

Références et publications

Voir sous: http://www.flexcell.ch

Annual Report 2004

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

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Project- / Contract Number	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 are 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. Therefore, the Institute of Microtechnology (IMT) aims at transferring its technology on low-cost plastic substrates, in a way that is compatible with the specific fabrication process available at VHF-Technologies S.A.

With the goal of enhancing the performance of the photovoltaic modules, the partners propose to increase the photo-generated current by using light trapping i.e nano-structured gratings in flexible solar cells. Simultaneously, the series connections and current collection is being improved in the completed solar modules. In order to reduce the fabrication cost for modules; here, more cost-effective substrates (PET or PEN instead of polyimide), faster structuring methods and better-adapted electrodes have been investigated.

This work resulted in laboratory-scale solar cells with 7% stable efficiencies deposited on PET substrates. On the production line, VHF-Technologies has shown that PET and PEN substrates with gratings, as supplied by OVD-Kinegram A.G., are both compatible with their fabrication process. Furthermore, the series resistance and the “dead surface” of the modules have been reduced, different laser ablation processes for interconnection have been tested and a new VHF-electrode with an improved design has been installed in the reactor: 3.6% stable efficiency was achieved so far in the production line.

Introduction / Project goals

On the worldwide market place, flexible photovoltaic modules are only commercialised by three companies: VHF-Technologies S.A. based in Yverdon in Switzerland, Iowa Thin Film Technologies and United Solar in United States.

Concerning the production capacity, only United Solar exceeds the significant volume threshold of several Mega Watts (MW) per year for flexible photovoltaic products. VHF-Technologies is currently developing a continuous roll-to-roll production line for reaching 1 MW per year by the end of 2005 and 5MW per year once the production process will be proven. Today, the company supplies modules essentially for advertisement, lighting systems and electronic devices. As long-term market, VHF-Technologies is interested in developing photovoltaic products for building integration (Fig. 1).

(a) (b)

Fig. 1: Flexible Photovoltaic modules fabricated by VHF-Technologies for (a) off-grid electronic applications and (b) building integration.

By increasing their production capacity, VHF-Technologies will drastically reduce the cost of their production. However, in order to be cost-competitive, the cost/efficiency ratio of the photovoltaic modules must be further reduced. During this project, methods for further improving the efficiency of solar cells deposited on flexible substrates have been investigated:

- Light-trapping in cells deposited on flexible plastic substrates,
- Improvements in the inter-connection method,
- Better adapted and faster structuring methods,
- Improvement of the reactor design.

At the same time, cost-effective substrates (PET or PEN instead of polyimide, as presently used) have been investigated and the feasibility for longer production runs have been tested.

Description of the project

A significant advantage of the present project is certainly the synergy between the domains of expertise of the different partners i.e. Institute of Microtechnology (IMT), Ecole d'Ingénieurs de l'Arc Jurassien (EIAJ), VHF-Technologies S.A., OVD-Kinegram A.G. and Paul Scherrer Institute (PSI).

In this context, the partners decided to investigate the light-trapping effects in cells in order to increase the photo-generated current and thereby the efficiency of the cells (principle presented Fig. 2). Thereby, IMT and PSI have complementary roles: IMT masters the experimental side and PSI possesses the theoretical experience in optics [1,2]; IMT itself has all the necessary materials and resources for investigations in this field (fabrication of textured substrates, solar cell deposition, laser-scribing facilities, characterization methods).

OVD-Kinegram is a leading company supplying large area nano-textured plastic foils: These foils (PET and PEN for instance) are compatible with VHF-Technologies's roll-to-roll process and their textures can be optimized for increasing the light-trapping in solar cells.

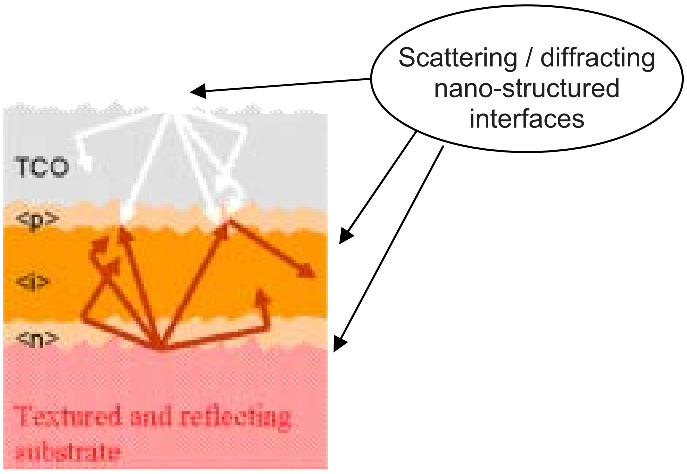

Fig. 2: Principle of light trapping in solar cells. The light entering into the cell is diffracted or scattered at each of the nano-textured interfaces. Consequently, the optical paths of the photons and their absorption probability increase. This results in higher photo-generated current.

Finally, EIAJ works 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.

Results

IMT/OVD-Kinegram

IMT were in charge of laboratory-scale tests. For increasing the efficiency of the solar cells, the possibility to incorporate flexible and low-cost textured substrates for increasing the light-trapping in a-Si:H solar cells was studied.

During the reporting year, nano-gratings fabricated in-house (at IMT) on glass and nano-gratings fabricated by OVD-Kinegram (roll-to-roll process) on PEN and PET have been tested (Fig. 3).

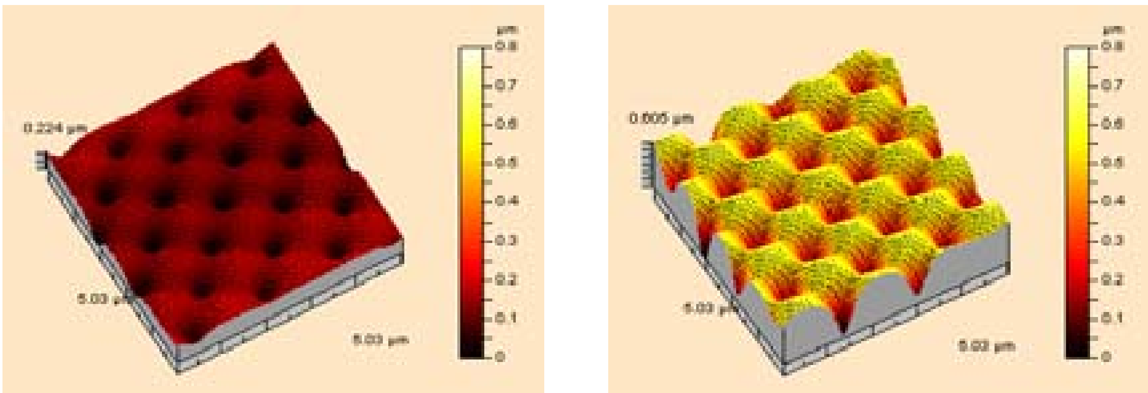

Fig. 3: nano-gratings with different dimensions, as tested during the project.

The best cells were obtained on textured PET substrates fabricated by OVD-Kinegram. Using Ag and LPCVD-ZnO [3] as back reflector and top contact, respectively, IMT succeeded in depositing solar cells with 7% stable efficiency on periodically textured PET substrates (Voc=0.890V, FF=61.3%, Jsc=13.1mA/cm2). According to the requierements of VHF-Technologies, LPCVD-ZnO was replaced by ITO, and stable efficiencies up to 6.7% were achieved so far.

PSI

PSI developed a new stable and thoroughly tested computer code for calculating the best adapted dimensions of gratings for light-trapping. According to this program, the best linear blazed structure should lead to an J_{sc}-enhancement of around 40%. This grating will be experimentally tested during the second phase of the project.

VHF-Technologies/EIAJ

Grating substrates fabricated by OVD-Kinegram on PET and PEN have been tested in the roll-to-roll production context. These substrates lead to good production yields but, sofar, no gain in J_{sc} gain was observed. During the second phase of the project, the grating dimensions will therefore be optimised and tested in the production line and the solar cells will be adapted to the new substrates.

Simultaneously, an Ag-paste grid has been optimised in order to reduce the series resistance, the “dead surface” of the modules has been minimized and different laser ablation processes for interconnection have been investigated. These developments result in lower connection resistance before and after environmental tests.

Finally, a new VHF-electrode with an improved design has been fabricated and installed in the roll-to-roll reactor: it results in higher production yields and long-run feasibility.

VHF-Technologies can currently produce modules with 3.6% stable efficiency (A4 size) on low-cost PEN substrates.

Collaborations

Two Swiss Institutes and two Swiss companies are closely collaborating within the project :

- IMT is in charge of the laboratory-scale developments for textured substrates and solar cells,
- PSI is in charge of the calculation of the optical properties of the devices,
- VHF-Technologies S.A. develops a roll-to-roll continuous production line for flexible photovoltaic modules,
- OVD-Kinegram A.G. is a leading company for the fabrication of nano-textured grating surfaces on plastic foils. OVD-Kinegram's roll-to-roll process is compatible with the process used by VHF-Technologies for the production of the flexible photovoltaic modules.

Evaluation for 2004 / perspectives for 2005

For this project, the technical results are sofar close to the milestones. Furthermore, a patent (Dispositif photoélectrique à substrat texturé n° EP 04 405345.2) on the use of gratings for solar cells could be applied for. The examiner's report for the patent will be received in early 2005.

At the end of the project (1^{st} July 2005), the shape and dimensions of the most suitable nano-textured substrates will be defined and incorporated into laboratory-scale solar cells in order to achieve 8% stable efficiency. The same substrates will be produced on large-scale surface area by OVD-Kinegram and supplied to VHF-Technologies: using this method, 5% stable efficiency should be attainable in the production line.

In addition, VHF-Technologies will from now intensify its search for an industrial partnership with Swiss or foreign companies from the application side. The goals are here to realize and test new product prototypes and to get a real commitment regarding distribution and market access for VHF-Technologiesš products.

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Nano-Patterning

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Duration of the Project (from – to)	1.7.02 – 31.12.04

ABSTRACT

The emphasis of the project is to enhance the efficiency of thin film solar cells by means of light trapping. The industrial partner in the project VHF-Technologies who fabricate amorphous silicon cells using a p-I-n structure roll to roll process on polyimid substrates. The light trapping scenarios that are presented here have to fulfill the following requirements:

1. the process must be roll-to roll compatible.
2. the light trapping patterns must be random (in complementary with other approaches).
3. the features that lead to light trapping should be in the nano-metric range in order to turn from Lambert-scattering to Mie scattering. Therefore the project the surfaces that have to be generated are called "Super-Lambert" surfaces.
4. The cost of the technology that generates "super Lambert" surfaces must be in a reasonable relationship wit respect to the efficiency gain that can be achieved.

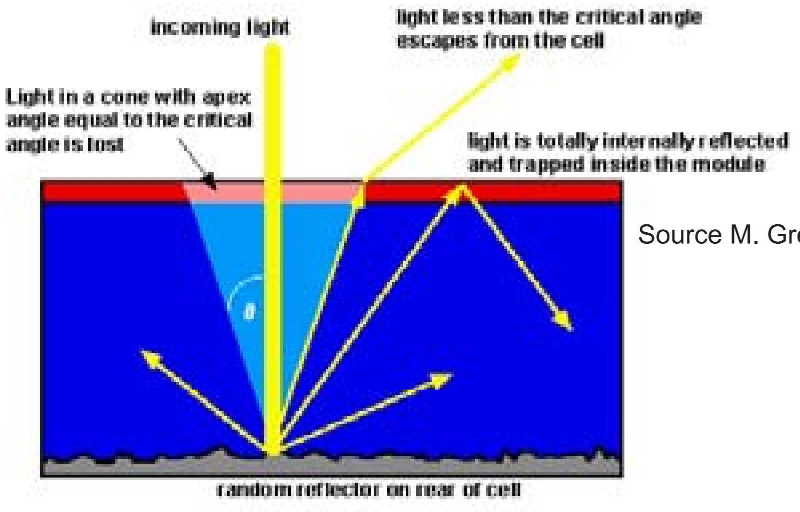
The latter point was estimated; the photocurrent gain from state-of the art cells (10.66 mA/cm^2) can be increased to 14 mA/cm^2 using a standard Lambert surface and even up to 17 mA/cm^2 using a super Lambert surface.

A first approach consisted to manufacture polyimide / Al /µc-Si:H substrates. Subsequent heating let Al diffuse into the grain-boundaries and creates selective sites for Al or Si etching. By that the µc-Si:H grain boundary pattern is replicated into the substrate. Some first experiments have been carried out; however the Al-oxide prevented the diffusion. A second approach consisted in SPC (solid phase crystallization) of a polyimid / a-Si:H / Al substrate. SPV could be tailored in a way that selective sites could be successfully generated. Pattern transfer for nano-scale features could be realized in the substrat.

Using such patterns, only a 5% gain in photocurrent could be achieved, far beyond the 60 % expectation. Comparing with other results we conclude, that the predicted gain can only be achieved if the surface of the cell remains unpatterned. The absorber material must smooth the pattern, if not the light will be coupled out instead of being trapped.

Introduction

Light trapping can be achieved by the scenario presented in Figure 1 according to Yablonovitch, E. and Cody, G.D. (1982), "Intensity Enhancement in Textured Optical Sheets for Solar Cells," *IEEE Transactions on Electron Devices*, Vol. ED-29, pp. 300-305.



Source M. Green University of New South Wales

As soon as the back reflector is suitably patterned, the loss cone of directly back reflected light can be kept small and the "lateral waveguide effect" is pronounced. By that principle, the photocurrent of the cell can be enhanced.

Description of the project

The successful patterning scenario is presented in fig. 2, called the SPV (solid phase crystallization) of AIC (Aluminium Induced Crystallization):

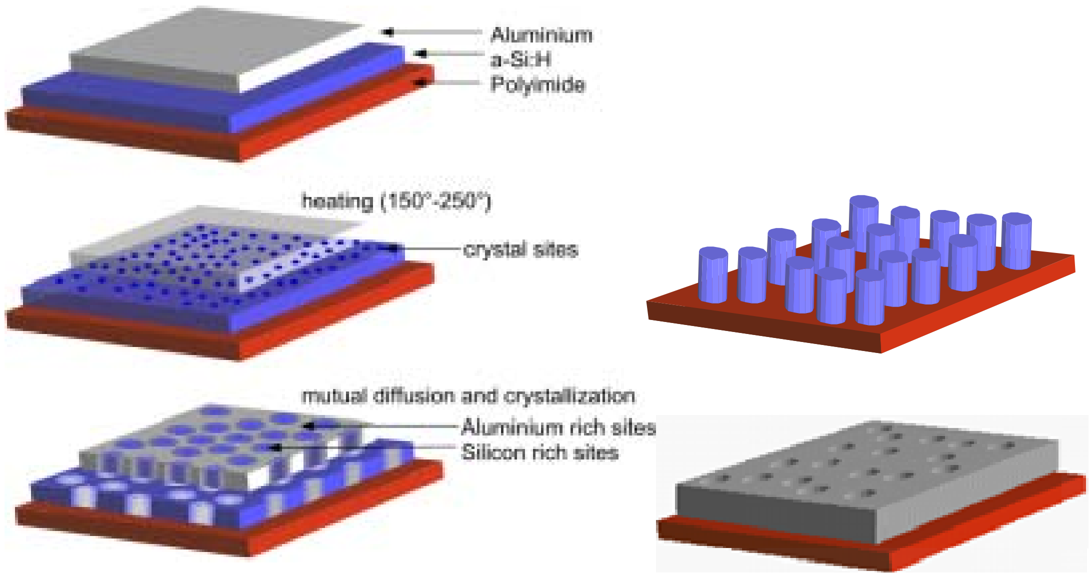


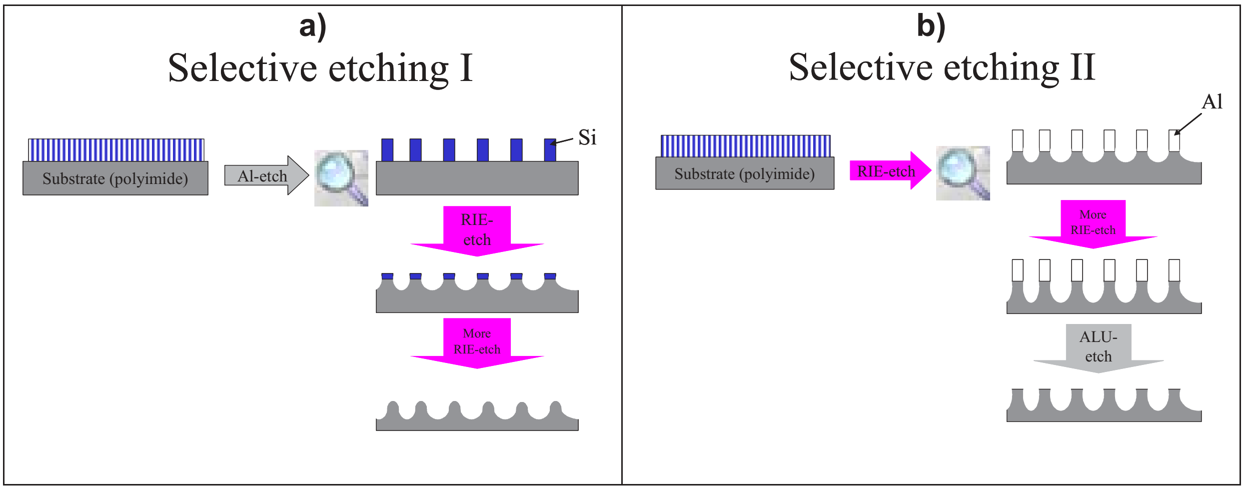
Fig. 2: SPC in order to create selective sites that allow selected etching for patterning.

1. Choice of full-process nanopattern transfer

At the final stage of the project the nano-patterning of polyimide substrate involving AIC has to be implemented in the fabrication of solar cell by the industrial partner, VHF Technologies SA. It means that the polyimide nano-patterning process: a-Si layer, Al-layer deposition, AIC process and selective RIE etching can be performed in one reactor, and is compatible with cell fabrication. The nano-patterned polyimide substrate will be, again, coated with aluminum as a diffusively reflecting back contact for the solar cell. The conventional Si-based solar cell will be then deposited by « standard conditions »onto this diffu sor.

The industrial partner had to choose between two processes based on AIC for polyimide nano-patterning. Both are shown in the Fig. 3

Two selective etching processes proposed for polyimide nano-patterning: a) first step involves Al-etching (wet etching), followed by RIE process; b) first step is RIE process, followed by wet Al etching.



Both processes were discussed in details and finally our choice was the process based on selective etching II, without the last phase involving wet Al etching. The choice of this process is because of necessity to avoid etching in acid bath to remove Al. In fact, using actual solar cell fabrication process it is difficult to implement liquid phase etching due to its incompatibility with reactor. Thus, the nano-patterning of polyimide should be based only on vapour phase process.

2. Solar cell fabrication and testing

The aim to this step is to implement the Aluminium-induced Crystallisation of a-Si into the fabrication of a complete solar cell and testing of its efficiency.

2. Experimental details:

2.1. Substrate fabrication and its nano-patterning.
The bare polyimide substrate available commercially were used to deposit a-Si:H layer by PECVD process using roll-to-roll technique in SiH4/H2 plasma at temperature of 120°C. The deposition conditions were typical conditions used by VHF-Technologies, and the a-Si:H layer thickness was 100 - 200nm. Following the a-Si layer deposition, the Al layer of equal thickness was deposited by magnetron sputtering.
The polyimide substrates with a-Si/Al double layer were cut by pieces of $10x10cm^2$ and subjected into heat treatment at 285°C in inert N2 atmosphere during 1 hour. The success of AIC process was quickly checked by immersion into acid mixture to remove Al. If Al layer was completely removed from the polyimide and the sample was transparent (only a-Si layer was left), this means that the

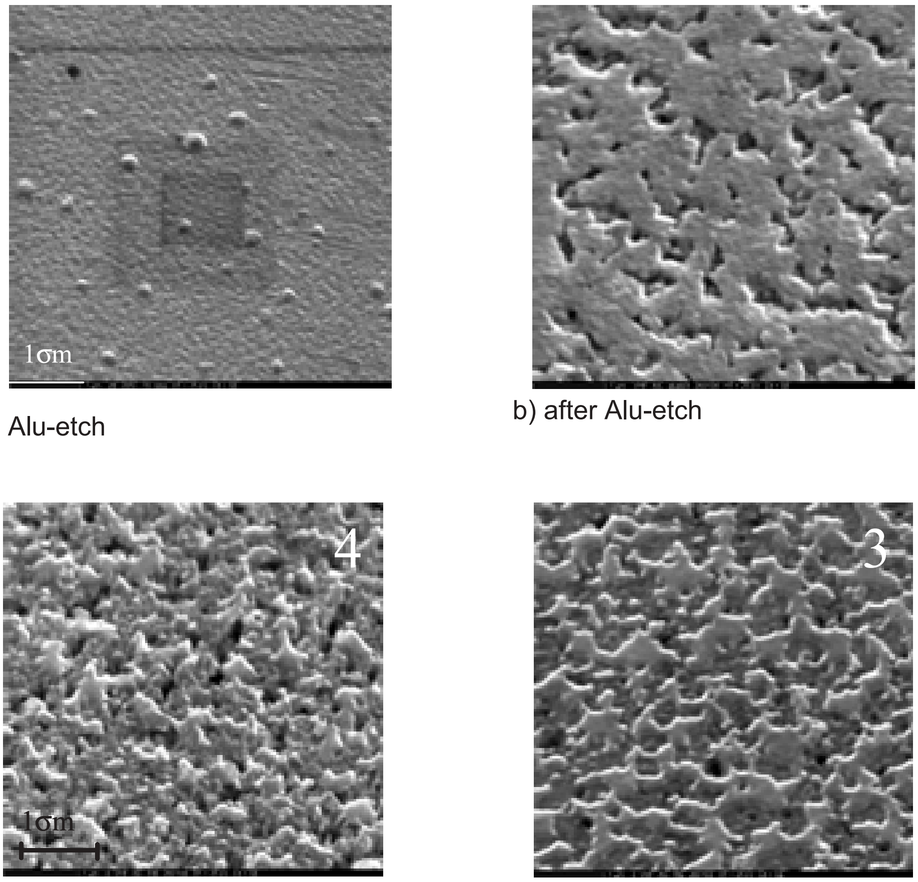
interdiffusion of Si into Al was not proceeded. In case the polyimide was opaque (or semi-opaque), the AIC process was proceeded. This quick check was also confirmed by SEM studies.
The reactive ion etching (RIE) was performed using normal condition described in the Part 1.

2.2. Solar cell fabrication.
Complete amorphous silicon solar cell fabrication was done at the University of Neuchâtel (Institute of Microtechnology) in collaboration with the group of Prof. A. Shah. The double Ag/Cr layer covered with very thin ZnO layer was used as a back-contact and deposited directly on the nano-patterned polyimide. Then, the n-i-p a-Si layer was deposited. Al-doped ZnO layer of high roughness deposited by Low-Pressure Chemical Vapour Deposition (LP-CVD) was used as a top-contact.

2.3. Solar cell testing.
The I-V and the spectral response facility at IMT was used for the precise measurements of the cells.

3. Results and Discussion

The double layer (a-Si:H/Al) polyimide foils were subjected to AIC process as described in experimental Details. The effectiveness of this process (the interdiffusion of Si into Al) was checked by quick test and then, confirmed by SEM examination. The surface morphology of the samples before and after AIC, followed by Al-etching are shown in Figs. 4a and 4b.



a) before Alu-etch

b) after Alu-etch

c) long SPV

d) RIE etching of Si-rich sites

Fig 4: SEM observation of polyimide/a-Si//Al sample after AIC process : a) before Alu-etch ; b) after Alu-etch. The appearance of the grains of sub-micron size indicates that the interdiffusion of Si and Al was successful.
The Figure 4 c) illustrates the Si-rich islands intercalated with the Al-rich matrix. Once the Aluminum was etched out, the Si-rich grains remain at the polyimide substrate.

Following the fabrication process, the sample subjected to AIC, was treated by RIE in SF_6 / O_2 reactive atmosphere for 10 min. The surface morphology of the samples were examined by SEM (Fig. 4d). Both samples show similar morphology with a slightly different grain size. This difference in morphology can be attributed to temperature gradient upon the heat treatment, as the samples were placed in the different places in the oven. The layer is mainly composed on Al-matrix, as Si-rich areas was etched out.

The efficiency of light scattering of the samples together with a standard perfect diffusor reference were examined by Angle-Resolved Spectrometry (Fig.5). As expected, all the samples show very good diffuse reflectivity. The light reflectivity at high angles (between 20 and 40°) is comparable with the reflectivity at low angles (0-20°), though its absolute value is quite low.

In addition, the reflectivity (specular and diffusive) measurements (NIR-VIS-UV range) were performed on the samples after AIC process, before and after RIE (10 min). It was shown that the sample before RIE has higher specular reflectivity but lower diffuse reflectivity between 600 and 1200nm (red-NIR). By that, the RIE process results in the enhancement of light diffusion in this energy range.

Fig. 5: Light scattering intensity of the samples, subjected to AIC process and treated by RIE (10 min). The method applied for this measurement is called angular resolved scattering

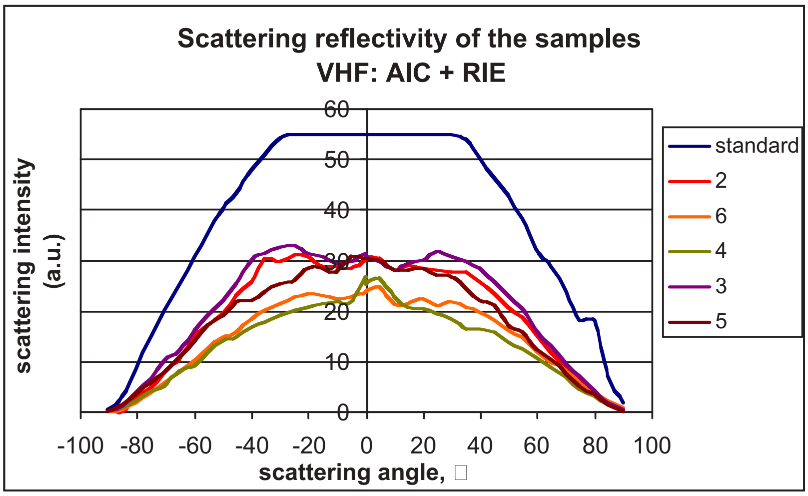
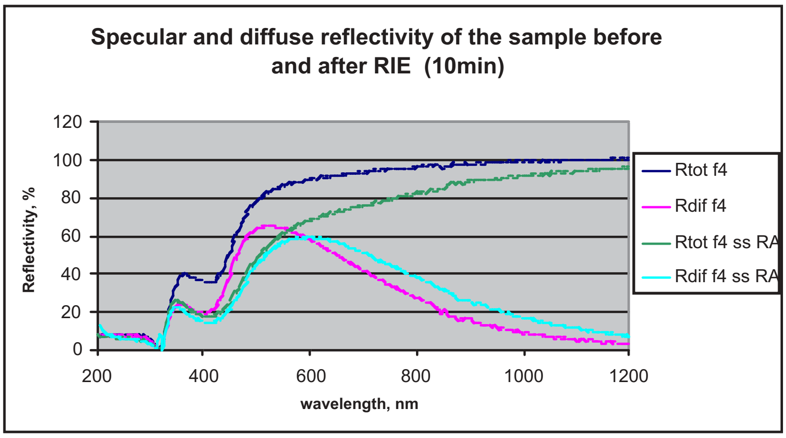


Fig. 6: Specular and diffuse reflectivity of the sample subjected to AIC process before and after RIE treatment (10 min). Blue and red line correspond to non-treated by RIE sample
Time of RIE treatment also results in light diffusion enhancement. Increasing time of RIE to 60 min increase the diffuse light intensity.



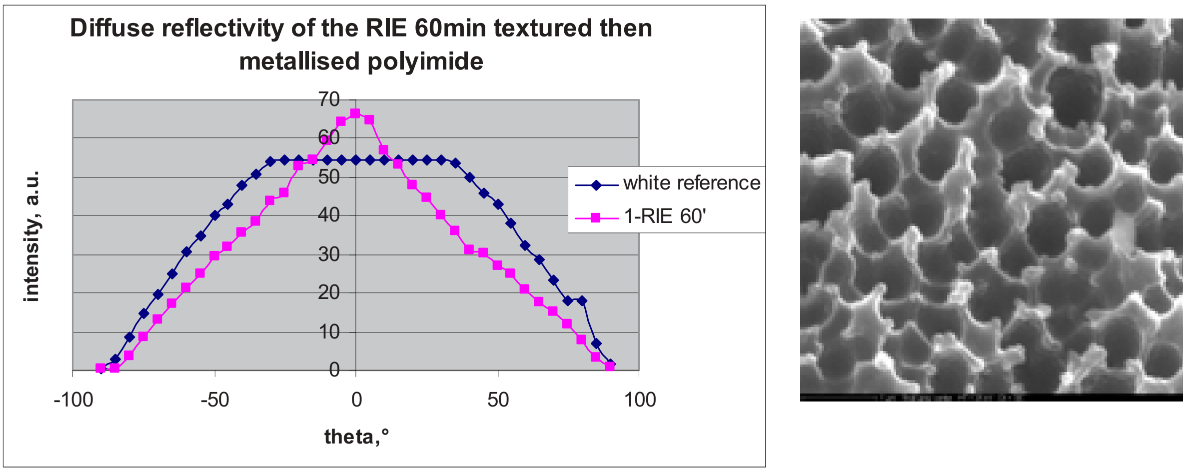
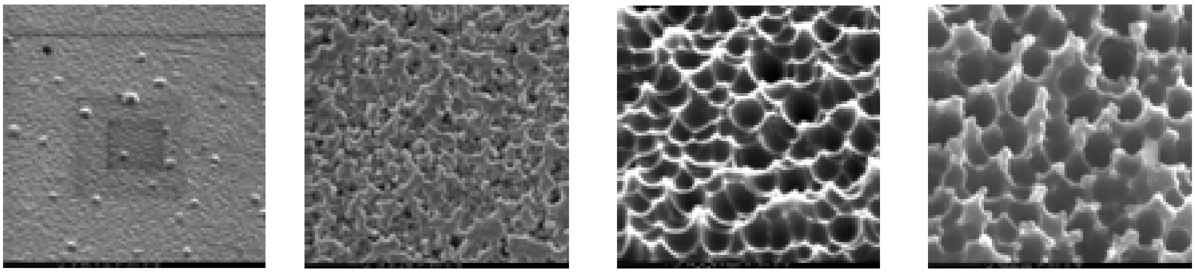


Fig. 7: Scattered reflectivity of RIE etched (60min) sample, pre-treated by AIC. Metallisation with Al was done after RIE process. Reference white standard sample reflectivity was plotted for comparison (left). SEM micrograph of the sample after RIE 60min (right).

The proposed to industrial complete process of polyimide nano-patterning, as called before Selective Etching II is shown below.

Selective etching II.



1 - AIC | 2 - RIE, 10min | 3 - deep RIE, 60min Alu-etching | 4 - Al metalization

Fig. 8. Due to incompatibility of wet etching process (Alu-etch, to remove Al) with the production line, the industrial partner considered it necessary to stop Selective etching on the step 2. Therefore, for the fabrication of solar cells, polyimide substrates subjected to AIC process and then, treated by RIE (time of treatment: 10 and 20min) were used.

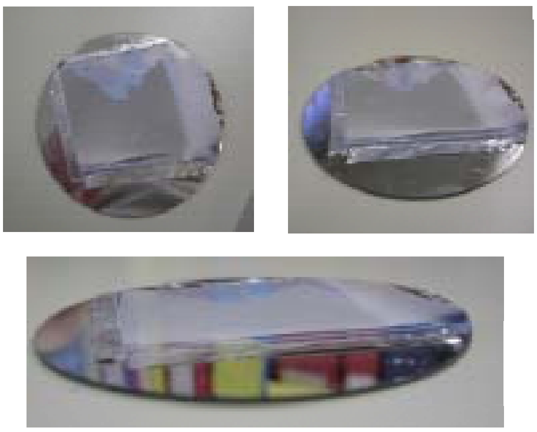


Fig. 9: Structured (RIE 60min) and metallised polyimide sample tilted at different angles (between 10 and 90°) to show an efficient light diffusion.

Solar cell characterisation involves several stages:

1. Atomic Force Microscopy (AFM) characterisation of the polyimide substrate, after the deposition of back-reflector (thin Ag/Cr/ZnO layer).
2. Measurement of solar cell efficiency: photocurrent, Fill Factor (FF), Jsc and Voc.
3. Spectral response measurement in order to evaluate gain and loss scenarios

1 AFM Characterization

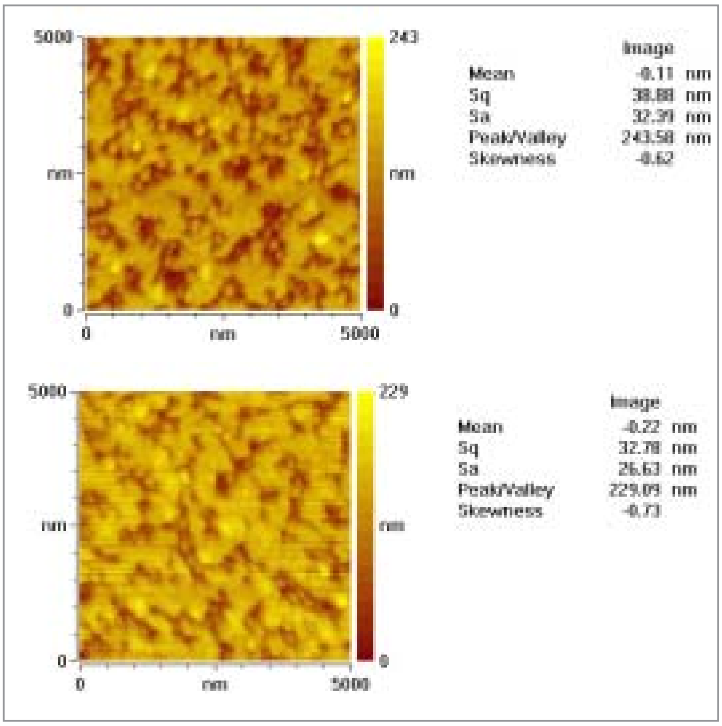


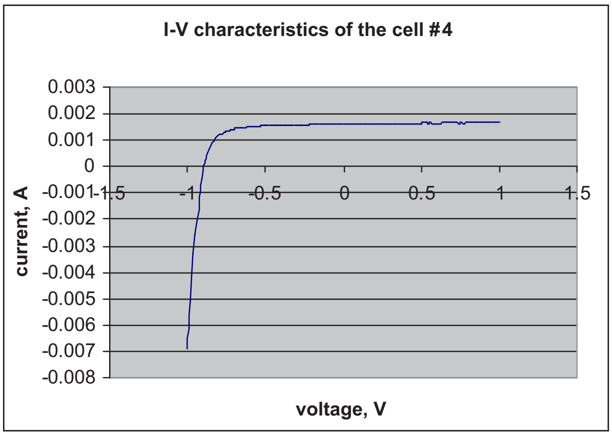
Fig.10: AFM scan of the structured by RIE (10min) polyimide substrate without (a) and with (b) back-reflector Ag/Cr/ZnO layer.

The analysis of RMS roughness (indicated as Sq) shows that its value is lower by 6nm for the polyimide covered with back-reflector, as compared to the uncovered polyimide. This means that the back-reflector deposition slightly flatten the rough polyimide surface. The same results are observed on polyimide, treated by RIE for 20 min (a decrease in 5nm of RMS value was observed).
The Table 1 compares results on two solar cells, deposited on structured by RIE polyimide (time of RIE 10 and 20 min). Table 1 from AFM measurements:

sample	RMS, nm (without Cr/Ag/ZnO)	RMS, nm (with Cr/Ag/ZnO)	Decrease in RMS
PI 1 (RIE 10min)	39	33	18.2
PI 2 (RIE 20min)	50	45	11.1
Increase in RMS PI1 /PI2	28.2	36.4	

One can conclude that a) a deposition of back-reflector layer results in diminishing of RMS roughness by about 10-20% as compared to bare polyimide substrate; b) the time of treatment increase the surface roughness: PI2 has higher RMS than PI1 by 36%.
The total and diffuse reflectivity spectra of these two samples (PI1 and PI2) with deposited back-reflector show that the total reflectivity is very similar for both samples. To the contrary, the diffuse reflectivity is much higher for the sample, treated by RIE for 20 min. This confirms our studies on Al-metalized polyimide, showing an increase of light diffusion with increasing RIE time.

3. Solar cell characterization



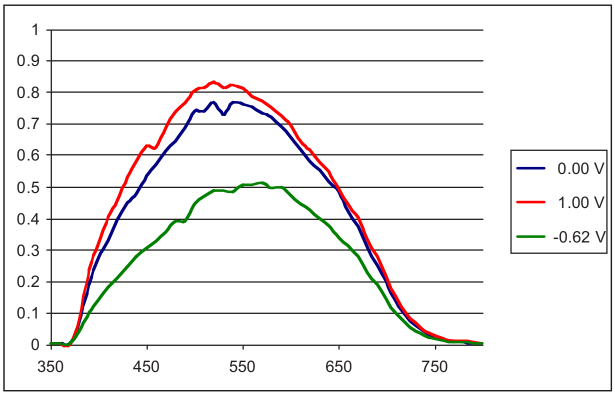


Fig. 11: I-V characteristics of a-Si :H cells deposited on AIC patterned substrates. The net gain is 5% which confirms the success of the AIC method. However far below the expected value.

Fig. 12: spectral response of the cell shown in fig. 11. The gain is clearly due to light-trapping in the near infrared regime.

Conclusion

Many studies have been carried out with the objective to increase light-trapping from diffuse back-reflection from the rear contact of a thin film solar cell. In general the experimental result came never close to that what theory predicted. The authors assume, that experimental realizations are different as shown in fig. 1 having a rough beck-contact but a perfectly smooth surface that allows total reflection. As soon (to be still theoretically confirmed) the cell replicates the roughness to a certain extend, strong out-coupling of the light occurs. There are two outlooks possible:

1. The roughness can be perfectly smoothed by the cell layer.
2. The scattering effect of the back contact is induced not by geometrical roughness, but by anisotropy of the index of refraction (e.g. opalescence). We feel that future scenarios have to follow this way.

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Flexible CIGS solar cells and mini-modules (FLEXCIM)

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Duration of the Project (from – to)	01.03.2004 – 31.10.2005

ABSTRACT

Thin film $Cu(In,Ga)Se_2$, called CIGS, solar cells are known for high efficiency and long term stable performance. Flexible CIGS solar cells were developed on polyimide (UPILEX ^{TM}) and steel metal foils of 5 x 5 cm^2 size. No diffusion barrier layer was applied on steel or polyimide foils. A recently invented method, developed by ETHZ group, for controlled and reliable incorporation of Na in CIGS with a post-deposition treatment was applied. Flexible solar cells of 10-12% efficiency were routinely obtained on steel and polyimide foils providing the proof of concept. Further optimisation of CIGS deposition processes was focussed for solar cells on polyimide substrates. As a result cell efficiencies were further improved and measurements at ISE-Fhg Freiburg, Germany confirmed 14.1% efficiency under simulated AM1.5 standard test conditions for solar cells directly grown on Upilex polyimide films. This is the highest efficiency world record reported to date for any kind of solar cell grown on polymer films.

The measurements of quantum efficiency and reflection losses suggest that by application of antireflection coating reflection loss can be reduced and about 8-10% additional gain in cell efficiency can be expected; this would enable flexible CIGS solar cells on polymer (and on metal) foils with efficiencies exceeding 15%.

Large area CIGS deposition system for 30 x 30 cm^2 substrates is in advance stage of development. Substrate heater and evaporation sources have been constructed in-house and installed in a high vacuum evaporation system also designed in-house.

Finally, CIGS solar cells in substrate configuration were developed on indium tin oxide (ITO) transparent back contacts. An intentionally grown $MoSe_2$ intermediate layer on ITO, prior to CIGS deposition, causes a significant efficiency improvement, suggesting that $MoSe_2$ can facilitate a quasi-ohmic contact on a variety of contact materials. Solar cell efficiencies of up to 11.8% are obtained using an ITO/$MoSe_2$ back contact. Such solar cells will be useful in multijunction (tandem) solar cells.

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 19.3% 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 developing processes for high efficiency CIGS flexible solar cells with low deposition temperature processes and incorporating controlled amount of Na in CIGS for efficiency enhancement (see EU-METAFLEX project report). 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 metal foils. ETHZ group has 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 to larger area deposition of layers.

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

Work and results

Flexible solar cells on metal and 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 steel (left) and polyimide (right) foils.

Commercially available polyimide (UPILEX ^{TM}) and steel metal foils were used to grow solar cells on 5 x 5 cm^2 substrates (see figure 1). No diffusion barrier layer was applied on steel foil. Layers of ZnO:Al/ZnO/CdS/CIGS/Mo were grown as described in earlier reports. Substrate temperature during CIGS deposition was below 450 C (this is a reference value, actual 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 and polyimide foils. For further optimisation of CIGS deposition processes and because of limited resources, R&D work was focussed on polyimide films only. CIGS on metal foils will require a different optimisation approach. Figure 2 shows the cross-section image of a typical high efficiency CIGS solar cell on polyimide film.

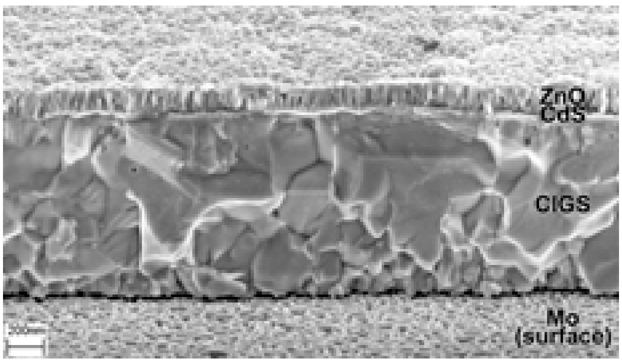

Figure 2: Scanning electron microscopic cross-section image of a flexible CIGS solar cell on Upilex polyimide film. A post deposition treatment was applied for in-diffusion of Na in CIGS to passivate the grain boundaries.

As shown in figure 3, efficiency measurements performed at ISE-Fhg Freiburg (Germany) have confirmed 14.1% efficiency (Voc = 649 mV, Jsc = 31.5 mA.cm-2, FF= 69.1%, total area = 0.595 cm2, no antireflection coating) under simulated AM1.5 standard test conditions. This is the highest efficiency reported to date for any kind of solar cell grown on polymer films.

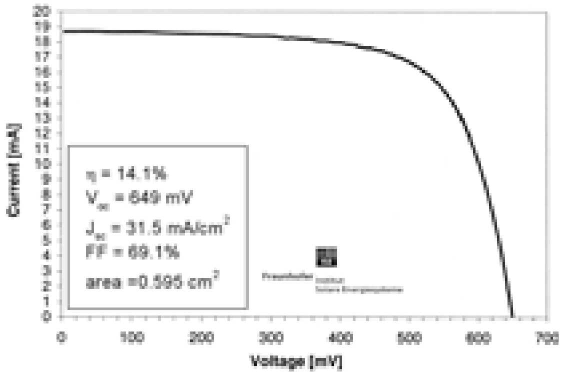

Figure 3: J-V measurements performed under simulated AM1.5 standard test conditions at ISE-Fhg Freiburg (Germany) have confirmed 14.1% efficiency (total area measurement, no antireflection coating) of the flexible CIGS cell on polyimide film. This is the highest efficiency record for any type of solar cell grown on polymer foil.

An average reflectance loss of about 13% was measured in the visible-near IR spectral region for these solar cells (see figure 4). Therefore, an application of commonly used anti-reflection coating would minimize the reflection loss and a further gain of about 8-10% in efficiency would enable more than 15% efficiency flexible CIGS solar cells on polyimde films.

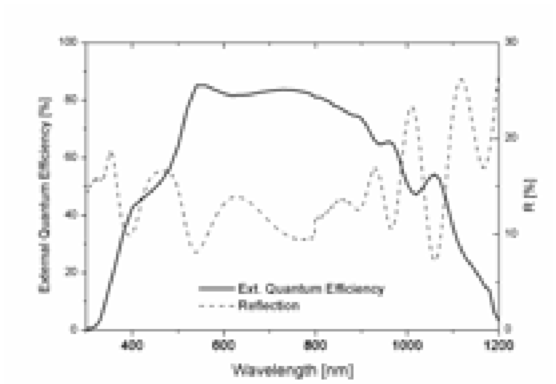

Figure 4: Quantum efficiency and reflection loss measurements of the 14.1% flexible CIGS solar cell. The reflection losses can be reduced by applying antireflection coating.

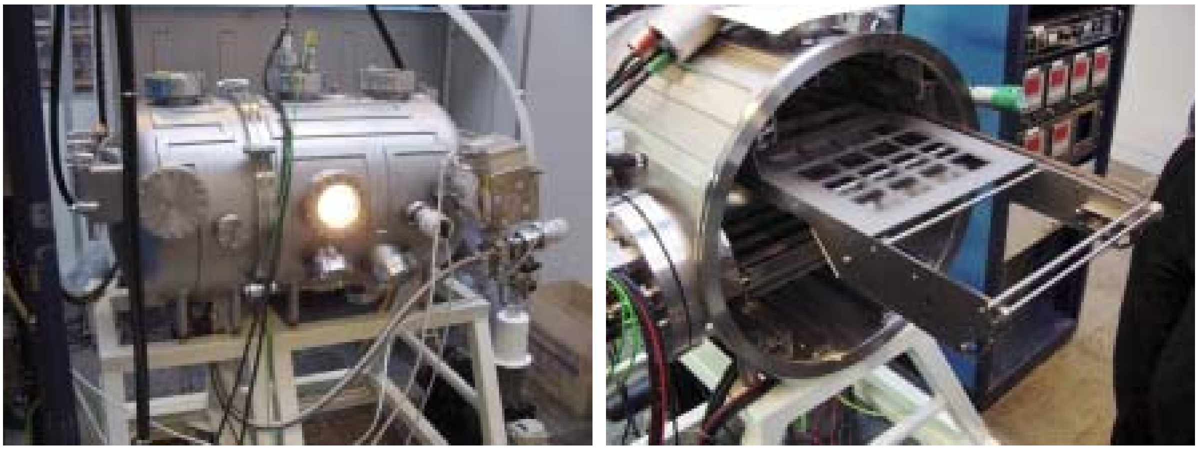

Figure 5: Pictures of in-house developed CIGS vacuum deposition system for large are deposition on up to 30 x 30 cm^2 substrates.

CIGS solar cells on TCO coated substrates

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

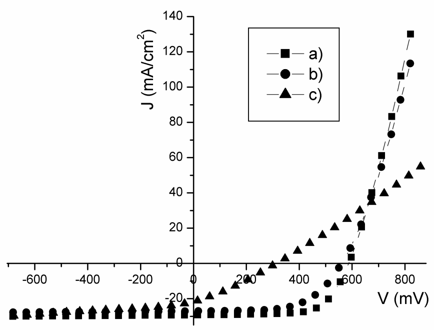

Figure 6: I-V characteristics under AM1.5 illumination of CIGS solar cells in substrate configuration with ITO/$MoSe_2$ back contact (a and b) and with ITO back contact (c). To form an intentionally grown $MoSe_2$ intermediate layer on ITO back contact, for cell (a) the Mo was selenized at 450°C, for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

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

Table I: Photovoltaic parameters for solar cells with and without intermediate $MoSe_2$ layer between ITO back contact and CIGS; for specifications please refer to Fig. 6 and the text.

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

National and international collaboration

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

Evaluation-2004 and outlook-2005

Flexible CIGS solar cells on polymer and metal foils were developed with a novel process developed at ETHZ. A world record efficiency of 14.1% for flexible cells on polymer foils was certified by ISE-FhG, Freiburg, Germany. Quantum efficiency and reflection measurements suggest that cells with efficiencies exceeding 15% can be achieved by reducing the reflection losses. Future work will be focussed on investigating the manufacturability aspects of the CIGS deposition process and process simplifications, and addressing the issues of metallic substrates. Strategies for mini-module development will be formulated. Preliminary experiments have proven that $MoSe_2$ intermediate buffer layer can be applied to develop solar cells on alternative back contact materials.

Large area CIGS deposition equipment has been assembled in-house. Future work will investigate the evaporation profile of home-made linear evaporation sources of constituent elements of CIGS and uniformity issues of the large area substrate.

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%***, 31st IEEE Photovoltaic Specialist Conference, Orlando, 3-8 January 2005

[2] D. Rudmann, D. Brémaud, H. Zogg and A.N. Tiwari, ***Na incorporation into Cu(In,Ga)Se2 for high-efficiency flexible solar cells on polymer foils***, Accepted for publication in J. Appl. Phys. 2004/2005

[3] D. Rudmann, D. Brémaud, M. Kaelin, H. Zogg and A.N. Tiwari, ***CIGS growth processes for solar cells on flexible polymer substrates,*** to be presented at the 20th European Phototovoltaics and Solar Energy Conference, Barcelona June 2005.

Annual Report 2004

Towards the roll-to-roll manufacturing of cost effective CIS modules- intermediate steps (METAFLEX)

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Project- / Contract Number	BBW-NR. 01.0108 / EU PROJECT ENK6-2001-00516
Duration of the Project (from – to)	01.12.2001 – 30.11.2004

ABSTRACT

The objective of the EU project METAFLEX is to develop processes leading towards the roll-to-roll manufacturing of flexible $Cu(In,Ga)Se_2$ (called CIGS) solar cells and modules in future. The contributions of the ETHZ group are directed: (i) on the development of CIGS solar cells on polyimide and mini-modules in collaboration with ZSW, Stuttgart; (ii) development of a low temperature (450 °C or lower) CIGS deposition process and a method for controlled and reliable incorporation of Na in CIGS for high efficiency solar cells.

Studies were performed to investigate the influence of Na on CIGS layers and cell depending on method of Na incorporation. A novel post deposition treatment (PDT) method (patent applied) for controlled incorporation of Na in CIGS was developed. Our results suggest that In–Ga interdiffusion is hindered by Na primarily at high substrate temperatures, while at lower temperatures the interdiffusivity is low with or without Na. Cu diffusion in (Cu-poor) CIGS films is also slowed down by Na, but this effect becomes obvious only at low substrate temperatures. When the CIGS growth temperature is lowered to a critical level, such as to 370 °C in our experiment, the impeding influence of Na becomes apparent: A homogeneous Cu distribution cannot be established anymore in absorbers directly grown on soda lime glass (SLG), while PDT absorbers still lead to working cells. With increasing substrate temperatures, the energy barriers for Cu (and In, Ga) diffusion induced by Na can be overcome better due to the higher thermal energy, which leads to higher efficiencies for cells on SLG as the crystal quality increases. Maximum efficiencies achieved with PDT absorbers grown at temperatures of 400 °C and 370 °C are 13.8 % and 12.4 %, respectively are among the highest reported for such low growth temperatures.

The advantage of this novel PDT method for flexible solar cells on polymer substrates is demonstrated by developing world record efficiency (13.2% followed by 14.1%) flexible solar cells on polymer foils. Monolithically interconnected flexible CIGS mini-modules on 5 x 5 cm^2 polymer foils were developed in collaboration with ZSW Stuttgart.

Introduction and project objectives

Polycrystalline Cu(In,Ga)Se2 (called CIGS) thin film solar cells are important because of very high efficiency, long term stable performance, and their potential for low cost generation of solar electricity. Flexible and lightweight solar cells are interesting for a variety of terrestrial and space applications. Integration of flexible CIGS solar modules in buildings (roofs and facades) is an emerging field, while roll-to-roll manufacturing of solar modules has a potential to significantly reduce the cost, provided some key problems are solved.

The objective of this EU project is to develop processes leading towards roll-to-roll manufacturing of flexible CIGS solar cells and modules in future. The contributions of the ETHZ group are directed: (i) on the development of CIGS solar cells on polyimide and mini-modules in collaboration with ZSW; (ii) development of low temperature (450 C or lower) CIGS deposition process and a method for controlled and reliable incorporation Na in CIGS for efficiency improvement.

Short description of the project

High efficiency thin-film solar cells based on polycrystalline CIGS require the incorporation of typically 0.1at.% of sodium into the CIGS absorber layers. Most often, Na is introduced during CIGS growth by diffusion either from a soda-lime glass (SLG) substrate through the Mo back contact or from a thin Na containing precursor layer deposited prior to CIGS growth. In the first case, controlled Na incorporation can be difficult due to variations in the properties of the SLG, while in the second the precursor thickness is crucial, since sufficient Na supply has to be ensured while avoiding delamination. For flexible solar cells, preferred substrates are metal and polyimide foils, which in general do not contain Na and for which low temperature growth processes are important. Na addition in optimum amounts is needed for optimisation of devices grown on such Na-free substrates, which may be automatically fulfilled when Na is in-diffused after CIGS growth.

A comprehensive investigation of the role of Na and its incorporation method was performed in this project. The presence of Na during growth leads to electronically and often also structurally modified CIGS layers. However, we observed typical electronic Na effects also when Na was in-diffused into Na-free CIGS absorbers using a post-deposition treatment (PDT). The application of the PDT led to high cell efficiencies especially at low growth temperatures of 400 and 450 °C. No consequences of post-deposition Na incorporation on microstructural properties of CIGS were discernible, which suggests that generally the *main* contributions to Na-induced cell improvements arise from electronic rather than from structural effects of Na. However influences on composition (Ga/In ratio) grading across layer thickness were measured (collaboration with IPE Stuttgart).

Flexible solar cells on commercial polyimide film (UPILEX) were developed with this novel PDT method (patent applied) and highest record efficiencies were achieved. Laser scribing and patterning methods developed by our project partner, ZSW, Stuttgart were applied to solar cells layers grown at ETHZ. First monolithically interconnected mini-modules were developed in collaboration with ZSW.

Work and results

Development of solar cells

During this year we performed experiments to compare performances of cells made from post-deposition-treated absorbers with cells prepared from absorbers grown with Na diffusing from the SLG substrates. Such absorber pairs were prepared at various substrate temperatures. Since the main electronic effects of Na can be expected to be similar in both kinds of absorbers, we obtain an indication of the importance of structural Na effects. For simplicity, Na incorporated by the two methods will be referred to as “PDT Na” and “SLG Na”, and cells prepared from the two kinds of absorbers are abbreviated as “PDT cells” and “SLG cells”.

CIGS layers of about 2 µm in thickness were grown by evaporation of the constituent elements with the 3-stage process on Mo/Al_2O_3/SLG (for PDT cells) or Mo/SLG (for SLG cells). The Al_2O_3 layer served as a diffusion barrier for Na (and K) from the SLG substrate, such that PDT absorbers were prepared in the absence of Na. During the first stage of the CIGS deposition process, the substrate temperature was kept at 400 °C, while during the second stage, the maximum substrate temperature $T_{sub,max}$ remained at 400 °C or rose to 450, 500, 540, or 580 °C. In addition, some absorbers were grown with 370 °C substrate temperature throughout the process. Immediately after cooldown of the samples, the PDT was applied (*in situ)*: Onto PDT absorbers, approx. 30 nm of NaF were deposited, while SLG absorbers were shielded from NaF exposure. Then the absorber pairs were annealed, still in vacuum, at 400 °C for 20 min, except for the absorbers prepared at $T_{sub,max}$ = 370 °C, which were annealed at 370 °C.

Solar cells were processed from these absorber pairs by chemical bath deposition of CdS buffer layers, rf sputtering of i-ZnO/ZnO:Al front contacts, and evaporation of Ni/Al contact grids. No anti-reflection coatings were applied. For evaluation of cell performance under simulated AM1.5 illumination, averaged values of typically 12–14 cells per sample were used. Cells with very atypical characteristics were excluded from the statistics.

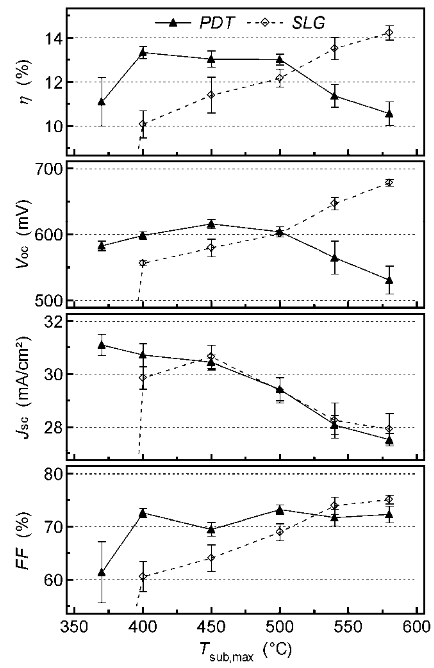

Figure 1: Dependence of (absolute) J–V parameters of PDT and SLG cells on maximum substrate temperature. Displayed are mean values and standard deviations of typically 12–14 cells per data point.

Properties of solar cells

The parameters of the SLG cells (Fig. 1) show an approximately linear increase in average efficiency from 10.1 to 14.2 % for $T_{sub,max}$ increasing from 400 to 580 °C. The improvement arises from increasing open-circuit voltage (V_{oc}) and fill factor (*FF*), while the short-circuit current (J_{sc}) decreases. In contrast, the average efficiencies of PDT cells decrease slightly from 13.3 % at 400 °C to 13.0 % at 500 °C, followed by a drop towards 10.6 % at 580 °C. While *FF* remains fairly constant, V_{oc} first increases and then decreases with $T_{sub,max}$ and J_{sc} decreases constantly. SLG cells grown at 370 °C were shorted. Corresponding PDT cells resulted in efficiencies around 11 % or were shorted as well for currently unclear reasons. Maximum cell efficiencies obtained from PDT cells were 13.8 % (12.4 %) with $T_{sub,max}$ = 400 °C (370 °C), and 14.9 % from SLG cells prepared at $T_{sub,max}$ = 580 °C. The efficiencies of the low-temperature-grown PDT cells are among the highest reported in the literature for such low substrate temperatures.

Thus, PDT cell performance, in comparison with SLG cells, is inferior at high, similar at medium, and superior at low $T_{sub,max}$ (see Fig. 2). The differences in J_{sc} are negligible, which is in accordance with previous experiments, where the effects of Na did not influence J_{sc} either [2]. In contrast, V_{oc} (especially at high $T_{sub,max}$) and *FF* (especially at low $T_{sub,max}$) are affected differently by the different Na incorporation methods.

Capacitance–voltage measurements performed on SLG and PDT cells grown at 400 °C yielded differences in the carrier concentrations of the absorbers of about half an order of magnitude (3.1×10^{15} cm^{-3} for SLG cells, 1.8×10^{16} cm^{-3} for PDT cells), which can be calculated to improve V_{oc} by about 45 mV for the case of dominating recombination in the space-charge or in the quasi-neutral region of the absorber. This agrees well with the measured average difference in V_{oc} of 42 mV.

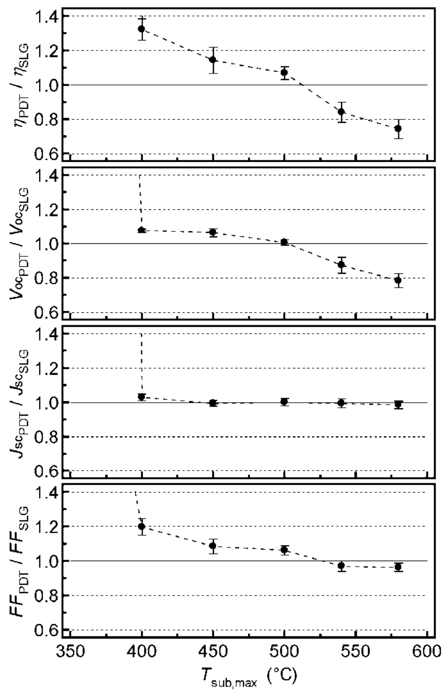

Figure 2: Substrate temperature dependence of J–V parameters of PDT cells relative to those of SLG cells. The data is calculated from the mean values and standard deviations shown in fig. 1.

The shapes of the current density–voltage (*J–V*) curves of PDT cells (Fig. 3) are little influenced by $T_{sub,max}$, with no indications of a current blocking effect at bias voltages exceeding V_{oc}. Only the cells prepared at 370 °C have slightly worse parallel and series resistances. In contrast, mainly for low $T_{sub,max}$ (400 and 450 °C), SLG cells exhibit slight current blocking. This roll-over is not as pronounced as in Na-free cells, where it was attributed to Se loss during the annealing step of the PDT. Hence, the presence of Na in CIGS films and/or on CIGS surfaces suppresses the current blocking effect at least to some extent. Since Se atoms that are bonded less strongly will have a higher probability to desorb, an increased number of grain boundaries (or a generally poorer material quality) could enhance Se loss from or via grain boundaries. Na might “stuff” the grain boundaries to some extent, impeding the diffusion of Se along them. Furthermore, when Na chemically passivates the CIGS grain boundaries and surfaces (e.g. by passivating dangling bonds), the activation energy needed to remove a Se atom from a grain may be increased.

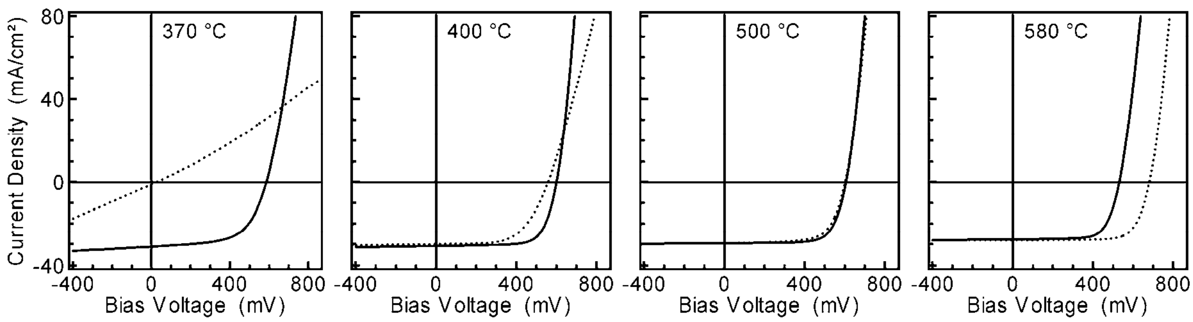

Figure 3: J–V characteristics of PDT (solid lines) and SLG (dotted lines) cells prepared at different substrate temperatures. Displayed are averaged J–V curves representing typical cell behaviour.

Influence on composition gradient

The Ga/In concentration ratio, and therewith also the band gap, varies through the absorbers (Fig. 4): A notch is observed with SIMS about 400 to 500 nm below the surface, which originates most probably from “spontaneous band-gap grading” inherent to the 3-stage process. The In and Ga depth profiles are comparable in shape for all absorbers grown at $T_{sub,max} \leq 450$ °C. At higher $T_{sub,max}$, the notches are more shallow, probably due to enhanced In–Ga interdiffusion during CIGS growth, but in PDT absorbers, the depth profiles are always more smoothed than in respective SLG absorbers. This indicates that In–Ga interdiffusion at higher $T_{sub,max}$ is better in the absence of Na (i.e., in PDT absorbers), in agreement with earlier work.

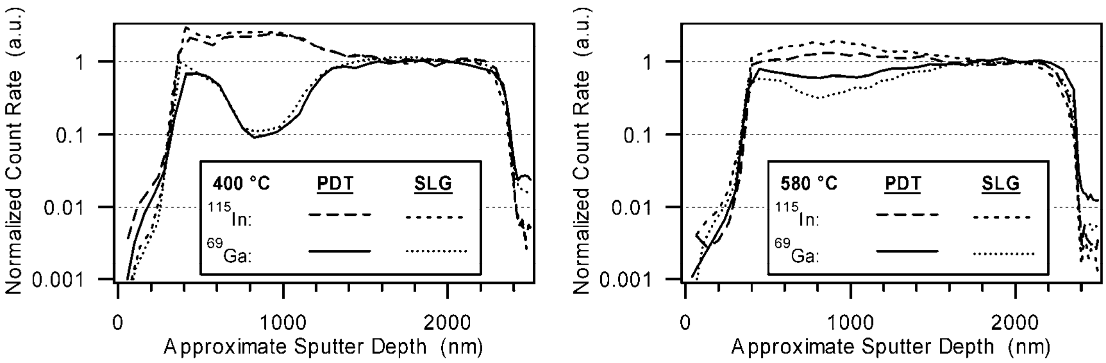

Figure 4: SIMS depth profiles (measured at IPE Stuttgart) of ^{115}In and ^{69}Ga through PDT and SLG cells grown at 400 °C (left) and 580 °C (right). For clarity, all curves have been normalized to unity at 2000 nm. The depth of the notch at about 400 nm below the CdS/CIGS interface indicates that In–Ga interdiffusion is impeded by Na at high substrate temperatures, while at low substrate temperatures the interdiffusion is slow with or without Na.

These results are supported by composition measurements of the upper parts of the absorbers by means of energy-dispersive x-ray analysis (EDX) in a scanning electron microscope (Fig. 5). We thus infer that Na slows down In–Ga interdiffusion at higher substrate temperatures, while below about 500 °C the available thermal energy does not suffice anymore to smooth the In and Ga concentration variations with or without Na.

The Cu/(In+Ga) concentration ratios in the upper parts of both kinds of absorbers, as determined with EDX, slightly increase towards higher $T_{sub,max}$ (see Fig. 5). This originates from process control, which is based on end-point detection. The origin of the small differences between the Cu concentration in PDT and SLG absorbers grown at $T_{sub,max} > 500$ °C is not understood. However, the most notable difference in Cu concentration is observed at $T_{sub,max} = 370$ °C: While the PDT absorber revealed slightly Cu-poor overall concentration, the SLG absorber yielded a Cu-rich concentration, although the amount of Cu deposited was identical for the two samples. Therefore, the SLG absorber must have an inhomogeneous Cu depth profile, with Cu excess in the upper and Cu deficiency in the lower part of the sample. The end-point detection profile for the samples prepared at 370 °C suggests that during the second stage, Cu_xSe phases appear much sooner than at higher substrate temperatures, i.e., before the *overall* composition is stoichiometric. Hence, the thermal energy at 370 °C does not suffice anymore to homogenize Cu concentration gradients in CIGS quickly enough for these film deposition rates. Obviously, the presence of Na during growth inhibits the formation of a homogeneous CIGS phase, resulting in degraded absorber quality. No working solar cell devices could be processed from these absorbers anymore, possibly because their conductivity was low or n-type or because Cu_xSe distributed along grain boundaries induced shunts.

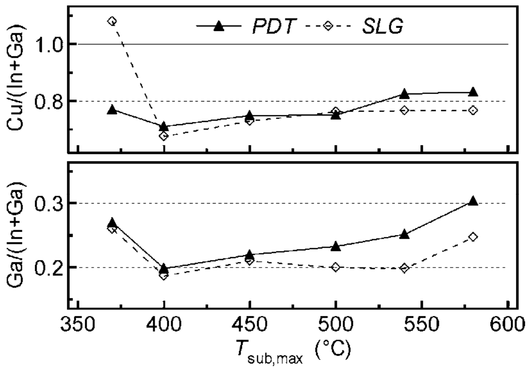

Figure 5: Compositional properties of the upper parts of PDT and SLG absorbers as measured with EDX attached to a scanning electron microscope (20 kV acceleration voltage).

Consequently, there is evidence that not only In and Ga diffusion is impeded by Na in CIGS films, but also the Cu diffusion. It may be interesting to note that with (In-free) CGS, but at a higher $T_{sub,max}$ of 450 °C, results corresponding to those of the described (In-containing) CIGS films prepared at 370 °C were obtained. The origin of this behaviour is probably that a higher thermal energy is required to form CGS, as is expected from its higher melting point.

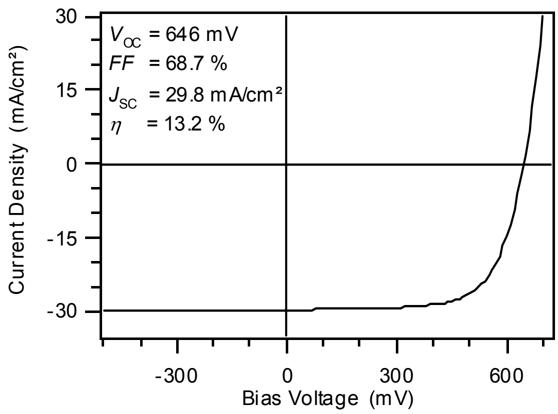

Figure 6: J–V characteristics of a flexible CIGS solar cell on polyimide foil (measured under AM1.5 illumination at ZSW). Na was incorporated into the CIGS using the post-deposition treatment. Recently higher efficiency (14.1%) cells were developed, as presented in the BFE project (FLEXCIM) report.

Flexible solar cells and mini-modules on polyimide film

The method of post-deposition Na incorporation was applied for processing flexible CIGS solar cells on polyimide substrates. Using Upilex foils and $T_{sub,max}$ = 460 °C, a cell efficiency of 13.2 % was measured under simulated AM1.5 conditions at ZSW, Stuttgart (V_{oc} = 646 mV, FF = 68.7 %, J_{sc} = 29.8 mA/cm², total area = 0.595 cm²; no anti-reflection coating; see Fig. 6). This was the highest reported efficiency until recently when we achieved a further improvement in cell efficiency to 14.1% (please see BFE project report for details).

Figure 7: Monolithically interconnected flexible CIGS mini-modules on polyimide developed in collaboration with ZSW.

We don't have laser scribing facilities in our group while project collaborator ZSW has developed the methods of laser scribing and patterning of different layers to develop monolithic modules. In collaboration with ZSW first monolithically interconnected CIGS mini-modules on polyimide films were developed for CIGS layers grown at ETHZ (see figure 7).

National and international collaboration

The partners of the METAFLEX project are: ZSW-Stuttgart (D), Würth Solar (D), Stuttgart University (D), CIEMAT (E), INASMET (E), ISOVOLTA (A), ETHZ (CH).

Evaluation-2004

Post-deposition Na in-diffusion into CIGS is a means to profit from electronic Na effects while excluding influences of sodium on the growth kinetics. The presented comparison of the performances of SLG and PDT cells allows to draw some conclusions about the importance of structural Na effects: With low CIGS growth temperatures, PDT cells perform better than SLG cells due to a delaying influence of Na on CIGS phase formation. This is inferred from the observed Na-induced impediment of the reaction of Cu_xSe with Cu-poor CIGS and of In–Ga interdiffusion. With high CIGS growth temperatures, the efficiencies of SLG cells are superior to those of PDT cells. Since highest cell efficiencies were achieved with SLG absorbers grown at high substrate temperatures, the Na-induced modifications of CIGS growth kinetics might become beneficial once a certain threshold substrate temperature is exceeded. Reasons for the decreasing efficiencies of PDT cells with increasing growth temperature are suggested to be less effective passivation of defects with the employed PDT procedure and less favourable band-gap grading. An optimized PDT might improve the quality of absorbers grown at higher substrate temperatures.

Maximum efficiencies achieved with PDT absorbers grown at temperatures of 400 °C and 370 °C are 13.8 % and 12.4 %, respectively. These values are among the highest reported for such low growth temperatures. Hence, post-deposition Na incorporation is a promising method particularly for the development of flexible solar cells on polymer substrates. This is proven by developing world record efficiency (13.2% followed by 14.1%) flexible solar cell on polymer foils. Monolithically interconnected flexible CIGS mini-modules on 5 x 5 cm^2 polymer foils were developed in collaboration with ZSW Stuttgart.

Publications and conference presentations

[1] D. Rudmann, A.F. da Cunha, G. Bilger, M. Kaelin, F. Kurdesau, H. Zogg and A.N. Tiwari, ***Efficiency enhancement of Cu(In,Ga)Se_2 solar cells due to post-deposition Na incorporation***, Accepted for publication in Applied Physics Letters, 84, 1129, 2004.

[2] F. Kessler and D. Rudmann, ***Technological Aspects of Flexible CIGS Solar Cells and Modules***, To be published in Solar Energy, 2004 (**Invited paper**).

[3] D. Rudmann, D. Brémaud, A.F. da Cunha, G. Bilger, A.Strohm, M. Kaelin, H. Zogg and A.N. Tiwari, ***Sodium incorporation strategies for CIGS growth at different temperatures,*** Accepted for publication in Thin Solid Films 2004.

[4] D. Rudmann, D. Brémaud, H. Zogg and A.N. Tiwari, ***Na incorporation for low temperature Cu(In,Ga)Se_2 growth***, Proceedings of the 19^{th} European Phototovoltaics and Solar Energy Conference, Paris, June 2004.

Annual Report 2004

New buffer layers for efficient chalcopyrite solar cells (NEBULES)

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Project- / Contract Number	BBW-NR. 02.0074 / EU PROJECT ENK6-CT-2002-00664
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.

It is known that high efficiency thin-film solar cells based on $Cu(In,Ga)Se_2$ (CIGS) are obtained using CdS buffer layers grown by chemical bath deposition (CBD). The highest efficiencies achieved with CdS buffer layers produced by physical vapor deposition (PVD) are significantly lower. To find reasons for this difference, structural and chemical properties of CBD- and PVD-CdS buffer layers and their interfaces with CIGS were investigated by means of bright-field, high-resolution and energy-filtered transmission electron microscopy, and also by energy-dispersive X-ray spectroscopy and scanning electron microscopy. By means of EDX, oxygen-containing surface layer could be measured at the CIGS/PVD-CdS interface, whereas such a layer could not be detected at the CIGS/CBD-CdS interface. A large defect density was detected at the PVD-CdS/CIGS interface, which is attributed to the larger lattice mismatch than at the CBD-CdS/CIGS interface. Cu diffusion from CIGS into CdS was found for the CBD- and the PVD-CdS sample. The PVD-CdS/CIGS interface turned out to be quite abrupt, whereas the CBD-CdS/CIGS interface is rather diffuse. The differences in efficiencies of solar cells with CBD- and PVD-CdS buffer layers can partly be explained by referring to the higher defect density and the probable absence of an inversion of the near-interface region from p-type to n-type at the PVD-CdS/CIGS interface.

Structural and chemical studies of interfaces between CIGS and In_2S_3 layers for application in Cd-free thin-film solar cells were investigated. The In_2S_3 layers were deposited by atomic layer deposition on CIGS layers at substrate temperatures ranging from 140°C to 240°C. Interfaces were investigated by means of scanning electron microscopy, bright-field and high-resolution transmission electron microscopy, electron diffraction, and energy-dispersive X-ray spectrometry. With increasing deposition temperature, the grain size distribution becomes sharper, whereas the grain size itself increases only slightly. An orientation relationship between CIGS-{112} and In_2S_3-{103} planes was found for the sample deposited at 210°C, whereas no orientation relationship was detected for the 240°C sample. Cu diffusion from CIGS into In_2S_3 was detected, as well as Cu depletion and In enrichment on the CIGS side of the interface. All three effects are enhanced with increasing deposition temperature. These results indicate the formation of a p-n homojunction in the CIGS layer.

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 can protect the CIGS surface from ion damage during the ZnO sputtering; it can reduce the shunting paths and may 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 nano- scopic characterisation is important. This can help to understand why chemical bath deposited CdS buffer layers yield higher efficiencies than the vacuum evaporated buffer layers.

One of the reasons to search for an alternative of CdS buffer is to minimise the absorption loss in the buffer layer. Therefore, wide band gap (> 2.4 eV) semiconductors are being investigated to substitute CdS layer in CIGS solar cells. Recently, in collaboration between 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). Structural and chemical properties of the CIGS/ALD-In_2S_3 interfaces have not yet been investigated in detail, especially in view of the effects of the deposition conditions of the buffer layers. In collaboration with ZSW Stuttgart we have started investigation of the structural properties of the In_2S_3 buffer layers and In_2S_3–CIGS interfaces grown under different conditions.

Work and results

Interface properties of CIGS solar cells with PVD- and CBD-CdS

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, the Ni/Al grids were evaporated for electrical contacting.

The CBD process for CdS deposition is very attractive owing to high solar conversion efficiencies. For industrial production, though, an in-line vacuum deposition as, e.g., physical vapor deposition (PVD), is preferred. However, the highest efficiencies achieved by PVD-CdS buffer layers hardly exceed 13 %. Always, a clearly poorer photovoltaic performance of solar cells with PVD-CdS buffer layers than of solar cells with CBD-CdS buffer layers was found. To understand the reasons for the difference in the solar-cell performance between CdS buffer layers produced by these two methods, CIGS/CBD-CdS and CIGS/PVD-CdS interfaces have been studied by means of scanning electron microscopy (SEM), transmission electron microscopy (TEM) and energy-dispersive X-ray spectrometry (EDX).

PVD-CdS layers show much larger grain sizes than CBD-CdS layers, and also a higher defect density at the CIGS/PVD-CdS interface, owing to a larger lattice mismatch These defects may affect the photovoltaic performance. For the case of PVD-CdS, the interface to the CIGS is quite abrupt, whereas on the CIGS side of the CBD-CdS/CIGS interface Cu depletion and Cd enrichment may have occurred (see Fig. 1). Cu in CdS increases its photoconductivity, and Cd can occupy Cu vacancies.

These defects may affect the photovoltaic performance. For the case of PVD-CdS, the interface to the CIGS is quite abrupt, whereas on the CIGS side of the CBD-CdS/CIGS interface Cu depletion and Cd enrichment may have occurred (see Fig. 1). Cu in CdS increases its photoconductivity, and Cd can occupy Cu vacancies. The results of the Cu and In interdiffusion provide an indication of an inversion of the near-interface region from p-type CIGS to n-type. The probable absence of this inversion in solar cells with PVD-CdS buffer layers is a possible reason for their lower efficiencies compared with solar cells with CBD-CdS buffer layer.

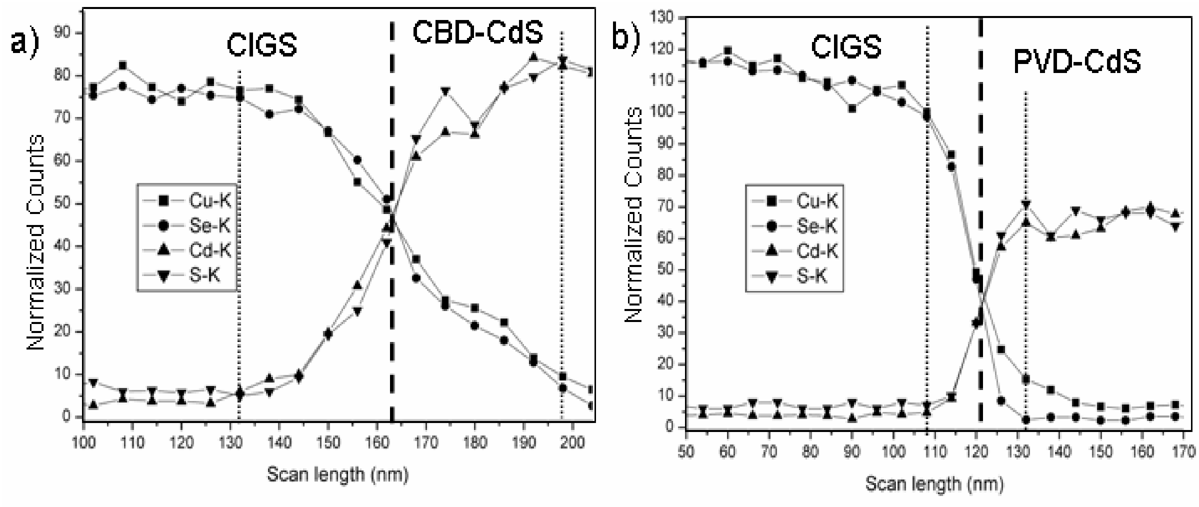

Fig. 1: Linear elemental distribution profiles across the CIGS/CdS interface extracted from elemental mappings, obtained by energy-dispersive X-ray spectrometry. For the CBD-CdS sample (a), there is Cu depletion and an increase of the Cd signal visible on the CIGS side of the interface, whereas no such behavior could be found for the PVD-CdS sample (b). The interface between CIGS and CdS is shown by the dashed-line, whereas the dotted lines estimate the transition interfacial region. The Cu-K signals were normalized to the Se-K level on the CIGS side in order to provide an easier comparison.

CIGS solar cells with In_2S_3 buffer layers

Within the frame of the present project, In_xS_y buffer layers deposited by atomic layer deposition (ALD) and physical vapor deposition (PVD) and their interfaces to CIGS have been studied. Recently, solar cells with ALD-In_2S_3 buffer yielded more than 16% efficiency. Besides ALD, also physical vapor deposition (PVD) is used to produce In_xS_y buffer layers, and efficiencies of over 14% have already been obtained (Ref. 6 of the publications in the frame of the research project). ALD-In_2S_3 samples were provided by the Zentrum für Sonnenenergie- und Wasserstoffforschung (ZSW), Stuttgart, Germany. PVD-In_xS_y samples were produced at the Stuttgart University, Germany.The optimum substrate temperature for the ALD-In_2S_3 buffer deposition has been determined to be approx. 210°C. For lower substrate temperatures, efficiencies are increasing with increasing temperature. To understand the reasons for this behavior, the samples were studied by means of transmission electron microscopy (TEM) and energy-dispersive X-ray spectrometry (EDX).

Linear elemental distribution profiles, extracted from EDX elemental mappings on CIGS/In_2S_3 interfaces, are shown in Fig. 2 for the 170°C, the 210°C and the 240°C samples. The dashed lines indicate the positions of the CIGS/In_2S_3 interfaces, given by the crossover of the Se and the S signals; these two elements did not show any change in all samples investigated, thus they are considered to interdiffuse only to a negligible extent. The linear profiles reveal a strong Cu and a slight Ga diffusion from the CIGS into the In_2S_3 layer. The extent of diffusion increases with increasing deposition temperature. In addition to the Cu and Ga diffusion, a depletion of Cu and an enrichment of In are visible on the CIGS side of the interface. Depletion and enrichment are also enhanced with increasing deposition temperature. Cu diffusion and occupation of In-sites in the In_2S_3 layer may occur near the CIGS/In_2S_3 interface, in addition to the Cu depletion and In enrichment on the CIGS side of the interface, which indicates that In might occupy Cu vacancies. These assumptions would imply the inversion of the near-interface region of CIGS from p-type to n-type. The inverted region becomes broader with increasing deposition temperature, which seems to have a beneficial effect on the junction formation. Thus, the cell performance improves.

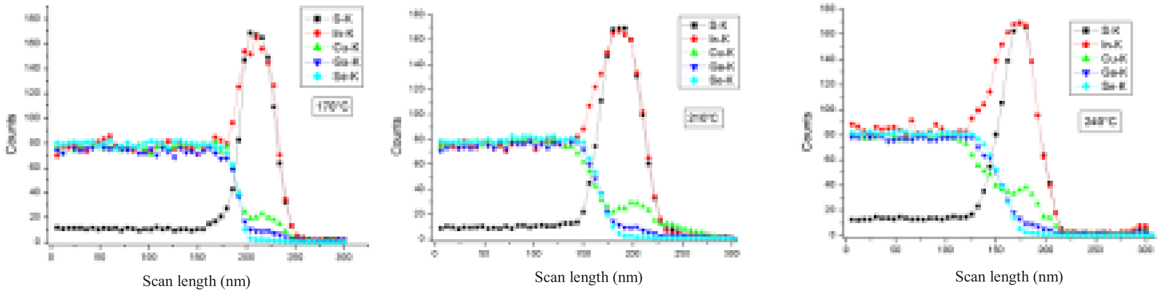

Fig. 2: Linear elemental distribution profiles, extracted from elemental mappings on interfaces of CIGS with In_2S_3 deposited at 170, 210 and 240°C.

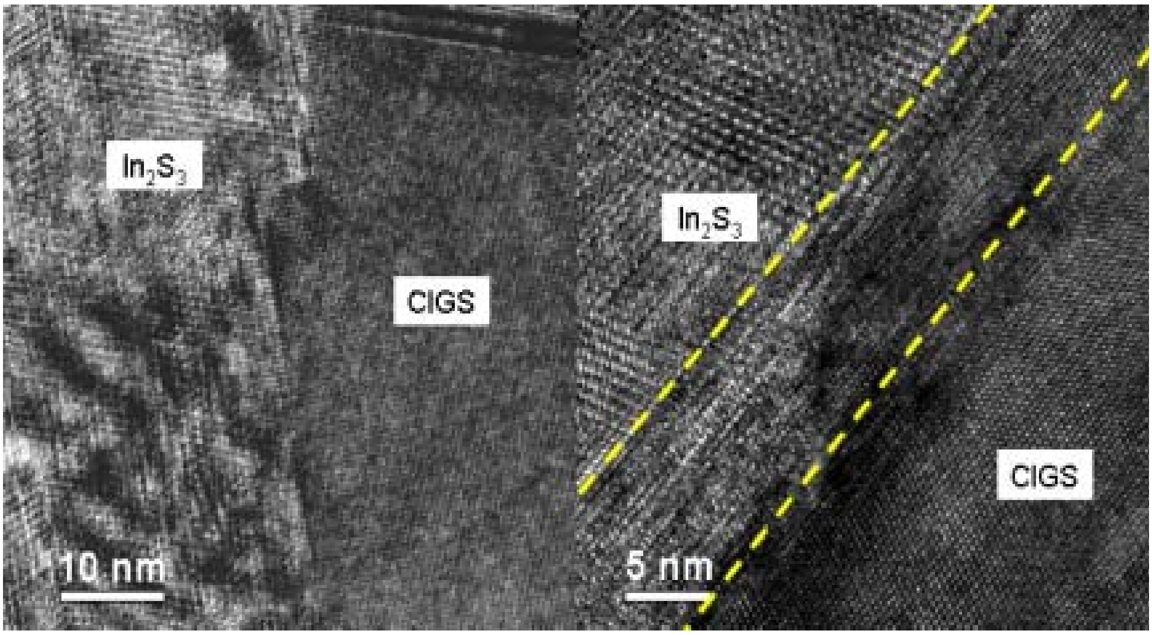

Fig. 3: High-resolution transmission electron micrograph from the interface of CIGS with In_2S_3 layers grown at 210°C and 240°C. While there is a good lattice match between In_2S_3 and CIGS for the 210°C sample, a phase is formed between CIGS and In_2S_3 in the 240°C sample.

The HRTEM images from the CIGS/In_2S_3 interface of both the 210°C and the 240°C samples (Fig. 3) show an abrupt interface. In contrast to the 210°C In_2S_3/CIGS interface, at the 240°C In_2S_3/CIGS interface an additional layer of about 10 nm thickness is revealed between In_2S_3 and CIGS. The additional layer was too thin to determine its phase (e.g., by means of electron diffraction). However, at interfaces between CIGS and PVD-In_2S_3 deposited at 300°C, a similar intermediate layer was found (Fig. 4). There, the thickness of this layer was large enough to identify the phase as $CuIn_5S_8$, which is an n-type semiconductor and has a band-gap energy of ca. 2.0 eV. Assuming that the thickness of this intermediate $CuIn_5S_8$ layer increases with further increasing substrate temperature, it will ruin completely the p-n junction of the solar cell and thus deteriorate the solar-cell performance for substrate temperatures larger than 240°C.

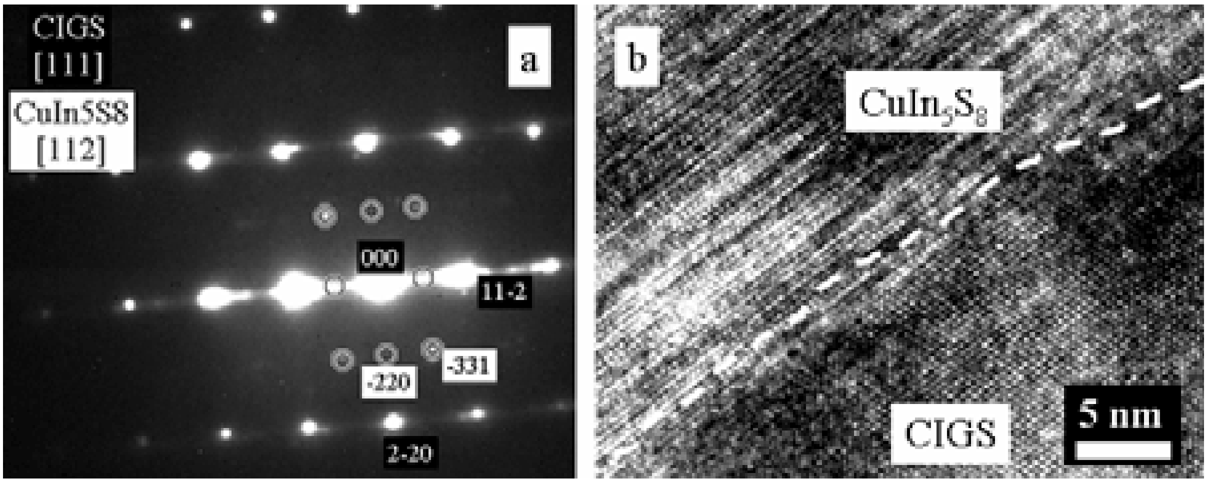

Fig. 4: Electron diffraction pattern (a) and high-resolution transmission electron micrograph (b) of a CIGS/$CuIn_5S_8$ interface in a CIGS solar cell with PVD-In_2S_3 deposited at 300°C.

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). Collaloborations with the group of Prof. G. Kostorz (IAP, ETHZ).

Evaluation 2004 and outlook 2005

Work was performed as planned in the proposal. Reasons have been found to explain partly the significant differences in efficiency between solar cells with CBD-CdS and PVD-CdS buffer layers (3-4%, in general). If the CIGS is exposed to air for sufficiently long time an oxide surface layer is formed. A comparative study of the interface properties of CIGS solar cells with CBD- and PVD-CdS buffer layers has clarified that the chemical bath deposition can *in-situ* etch away the surface oxide layer of CIGS prior to the deposition of the buffer layer. The chemical bath deposition not only “cleans” the CIGS surface, but the resulting layer may be more suitable for band alignment with CIGS.

ALD-In_2S_3/CIGS interfaces have been intensively studied, and a better understanding of the interface formation for different substrate temperatures is achieved. It appears that for substrate temperatures higher than ca. 220°C, the formation of $CuIn_5S_8$ deteriorates the CIGS/ALD-In_2S_3 and also the CIGS/PVD-In_xS_y interface and therefore the solar-cell performance.

In conclusion, probably a reasonable density of vacancies in the buffer layer (as it is the case for In_2S_3 and other In_xS_y crystal structures) allows a strong Cu diffusion from CIGS into the buffer layer, and also the diffusion of cations (e.g., In^{3+}) from the buffer layer into CIGS, which finally leads to the inversion of the near-interface region of CIGS from p-type to n-type. This inversion seems to have a beneficial effect on the solar-cell performance.

For 2005, it is planned to study the interfaces between CIGS and sputtered In_xS_y layers, provided by ZSW. The microstructural and chemical properties of these interfaces can be directly compared to the properties of CIGS/ALD-In_2S_3 and CIGS/PVD-In_xS_y interfaces. Also, in cooperation with the Uppsala University, CIGS/ALD-Zn(O,OH,S) interfaces will be investigated. These results will provide a larger overview of promising candidates for buffer layer materials in high efficiency CIGS solar cells.

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 2004

Dye - sensitised Nanocrystalline Solar Cells

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Project- / Contract Number	EPFL ; EPFL-V
Duration of the Project (from – to)	January – December 2004

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. 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.

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. Significant progress has been made during the past year, particularly in regard to thermal stability.

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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 EPFL in this area 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, 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

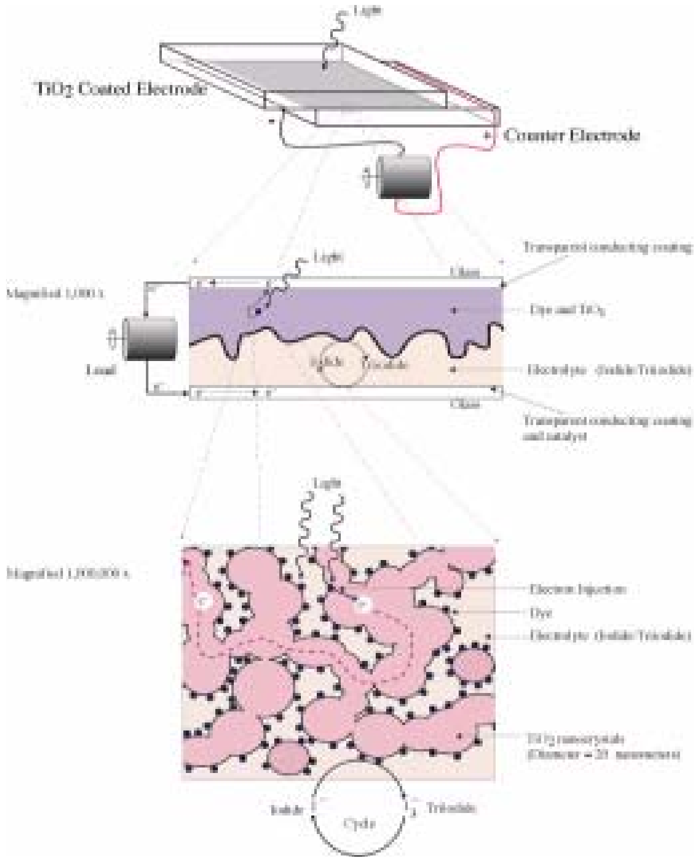

Fig.1: Structure of dye-sensitised photoelectrochemical cell on different scales. (Top): a complete cell (centimeter scale). (Centre): electrodes and electrolyte, micron scale. (Bottom) nanoscale semiconductor interconnected porous layer, with adsorbed monolayer of dye and entrained electrolyte.

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 cristallite of the 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 in contact 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.

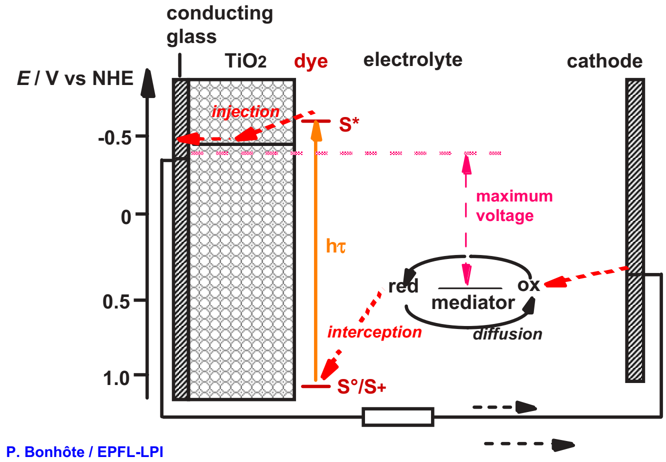

Fig.2: charge transfer mechanisms in the dye-sensitised nanocrystalline photoelectrochemical cell. The sensitiser (S) is excited by the energy of the absorbed photon, then relaxes by electron injection into the semiconductor layer. The charged dye molecule is neutralised by the redox system, itself regenerated at the counterelectrode by electrons passed through the load. Potentials are referred to the standard calomel electrode (SCE).

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.

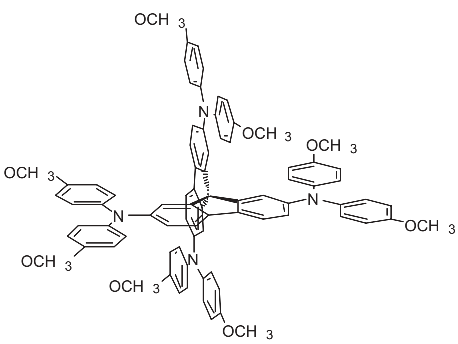

Figure 3: structure of spirobifluorene hole-conducting p-type organic semiconductor. The flourene structures are perpendicular, conjoined through a carbon site common to both.

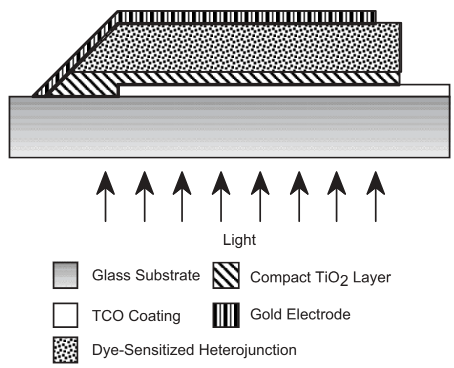

Figure 4: Schematic of the dye sensitized heterojunction PV cell.

Ongoing Work and Results 2004

Considerable attention has been given to the details of the dye molecular structure in order to optimise its optical properties and its compatibility with the electrolyte and the semiconductor substrate. Subtle variations of structure can have significant effects on both of these parameters. The preferred dye for this development programme remains the "N3"-type, bis (2,2'-bipyridine-4,4'-dicarboxylic acid) ruthenium (II) $(NCS)_2$. Fig. 5 presents as an example the difference in optical absorption spectra between the *cis-* and *trans-* forms of this dye (3).

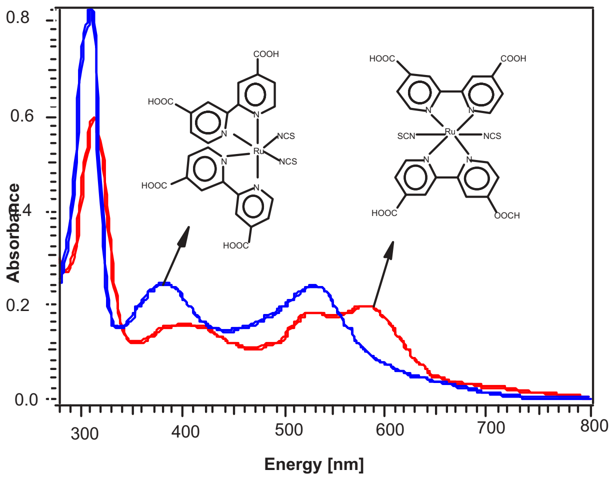

Fig.5: UV-visible absorption spectra of *cis-* and *trans-*bis(2,2'-bipyridine-4,4'-dicarboxylic acid) ruthenium (II) $(NCS)_2$, or N3-type, complexes.

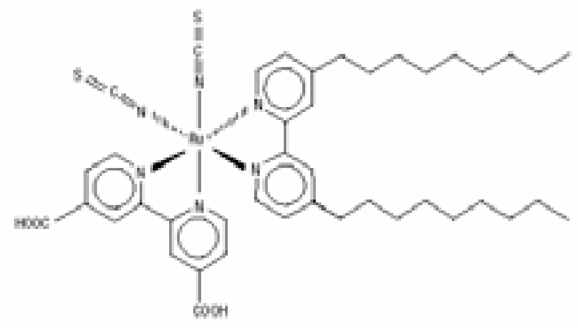

Fig.6: Structure of the amphiphilic dye Z-907, (*cis*-Ru(H_2dcbpy)(dnbpy)(NCS)2, where the ligand H_2dcbpy is (4,4'-dicarboxylic acid-2,2'-bipyridine) and dnbpy is (4,4'-dinonyl-2,2'-bipyridine)

To enhance the temperature range tolerated by the sensitised PV system , there has been attention to the synergy of a modified dye associated with a polymer gel electrolyte. The photoactive molecule is modified by the substitution of hydrocarbon chains for the carboxyl groups on one of the bipyridyl components of the molecule. The consequent hydrophobic action suppresses the effect of any water contaminant in the organic electrolyte. As an example of dye molecular engineering, the molecule (laboratory code Z-907) shown in Fig. 5 has of course the two bipyridyl ligands bonded to ruthenium to establish photosensitivity; two thiocyanide ligands to broaden the spectral response; two carboxyl groups to chemisorb to the semiconductor oxide surface; and finally two hydrocarbon chains to present a hydrophobic surface to the electrolyte, thereby rejecting contaminant water. The consequence of this structure is the self-assembly of a monomolecular dye layer of specific orientation to provide the required physical properties, uniformly chemisorbed on the nanostructured semiconductor surface. The electrolyte used with it has modified rheological properties due to the addition of a gelating agent, a photochemically stable fluorine polymer, poly(vinylidenefluoride-*co*-hexafluoropropylene (PVDF-HFP), which was used to solidify a 3-methoxypropionitrile (MPN)-based liquid electrolyte to obtain a quasi-solid-state gel (6). The improved thermal tolerance is indicated in fig.7.

Other recent technical developments include attention to the physical properties of the electrolyte (4) enabling the fabrication of a stable, ≥8% efficient nanocrystalline dye-sensitized solar cell based on an electrolyte of low volatility.

National Cooperation

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

Fig. 7: Toyota "Dream House" with DSC windows (ground floor) through Toyota associate Aisin-Seiki, EPFL Licensee.

Fig.8: Professor Huo Yu ping, member of the Chinese Academy of Science (CAS) and Dr. Dai Sonyang, with the 500 W DSC array atthe CAS Institute of Plasma Physics, Heifei, China.

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, North America and Japan. Academically there are ongoing contacts with India, China and Korea. Consequences of these international cooperations are illustrated in figs. 7 & 8.

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Annual Report 2004

NANOMAX - dye-sensitised nanocrystalline solar cells having maximum performance

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Project- / Contract Number	NNE5-2001-00192, BBW 01.0268-2
Duration of the Project (from – to)	36 months ; 2001 - 2004

ABSTRACT

Nano-crystalline dye sensitised solar cells (DSC) are the only validated alternative to solid state junction photovoltaic cells. As such they are not only important in their own right, but serve as a useful stimulant to innovation in photovoltaics, and to PV research and development generally. World-wide, about 60 groups are engaged in a growing effort, especially in Japan. As well as an innovative concept, these cells use materials not previously investigated for PV applications. Most work in recent years on dye-sensitised solar cells has focussed on the optimisation of cells with a standard photoelectrode design, i.e. a single sensitising dye adsorbed on nano-crystalline titanium dioxide. Although great progress has been made in terms of stability, in large part due to work on electrolyte composition and sealing, progress in efficiency has proven difficult. In the NANOMAX project, coordinated by ECN, the Netherlands Energy Research Centre and sponsored by the Commission of the European Communities, there is a break with this practice. New concepts, both for cell design and in materials, are necessary to boost the efficiency from the present 8 - 10% and compete directly on efficiency grounds with silicon solid-state devices. In NANOMAX, cells with various new photoelectrode concepts and materials are fabricated and studied. In particular, cells with thinner or multiple-layer structures are investigated. The project is now terminated, with a final report now in preparation.

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Introduction

The main objective of NANOMAX is to prove that a stabilised 12% efficiency of solar to electric energy conversion is feasible for dye sensitised solar cells (DSC), if next generation cell concepts are applied. Innovative concepts, both for cell design and materials, are necessary to boost the efficiency from 8 - 10 % (1) when the programme commenced to 15% in the future. Major improvements in the photocurrent and photovoltage are required while maintaining a high fill factor. In this line of action, during the year 2004, EPFL produced evidence of an 11% efficient cell (Fig.1). We demonstrate a Ó8% efficie nct nanocrystalline dye-sensitized solar cell retaining over 98% of its initial performance after 1,000 h accelerated tests under thermal stress at 80ºC in darkness. Device degradation was negligible also during 1,000 h visible light soaking at 60°C. This h igh performance stable device was realized by using a robust electrolyte of low volatility in conjunction with the amphiphilic ruthenium sensitizer [Ru(4,4'-dicarboxylic acid-2,2'-bipyridine)(4,4'-bis(p-hexyloxystyryl)-2,2'-bipyridine)(NCS)2], coded as K-19, which was grafted together with 1-decylphosphonic acid on the mesoporous titania film acting as photoanode.

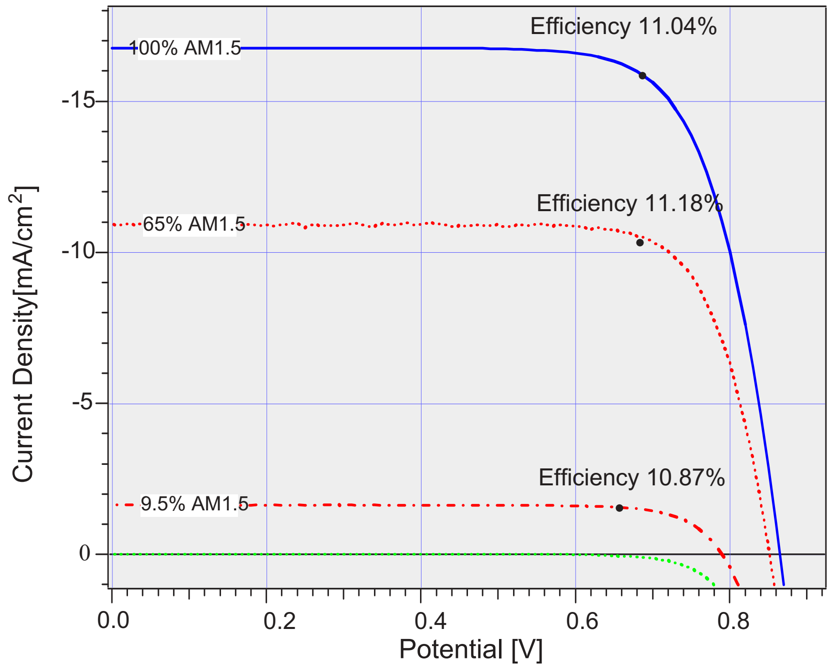

Fig.1: Photocurrent–voltage curve of a solar cell based on an electrolyte containing guanidinium thiocyanate as self-assembly facilitating agent. The sensitiser was passed three times over a Sephadex column for purification. The cell was equipped with an anti-reflecting coating. The conversion efficiency in full AM 1.5 sunlight was 11.04%. It incre ased to 11.18% under 65% AM 1.5 sunlight.

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.2, the fundamental operating unit is the organometallic dye molecule chemisorbed on the surface of a cristallite of the wide bandgap semiconductor, in this case titanium dioxide. Long experience of semiconductor photoelectrochemistry has established that the narrow-gap materials, with optoelectronic properties

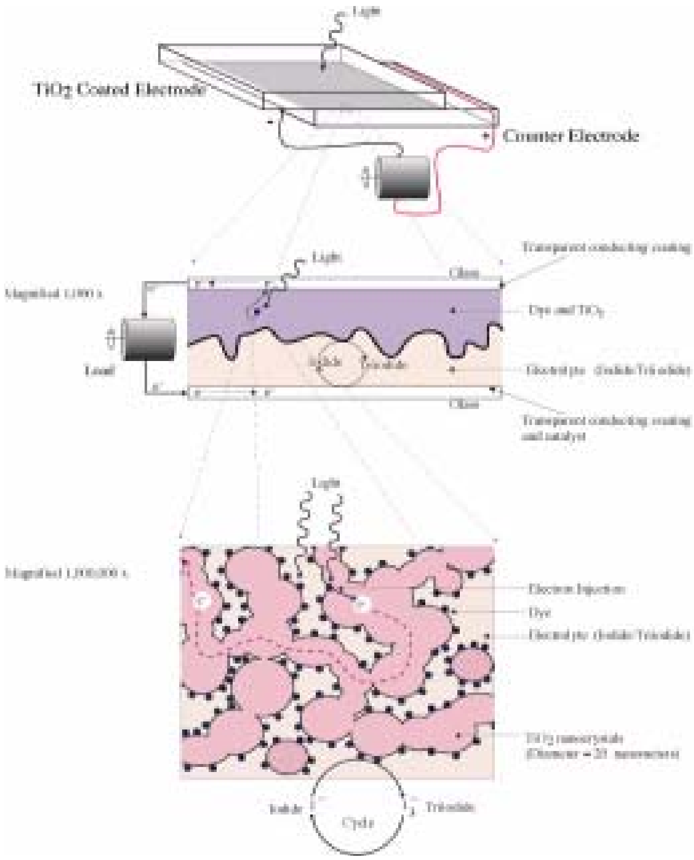

Fig.2: Structure of dye-sensitised photoelectrochemical cell on different scales. (Top): a complete cell (centimeter scale). (Centre): electrodes and electrolyte, micron scale. (Bottom) nano-scale semiconductor interconnected porous layer, with adsorbed monolayer of dye and entrained electrolyte.

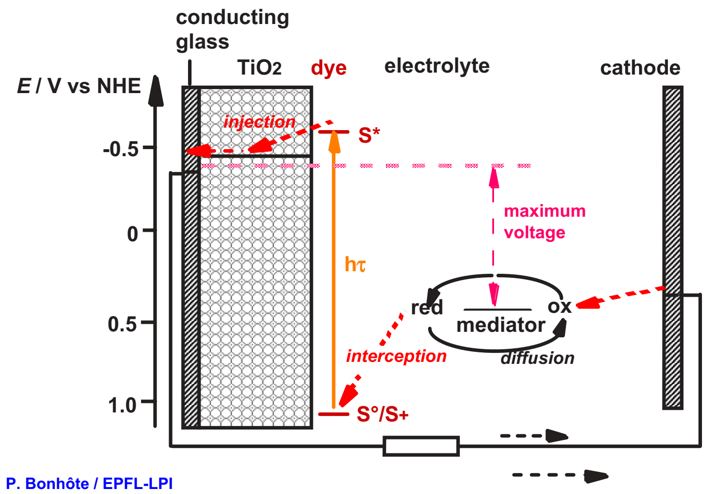

Fig.3: charge transfer mechanisms in the dye-sensitised nanocrystalline photoelectrochemical cell. The sensitiser (S) is excited by the energy of the absorbed photon, then relaxes by electron injection into the semiconductor layer. The charged dye molecule is neutralised by the redox system, itself regenerated at the counterelectrode by electrons passed through the load. Potentials are referred to the standard calomel electrode (SCE).

best adapted to solar energy conversion, are in general unstable in contact 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.3. 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. 4. The structure of the solid-state dye-sensitised heterojunction cell appears as Fig. 5.

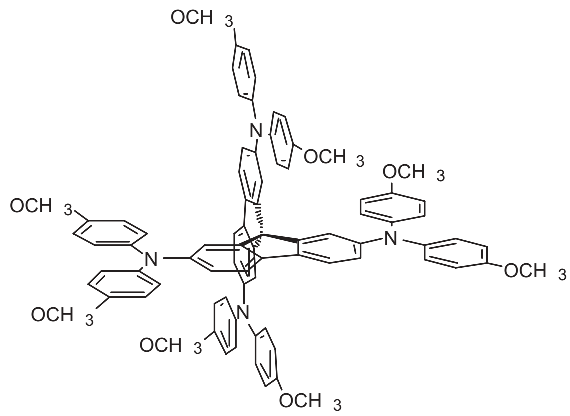

Fig. 4: structure of spirobifluorene hole-conducting p-type organic semiconductor. The flourene structures are perpendicular, conjoined through a common carbon site.

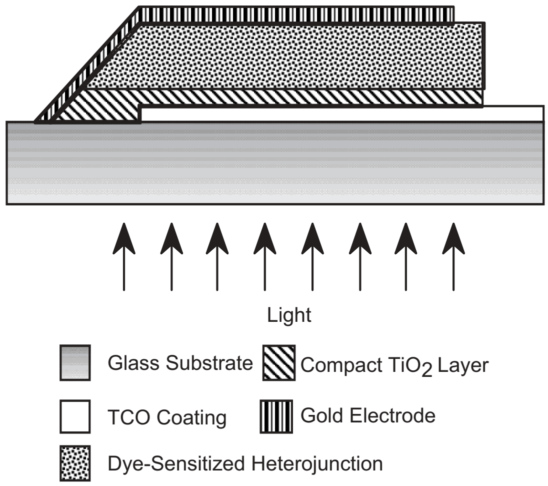

Figure 5: Schematic of the dye sensitized heterojunction PV cell.

Ongoing Work and Results 2004

Verification of a conversion efficiency > 1% in the course of the past year has already been mentioned, with the results presented in fig. 1. This was achieved particularly be optimisation of the electrolyte and the dye attachment procedure. The electrolyte contained guanidinium thiocyanate as self-assembly facilitating agent optimising the structure of the dye monolayer chemidoorbed on the nanocrystalline photoelectrode. The sensitising dye was carefully purified by passing it three times over a Sephadex column. The cell was equipped with an anti-reflecting coating. The conversion efficiency in full AM 1.5 sunlight was 11.04%. It increased to 11.18% under 65% AM 1.5 sunlight.

The stability of a cell under accelerated aging tests is also significant in validating its practical applicability particularly considering the thermal stresses associated with the outdoor environment under full sunlight. The results achieved in this area are also significant. An efficiency Ó8% for a nanocrystalline dye-sensitized solar cell also able to retain 98% of its initial performance after 1,000 h accelerated tests under thermal stress at 80°C in darkness. Device degradation was negligible also during 1,000 h visible light soaking at 60°C. This high performance and stable device was realized by using a robust electrolyte of low volatility in conjunction with the amphiphilic ruthenium sensitizer [Ru(4,4'-dicarboxylic acid-2,2'-bipyridine)(4,4'-bis(p-hexyloxystyryl)-2,2'-bipyridine)(NCS)2], coded as K-19, which was grafted together with 1-decylphosphonic acid as co-adsorbent on the mesoporous titania photoanode.

The final report on completion of the project is in preparation.

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 Communities, with the Swiss participation fiunded through OFES/BBW (Federal Office for Education and Science). Outside Europe, cooperation continues with partners in Australia, North America and Japan. Academically there are ongoing contacts with India, China and Korea.

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Annual Report 2004

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". GSA has a specific product concept – dye-sensitised electrochemical photovoltaic cells for indoor use – in the earlier programme. The stated objectives having been attained, the present action aims at increased stability, particularly at elevated operating temperatures. It aims at the up-scaling to commercial dimensions and the technology transfer to the partner industry of the necessary nanoparticle-based technologies required for the production of such dye solar cells. 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 intensiities, 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. The cells will be optimised for indoor applications. This project is a key contribution to the development of the company Greatcell Solar, providing relevant information and technology for its intended product.

Introduction

The objectives of the project were to enhance the performance 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 as well as sources. The results 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. Solvents for dye deposition and for the support of the electrolyte redox system have been evaluated, particularly for synergetic effects and a robust electrolyte with improved long-term performance is employed. Lifetime tests have given encouraging result

Technical Summary

The fundamental principles of the dye-sensitised solar cell are well established and widely reported (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 and transfer to the partner industry of the necessary materials and processes.

Ongoing Work and Results 2004

The goals of this project are the up-scaling and technology transfer of key nanoparticle-based technologies for the production of dye solar cells, which have been developed in ISIC 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 figure.

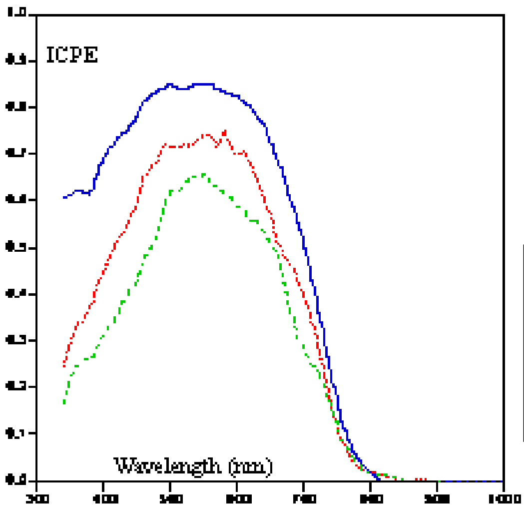

Fig. 1: spectral response, given as incident photon conversion efficiency against wavelength, of a dye-sensitised cell (∝ ∝) in comparison with a new (ſſſſſſſ) or used#4444#-hrs., 800 W/m^2) amorphous silicon cell.

For efficiency, there has been an emphasis on the chemisorption process for the attachment of the dye molecules to the titania film substrate. The level of protonation of the dye molecule has been identified as a critical parameter. Also use of alternative redox systems in place of the established iodide solution has been evaluated. One alternative redox system to the conventional iodide couple has been adapted for use in this low light intensity cell,based on a cobalt complex (2). While clearly under high intensities the use of such a large cation could lead to diffusion limitations, at low intensities such as 500 lux. performance is acceptable in this regard. However, solubility in the acceptable solvents is limited.

During the earlier phases 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 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 strorage 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 (3, 4). The structure of this dye is shown in Figure 2. This is a hydrophobic dye due to the presence of longer hydrocarbon chain ligands on the dye. Consequently, degradation by free water 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 free titania surface. A typical additive is decylphosphonic acid. The electrolyte utilized with the previous dye had to be modified for the Z907 dye because it wasdesorbed by the solvent, butyrolactone. The modified electolyte utilises alternate thiocyanate additives and higher concentration of iodine. A particular advantage of the dye is its compatibility with gelled ionic liquid electrolytes, which enhance thermal stability without deterioration of photovoltaic efficiency (4)

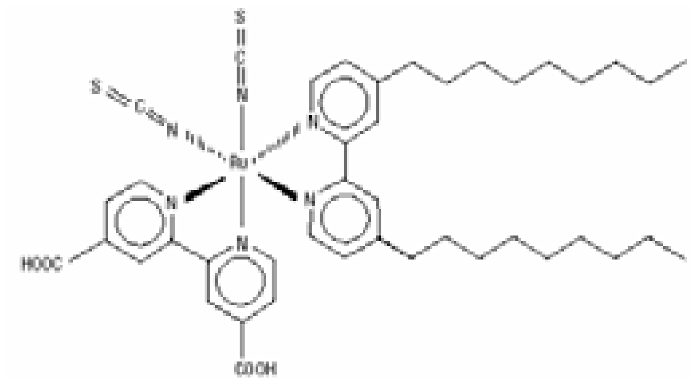

Fig. 2: structure of dye Z907 (3)

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

Perspectives

The performance goal of 28 σW/cm^2 at 500lux (indoor conditions) of the previous CTI/KTI action was achieved on 1cm^2 cells and over 24 σW/cm^2 on 7cm^2 as previously reported. To extend the range of sustainable operating conditions, stability at higher temperatures without loss of efficiency is now sought under contract 7019.1. The partner company intends to maintain and develop its R&D links with the EPFL laboratory in support of its product development.

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 (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 2004

Nanocrystalline flexible photovoltaic cells based on sensitised heterojunctions

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Project- / Contract Number	TopNano 21 - KTI N580 2.3.
Duration of the Project (from – to)	

ABSTRACT

In the standard dye-sensitised solar cell (DSC), photoexcited electroactive dye molecules inject electrons into a semiconductor substrate, becoming positively charged. The charge-neutral state is restored by reaction with a redox electrolyte. It has been a key research topic in the Laboratory for Photonics and Interfaces. Alternatively, the positive charge can be removed by contact with a solid-state "hole conductor" or p-type semiconductor. Strategies towards flexible solid state solar cells based on nanocrystalline titanium oxide and organic solid conductors were investigated. For the flexible cell geometry a metal foil was used as substrate and a semi-transparent gold layer as counter electrode which allows light transmission (back illumination). The device performance of solid state cells based on fluorinated tin oxide coated glass on the one hand and a metal foil on the other hand were characterized and compared by measuring the current voltage curves on back and front illumination.

Introduction

Dye-sensitised cells based on spiro-MeOTAD (2,2’7,7’-tetrakis(N,N-di-p-methoxyphenyl-amine)-9,9’-spirobifluorene) have gained attention as promising approach towards an organic solid-state solar cell [1-5]. In this type of device the light is absorbed by a ruthenium dye attached to the surface of the wide band gap semiconductor TiO_2. Upon excitation the dye injects electrons into the conduction band of the oxide and is regenerated by hole injection into the solid p-type semiconductor spiro-MeOTAD filling the pores of the TiO_2.

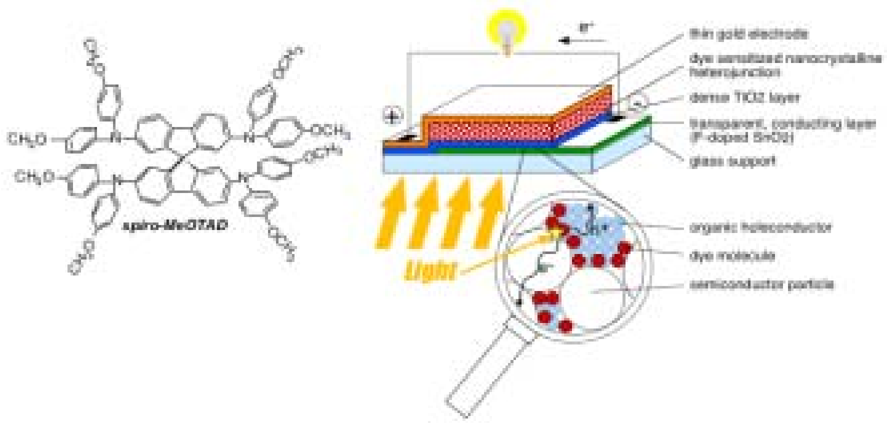


Figure 1 : Schematic build-up of a solid state dye solar cell based on nanocrystalline TiO2 and Spiro-OMeTAD as hole conductor.

Technical Summary

Two principal fabrication variants may be applied:

1. Replacement of SnO_2 glass by a plastic substrate with ITO coating and application of low temperature processed TiO_2 or replacement of TiO_2 by another semiconductor. The light enters through the substrate [6].
2. Replacement of SnO_2 coated glass by metal foils (Al, Ti, Mo). The light enters through the counter electrode which therefore should be transparent. This window has to form an ohmic contact with the organic hole conductor. This requires an electrically conducting material with a high work function such as gold (as a very thin semi-transparent layer) or a p-type semiconductor material such as copper iodide (CuI) [6].

Preferably the substrate should resist to a temperature of about 450°C which is required for the sintering of the ceramic layers in the cell, i.e. the mandatory compact TiO_2 layer ("barrier layer") and the nanocrystalline TiO_2. In the case of a temperature sensitive substrate, such as PET all device components need to be adapted to a low temperature processing, employing temperatures of about 200°C.

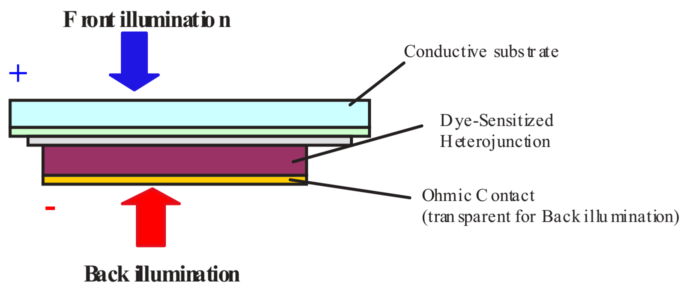


Figure 2 : Front and Back illumination.

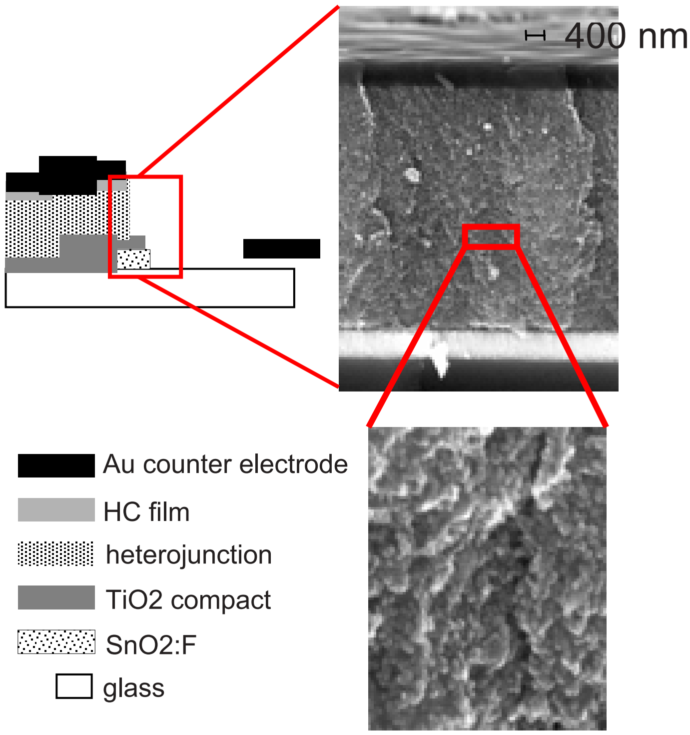


Figure 3: Micrograph of solid-state heterojunction cell, with structural schematic.

Ongoing Work and Results 2004

The current status of this technology was recently published by this Laboratory [7]. Three types of cell substrates were tested and compared in terms of the device performance:

1. Rigid cells with SnO_2:F coated glass substrate: **reference cell**
2. Rigid cells with titanium (instead of SnO_2:F) coated glass substrate: **titanium cell**
3. Flexible cells with stainless steel (provided by Solaronix) as substrate: **flexible cell**

The top gold counterelectrode and the nanocrystalline TiO_2 layer were the same for all 3 types of cells. For the counter electrode, a 30 nm thick gold film was deposited in form of 0.05 mm wide strips, each separated by 0.2 mm, making an overall contact area of 0.1 cm^2. This thin gold “window” transmits about 77% of the light at 520nm wavelength.

For all samples, a 50 nm thick compact TiO_2 layer was deposited onto to the substrate by spray pyrolysis [8] in order to prevent a direct contact between the dye regeneration system and the substrate. A TiO_2 nanocrystalline layer of 2 μm was then deposited by tape casting. Dye chemisorption required 8 hr. in $5x10^{-4}$M $(Bu_4N)[Ru(dcbpyH)_2(NCS)_2]$ (with $dcpyH_2$=2,2'-bipyridyl-4,4'-dicaboxylic acid) in CH_3CN:t-BuOH (1:1) at room temperature. The contacting organic film was deposited onto the dye-sensitized TiO2 by spin-coating a solution of 0.05M in Spiro-MeOTAD in chlorobenzene. In order to improve the device performance 13.5 mM in $Li[CF_4SO_2]_2N$, 0.11 M in tert-butylpyridine and 0.1 mM in $N(PhBr)_3SbCl_6$ were added to the spin-coating solution[1,3]. Finally the semi-transparent gold layer was evaporated onto the organic semiconductor film.

The glass substrate based cells were illuminated from the front, i.e. through the glass, or from the back through the semi-transparent gold electrode. The light intensity was 100 mW/cm^2 (metal halide lamp CDM-1000) or 5 mW/cm^2 (fluorescent lamp Philips PL-L 18W/84dsp). The titanium cell and flexible cell were characterized using illumination through the gold counter electrode. The obtained current-voltage curves were compared with the corresponding data of the reference cell for front and back illumination.

The short circuit current at 100 mW/cm^2 light intensity measured under back surface illumination is 0.67 mA/cm^2, compared to 2.97 mA/cm^2 for the front illumination through the glass. For the low illumination intensity of 5 mW/cm^2 the short-circuit currents are 24 µA/cm^2 and 60 µA/cm^2 for the back and front illumination respectively.Light loss in the wavelength range of 400-700 nm should only be about 26% based on the optical properties of gold. However, the loss in I_{sc} for the back illuminated cell is about 78% compared to the front illuminated cell for 100 mW/cm^2 and 60% under 5 mW/cm^2 intensity. Therefore the loss in I_{sc} cannot entirely be explained by the absorption for the back illumination geometry; an additional loss mechanism may result from the location of electron-hole pair generation within the dye-sensitized TiO_2.

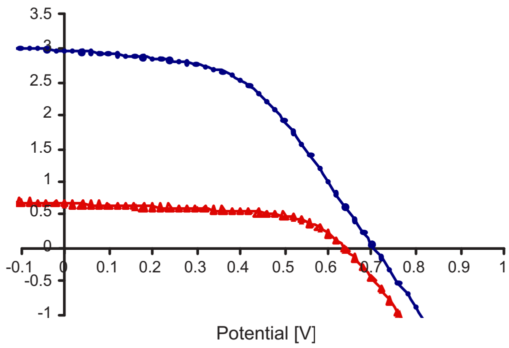
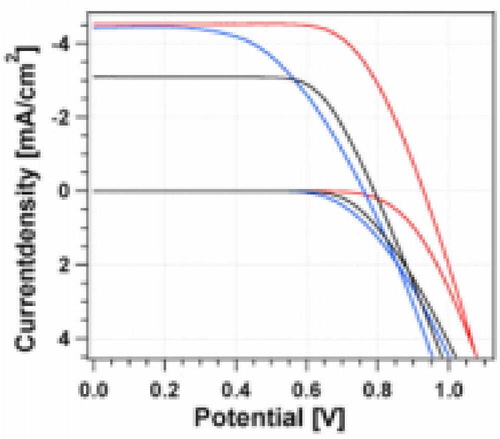


Figure 4: I-V plots of solid-state cells made of reference cell under forward (circles) and backward (triangles) illumination at 100 mW/cm^2.



Device	Jsc (mA/cm²)	Uoc (mV)	FF	η (%)
I	3.5	821	0.69	2.1
II	4.6	931	0.71	3.2
III	4.5	760	0.54	2.0

Figure 5: Improvement of performance of heterojunction cell by silver complexation of N3 dye.

The short circuit current of the titanium device is comparable to the current output of the back illuminated reference cell (670σA/cm^2) for which the light also passes through the gold layer. The corresponding open circuit potential is slightly higher for the titanium substrate device. This demonstrates that SnO_2 can be replaced by a metal without losing performance of the cell when back illuminated. The flexible cell on a stainless steel foil shows significantly lower current and potential than the rigid cell with the titanium film on a glass substrate. This loss in current and potential is expected to result from the increased mechanical stress for the TiO_2 layer in the case of the flexible cell design. Correspondingly the processing of the TiO_2 layer needs to be adapted to the flexible cell design. As shown in figure 5, metal complexation of the dye may also contribute to higher cell efficiency.

International Cooperation

The authors wish to acknowledge the supply of Spiro-OMeTAD by Covion Semiconductors GmbH, Germany. There is also ongoing technical contact with licensees of the DSC technology in Europe, Japan and U.S.A.

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MOLYCELL - Molecular Orientation, Low band-gap 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)	30 month, from 2004

ABSTRACT

Organic solar cells promise a strong reduction of photovoltaics (PV) cost 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 or-ganic-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) if fast improvements of the power efficiency and the lifetime can be achieved. There are still some crucial obstacles to overcome before a large-scale production of plastic 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 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 questions are being worked out in parallel:

1. Design and synthesis of new materials to overcome the large mismatch between the currently available polymer materials absorption characteristics and the solar emission spectrum and also to improve the mediocre 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 heterojunction built by blending of two organic materials serving as electron donor (hole semiconductor, low band gap polymers) and electron acceptor (n-type conductor, here soluble C60 derivative) under the form of an homogeneous blend and sandwiching the organic matrix between two electrodes. One of these electrodes is transparent and the other is usually an opaque metal electrode. 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 will 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, the photophysical and photochemical characterisation of such materials and heterostructures. Reel to reel fabrication expertise will be also available if necessary in 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

The specific contribution of the EPFL laboratory to the MOLYCELL consortium 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 "Grät zel cell".

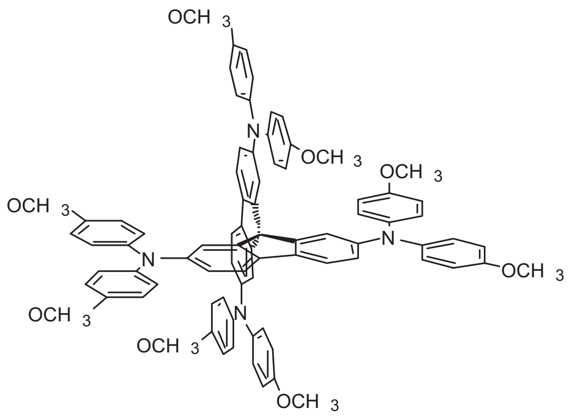

Fig. 1: structure of spirobifluorene hole-conducting p-type organic semiconductor. The flourene structures are perpendicular, conjoined through a common carbon site.

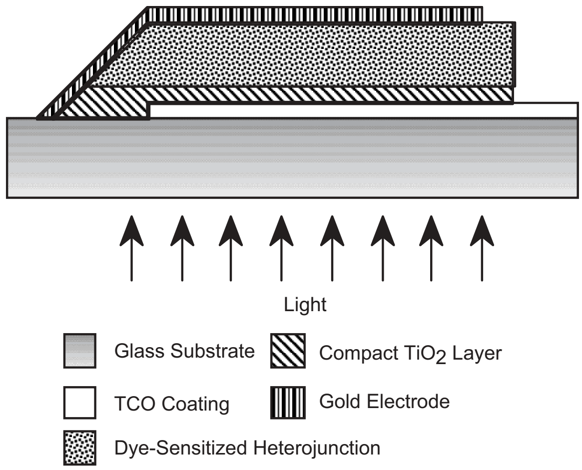

Figure 2: Schematic of the dye sensitized heterojunction PV cell.

Ongoing Work and Results 2004

A structure of work packages gas 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.

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.

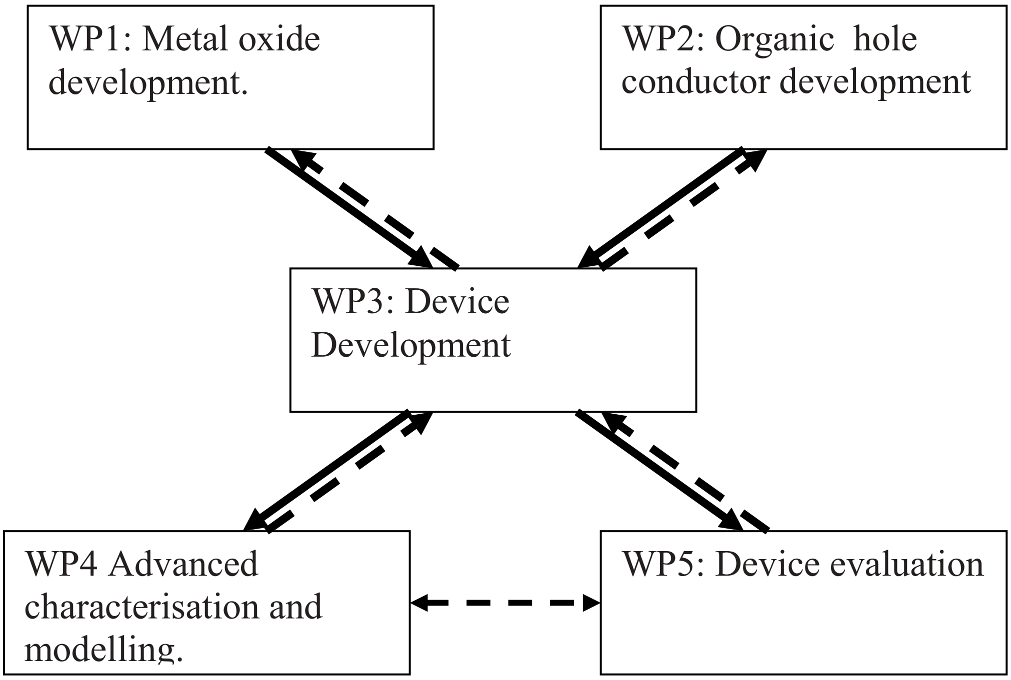

Fig. 3: workpackage structure for project coordination and management

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 founded 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 MOLYCEL L multinational specific targeted research/innovation project (STREP) of the 6th. Framework Programme of the European Union.

Partners:

Companies: Konarka Austria (AU), Konarka Technologies (CH);

Universities:
LIOS - Linz Institute for organic solar cells (AU)
ICL - Imperial College of Science, Technology and Medicine ICL (UK)
EPFL - Ecole Polytechnique Fédérale de Lausanne (CH)
JHIPC - J. Heyrovsky Institute of Physical Chemistry, Academy of Sciences of the Czech Republic (CZ)
Vilnius University Lithuania (LT)
EGE - University, Solar Energy Institute (TR)

Research institutes:
CEA - Commissariat a l'Energie Atomique (FR)
ECN - Energy Research Centre of the Netherlands (NL)
Fraunhofer ISE - Fraunhofer Institute for Solar Energy Systems (DE)
IMEC - Interuniversity Micro-Electronica Centrum vzw (BE)

Annual Report 2004

Photochemische, Photoelektrochemische und Photovoltaische Umwandlung und Speicherung von Sonnenenergie

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Project- / Contract Number	76645 / 36846
Duration of the Project (from – to)	Januar 2003 – Dezember 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. The O_2 production and the photocurrent were increased by a factor of about 3, as compared to layers without gold colloids. AgCl photoanodes as well as gold colloid modified AgCl photoanodes were combined with an amorphous silicon solar cell. The AgCl layer was employed in the anodic part of a setup for photoelectrochemical water splitting consisting of two separate compartments connected through a salt bridge. A platinum electrode and an amorphous silicon solar cell were used in the cathodic part. 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.

The synthesis of host-guest materials consisting of zeolite L, the channels of which are filled with dye molecules, is based on the fact that molecules can diffuse into individual channels. Functionalization of the external surface of the crystals is an option for fine-tuning their properties. Supramolecular organization of the dyes inside the channels has been shown by us to work extremely well. We can now report much progress on the functionalization of the channel entrances of zeolite L. We modified the channel entrances with reversibly and electrostatically bound, as well as covalently linked stopcock molecules. Furthermore, functionalization of the channel entrances has been achieved by a new reaction principle using protecting group chemistry. This "Sequential Functionalization of the Channel Entrances of Zeolite L Crystals" is a breakthrough in our research, because it opens the possibility to realize nearly any kind of imaginable modification of the channel ends of zeolite L or similar materials. We also reported the first successful experiments on excitation energy transfer from dyes inside the channels of zeolite L to dyes covalently bound to an external surface and from there, through a thin layer of silicon dioxide preventing electron transfer, further to a silicon semiconductor support.

Projektziele

Die Projektziele sind im Gesuch wie folgt formuliert:

Photokatalytische Wasserspaltung mit Ag/AgCl als Photoanode und einer Halbleiter Photokatode

bzw.

Entwicklung einer Dünnschicht-Antennen-Solarzelle basierend auf Farbstoff-Zeolith L Antennen eingebettet z.B. in Plastik-Substrat oder auf einem sehr dünnen Silizium-Substrat

zu brauchbaren 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

Photokatalytische 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.

Der Forschungsplan der photokatalytischen Wasserspaltung verfolgt zwei Wege. Einerseits wird daran gearbeitet die Effizienz der Photoanode durch Sensibilisierung und andere Herstellungsverfahren zu erhöhen, und andererseits wird mit geeigneten Halbleitern als Photokatode die photokatalytische Wasserspaltung mit AgCl als Photoanode untersucht.

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 und (iii) langfristig die Entwicklung einer Dünnschicht Tandemsolarzelle.

Durchgeführte Arbeiten und erreichte Ergebnisse

Photokatalytische Wasserspaltung

Die niedrige Absorptivität und Reaktivität an der Ag/AgCl Photoanode beeinflusst die Effizienz des Ag/AgCl Systems entscheidend. Durch die Erhöhung der Schichtdicke, und insbesondere durch Vergrössern der Oberfläche, kann die Absorption der Elektrode verbessert werden. Ein weitere Methode um das Reaktionssverhalten der Schicht zu beeinflussen ist die Zugabe von Verbindungen die das Ag/AgCl System sensibilisieren. Unsere publizierten Ergebnisse mit AgBr sensibilisierten AgCl Elektroden zeigen, dass der gewählte Weg der Sensibilisierung vielversprechend ist [1, 2].

Mit der Sensibilisierung der AgCl Photoanode mit Gold Nanopartikeln konnte die Effizienz des Ag/AgCl Systems markant verbessert werden. Mit Gold sensibilisierten AgCl Schichten konnte die produzierte O_2 Menge und der Photostrom um den Faktor 3 verbessert werden. Unsere Ergebnisse wurden in [3] publiziert und werden hier kurz zusammengefasst:

The AgCl photoanodes were prepared by electrochemical oxidation of a silver layer deposited on a glass support with a conducting gold layer (for details see Refs. 1 and 3). Photoelectrochemical experiments were done in a flow photoreactor system. Layers were exposed to successive illumination and dark periods of 100 min and 25 min duration, respectively. In Figure 1a the oxygen production and the anodic photocurrent versus time for an AgCl electrode without gold colloids are shown for several light and dark cycles. The photoanode shows an O_2 production, starting at around 200 nmol·h^{-1} and finally reaching a sustained O_2 production of 140 nmol·h^{-1} and a photocurrent of around 4 σA. The slight decrease of oxygen production is not due to lower photoactivity but to inferior mechanical stability of the layer after several illumination periods.

Small traces of Au colloids greatly influenced the photoelectrochemical activity. Gold colloids were sedimented on the AgCl layer by dipping it overnight into a colloidal solution. The results in Figure 1b show that AgCl layers modified with gold have a remarkably higher oxygen production and photocurrent than unmodified AgCl. After a slight decrease during the first part of the experiment, a steady O_2 production of around 500 nmol·h^{-1} and a photocurrent of around 14 σA can be observed. The higher photoactivity of gold modified AgCl layers can be explained by an increased absorption of the layer due to Au colloids (spectral sensitization), as well as the effect of gold particles in promoting the charge transfer process at the semiconductor/electrolyte interface, improving the photocatalytic oxidation capability of the AgCl system.

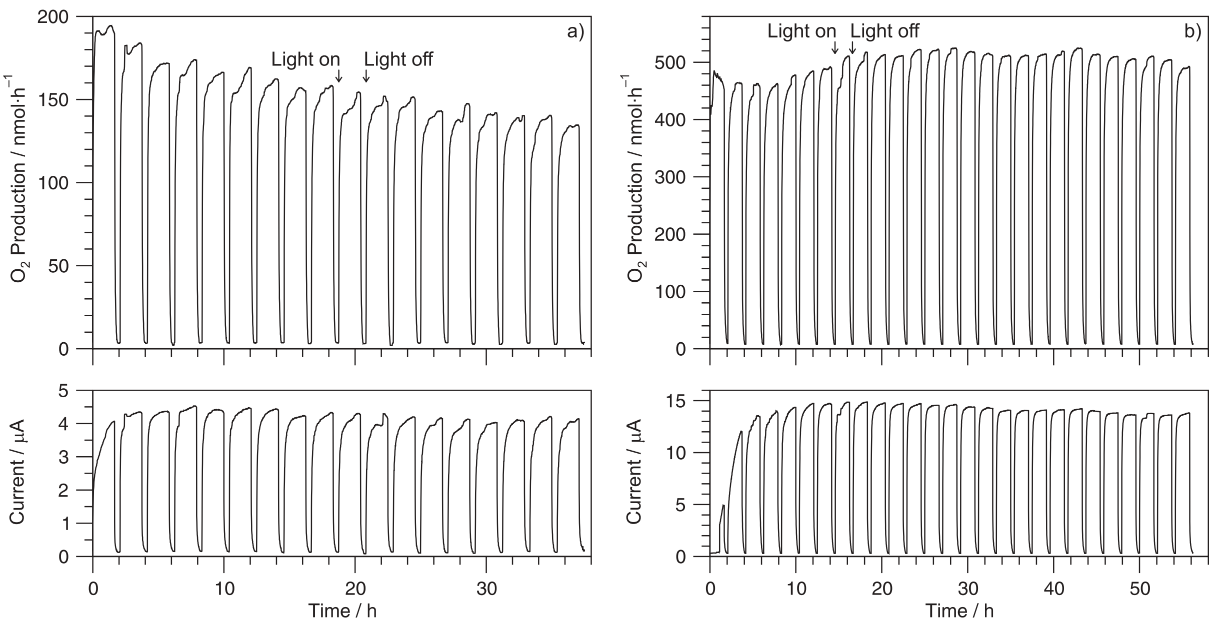

Figure 1. O_2 production and anodic photocurrent vs. time for an AgCl electrode without Au colloids, a), and modified with Au colloids, b), for several light and dark cycles.

Der Forschungsplan sieht auch vor, unsere AgCl Photoanode mit geeigneten Halbleitern als Photokatode zu kombinieren. 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 erzielt und sind in einer umfangreichen Publikation erschienen [5]. Ein Teil der Ergebnisse wird nun kurz zusammengefasst:

An AgCl photoanode was combined with an amorphous silicon solar cell and platinum as cathode. The AgCl layer was employed in the anodic part of a setup for photoelectrochemical water splitting consisting of two separate compartments connected through a salt bridge. A platinum electrode and an amorphous silicon solar cell were used in the cathodic part. In Figure 2a the O_2 and H_2 production and the anodic photocurrent vs. time are shown for several light and dark cycles. Illumination of the AgCl photoanode and the a-Si:H solar cell led to photoelectrochemical water splitting to O_2 and H_2. Sustained and stable O_2 and H_2 production could be observed. The system was exposed to successive illumination and dark periods of 120 and 45 min duration each. The AgCl photoanode showed an O_2 production between 90–100 nmol·h^{-1} and the platinum cathode an average H_2 production around 180 nmol·h^{-1}. The anodic photocurrent was between 10–11 σA.

A number of photoelectrochemical water splitting experiments were also carried out with gold colloid modified AgCl layers. The gold particles were sedimented on the AgCl layer by immersing it overnight into a colloidal solution. In Figure 2b the O_2 and H_2 production and the anodic photocurrent vs. time for an AgCl layer modified with Au colloids are shown for several light and dark cycles. The AgCl photoanode showed an O_2 production around 190 nmol·h^{-1} and the platinum cathode an average H_2 production around 380 nmol·h^{-1}. The anodic photocurrent was around 22 σA. Averaging over several experiments, we observed that small traces of Au colloids greatly influenced the photoelectrochemical activity of the AgCl system. The O_2 and H_2 production, as well as the photocurrent were usually increased by a factor of 1.5–2, depending on the layer's performance. Taking into account the differences in the experimental setups and conditions, this improvement can be considered satisfactory compared to the increase in O_2 production and photocurrent for experiments carried out in a flow photoreactor system mentioned above.

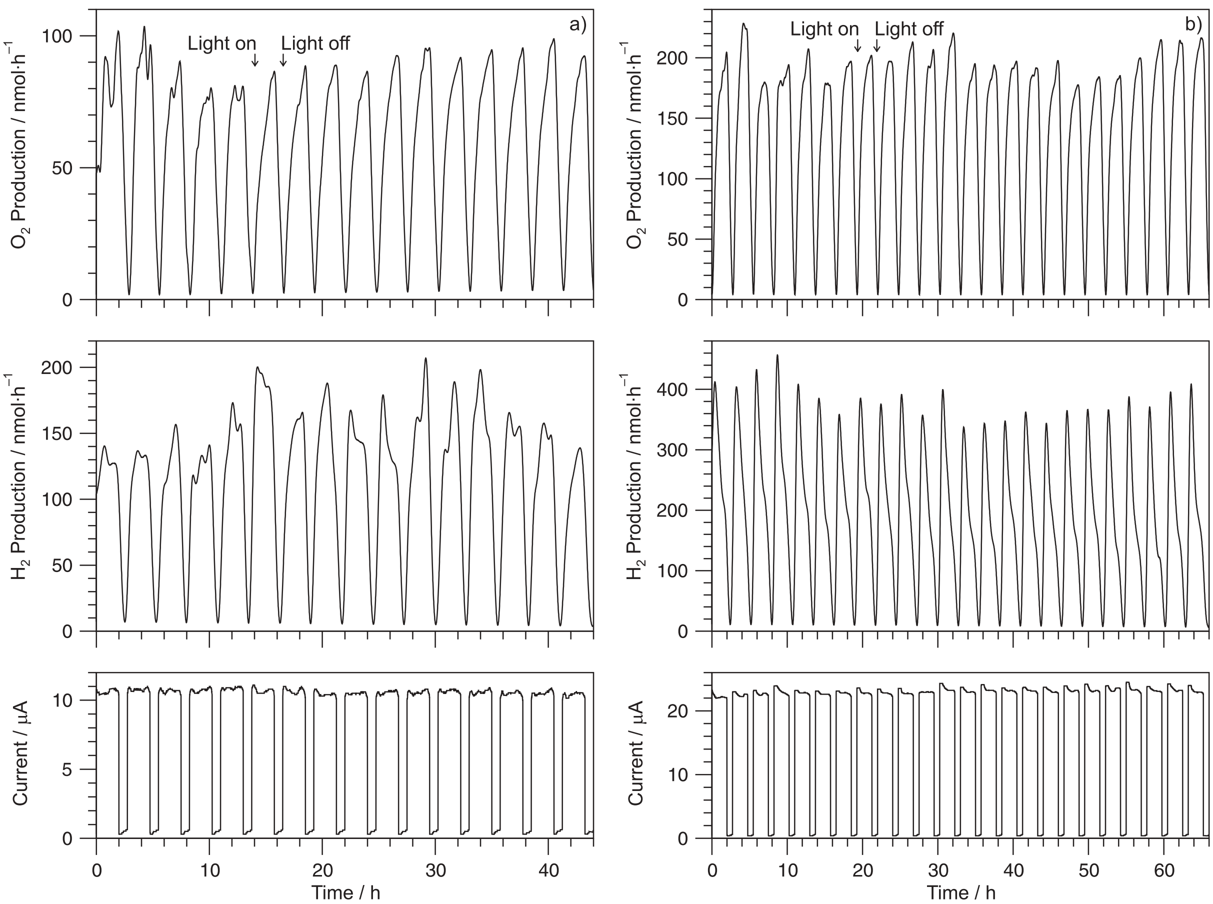

Figure 2. O_2 and H_2 production and anodic photocurrent vs. time for an AgCl electrode without Au colloids, a), and modified with Au colloids, b), combined with a Pt cathode and an amorphous silicon solar cell for several light and dark cycles.

Dünnschicht-Antennen-Solarzelle

The first stage of organization, which is the supramolecular organization of the dyes inside the channels, works extremely well. It allows light harvesting within a certain volume of a dye-loaded nanocrystalline zeolite L and radiationless transport to both ends of the cylinder or from the ends to the center. This has been reviewed in Refs. 6 and 7.

Much progress has been made on the important problem which concerns the functionalization of the channel entrances of zeolite L. We are now able to modify the channel entrances in different ways with:

∉ Reversibly bound stopcocks molecules (see Refs. 8, 9, and 10)

∉ Electrostatically bound stopcocks molecules (see Ref. 11).

∉ Covalently linked stopcock molecules (see Refs. 12, 13, and 14).

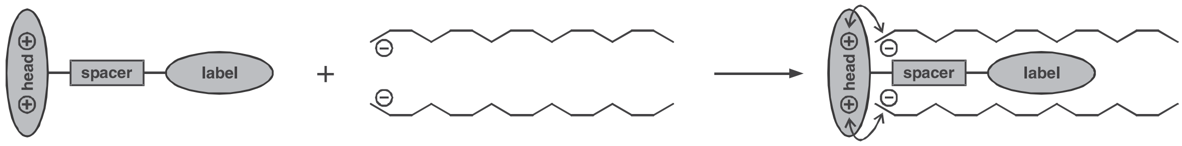

Figure 3. Principle of electrostatically bound stopcock molecules to zeolite L channels.

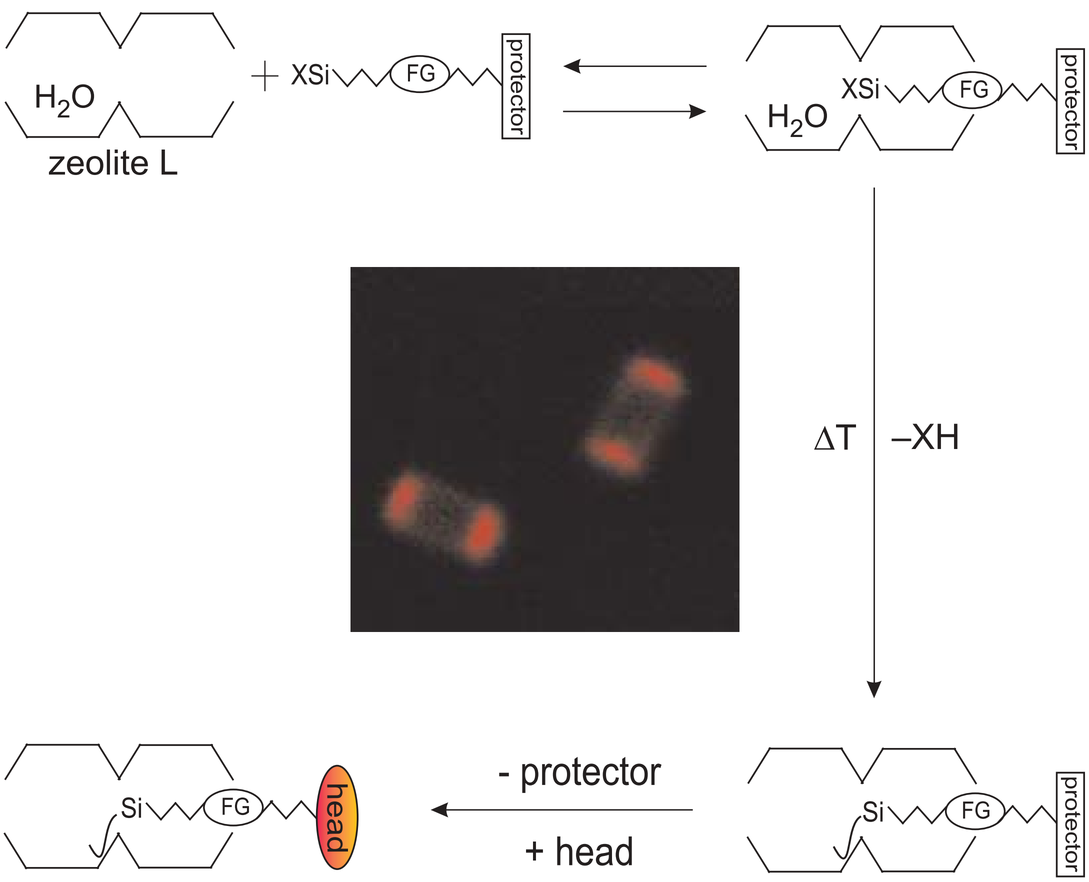

Figure 4. Sequential functionalization of the channel entrances of zeolite L crystals. The image shows two microcrystals modified with amino groups at the channel entrances which were further reacted with a red-luminescent head molecule.

The principle of electrostatically bound stopcock molecules to the channel entrances of zeolite L is illustrated in Figure 3. The possibility to functionalize the channel entrances of zeolite L made it possible to design experiments. For example, it allow monitoring electron hole pairs produced by energy transfer from the antenna via the stopcock to a semiconductor like silicon [12].

Regarding covalently linked stopcock molecules, the findings reported in Ref. 14 can be considered to be a breakthrough in this research, because they open the possibility to realize nearly any kind of imaginable modification of the channel ends of zeolite L or similar materials. Functionalization of the channel entrances of zeolite L crystals has been achieved by a new reaction principle using protecting group chemistry. It is broadly applicable and can be used to obtain a wide range of new functionalized zeolite based materials (see Figure 4).

In order to realize our dye-sensitized solar cells, thin or flat zeolite L crystals are of crucial importance. It is very difficult to synthesize flat zeolite L crystals with a length to base aspect ratio significantly smaller than 1. A. Zabala Ruiz has succeeded in this task (see Figure 5) [15]. The material has been tested in several experiments and shows excellent performance. This can be considered to be the second breakthrough we have realized in this research year.

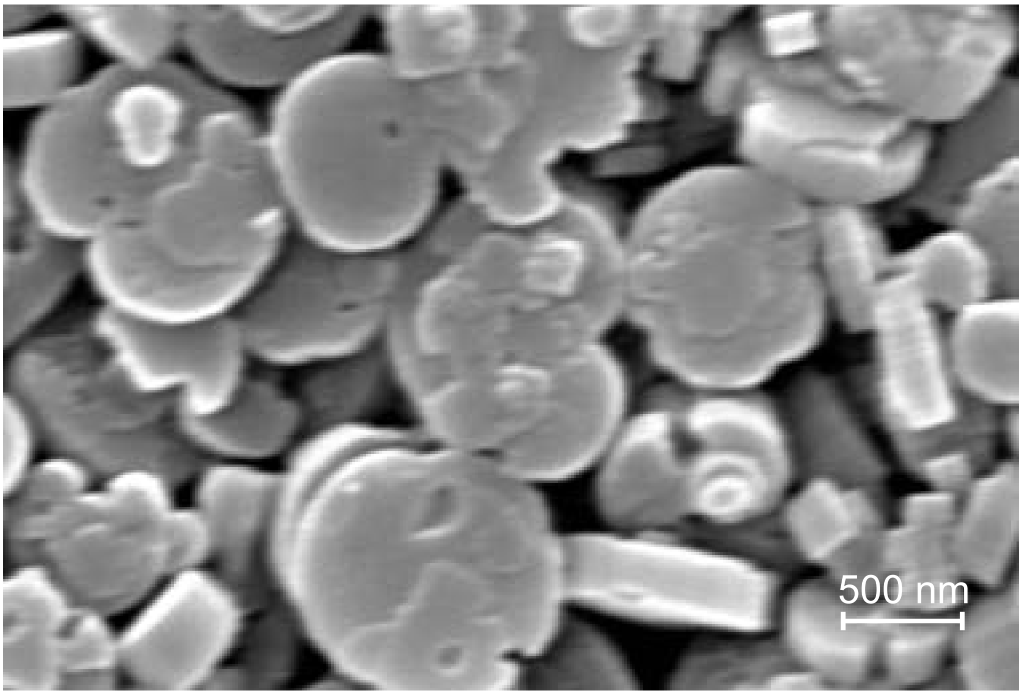

Figure 5. SEM image of flat zeolite L crystals with a length to base aspect ratio significantly smaller than 1.

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. R. E. I. Schropp	:	Debye Institute, Physics of Devices, Utrecht University, Utrecht, The Netherlands
Prof. Ken'ichi Kuge	:	Department of Information and Imaging Sciences, Chiba University, Chiba, Japan
Prof. Gary Hodes	:	Department of Materials and Interfaces, Weizmann Institute of Science, Rehovot, Israel

Prof. Roald Hoffmann	:	Department of Chemistry and Chemical Biology, Cornell University, Ithaca, USA
Prof. Peter Würfel	:	Institut für Angewandte Physik, Universität Karlsruhe, Deutschland
Prof. Rolf Brendel	:	Institut für Solarenergieforschung GmbH, Hameln/Emmerthal, Deutschland
Dr. Stefan Glutz	:	Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Deutschland
Dr. Edmond Amouyal	:	Laboratoire de Chimie Physique, Université Paris-Sud, Orsay, Frankreich
Prof. Luisa De Cola	:	Faculty of Science, University of Amsterdam, Amsterdam, The Netherlands

Bewertung 2004 und Ausblick 2005

Photokatalytische Wasserspaltung

Mit der Sensibilisierung der AgCl Photoanode mit Gold Nanopartikeln konnte die Effizienz des Ag/AgCl Systems markant verbessert werden. Mit Gold sensibilisierten AgCl Schichten konnte die produzierte O_2 Menge und der Photostrom um den Faktor 3 verbessert werden. Die Sensibilisierung der AgCl Photoande mit Gold wird weiter untersucht und ausgebaut. Geplant sind z.B. Versuche mit Ag/Au Nanopartikeln.

Für die Sensibilisierung der Ag/AgCl Photoanode können auch andere Verbindungen verwendet werden, wie z.B. Au_2S, Ag_2S, AgBr und AgI Nanopartikel. Es sind auch Versuche geplant, die Ag/AgCl Schicht 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 arbeiten zurzeit auch daran, regelmässige Zeolith A Monoschichten durch Sedimentation herzustellen. Die Leitfähigkeit der Monoschichten kann durch Beladung des Kanalsystems im Zeolithen erhöht werden.

Im nächsten Jahr werden auch andere Verfahren für die Herstellung von AgCl Schichten entwickelt. Die Verwendung von Membranen oder von mesoporösen Materialien als Matrix bei der Herstellung von AgCl Schichten wird auch untersucht.

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.

Im nächsten Jahr wird in Zusammenarbiet mit Prof. R. Schropp weiter untersucht, ob die Solarzellen aus amorphem Silizium in unsere Versuchsanordung integriert werden können. Durch Modifikation des Solarzellenaufbaus wird untersucht, ob diese in der Zelle für die Wasserstoffproduktion in direktem Elektrolythkontakt verwendet werden können.

Dünnschicht-Antennen-Solarzelle

Das Forschungsziel der nächsten Monate besteht darin, die oben erwähnten Versuche weiterzuführen. Insbesondere in Zusammenarbeit mit zwei Forschungsgruppen beabsichtigen wir eine Festkörper-Dünnschichtzelle und eine Farbstoff-Zeolith sensibilisierte Plastiksolarzelle zu realisieren.

Es ist erfreulich, dass sich jetzt auch die Industrie in erheblichem Masse für unsere Forschung interessiert und beabsichtigt Geld zu investieren.

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Module und Gebäudeintegration

Annual Report 2004

Photovoltaics Modules with Antireflex Glass

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Project- / Contract Number	100297 / 150369
Duration of the Project	From 1th August 2003 to 1th November 2004

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 incidence.

The increase in power-output of 3% or more, which the supplier express in his papers cannot be quantified. But a significant increase has been established. At least a difference of 2% can be measured in comparison with modules with and without antireflective treatment. An improvement in the behaviour with a low angle of incidence in outdoor tests can be measured. Whether it's an additional effect or just the improvement of the 2% cannot be quantified with these tests. This would be a subject of further investigations.

Einleitung / Projektziele

In den Unterlagen von 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 Steigerung mit relativ einfachen Mitteln von 3% ist für die Photovoltaik attraktiv [1] [2].

Das Projekt untersucht den Einfluss von antireflexgeätztem Gläsern und normalen Gläsern.

Der Einfluss der Antireflexoberfläche soll einmal im Quervergleich zwischen Modulen untersucht werden und auch bei Modulen, welche erst nachträglich im Säurebad behandelt werden. Die Leistungsmessungen werden doppelt geführt, zum einen mit dem eigenen 3S-Halogenleuchttisch und im TISO mittels einer Flashmessung. Freiluft Leistungs- und Ertragsmessungen werden ebenfalls beim TISO gemacht.

Das Projekt ist abgeschlossen und die Resultate sind in diesem Bericht veröffentlicht.

Kurzbeschrieb des Projekts

Das vorliegende Projekt beabsichtigt die Leistungssteigerung von PV-Elementen dank der Verwendung von antireflexgeätztem Glas zu quantifizieren.

Durchgeführte Arbeiten und erreichte Ergebnisse

Die Quantifizierung der Leistungsunterschiede wird mit Messungen bei den verschiedenen Arbeitsschritten dokumentiert. Für die möglichst homogene Leistungsdichte zwischen den Modulen wurden handverlesene und gemessene Zellen verwendet. Nach der Produktion der Netze wurden diese gemessen. Die Handhabung der verlöteten Netze muss sehr vorsichtig geschehen – bei der Messung beim TISO ist ein Zellenbruch entstanden und das erste Reservenetz konnte nicht weiter verarbeitet werden.

Antireflexgeätztes Glas

Optisch kann nur bei schrägem Lichteinfall ein Unterschied der Oberfläche gesehen werden. Wird mit der Hand über die Oberfläche gefahren, kann ein deutlicher Unterschied gespürt werden (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/m^2 (Flash)
- Leistungsmessung bei verschiedenen Strahlungsintensität (Flash)
- Freiluftmessungen bei verschiedenen Einstrahlungswinkeln

Ergebnisse

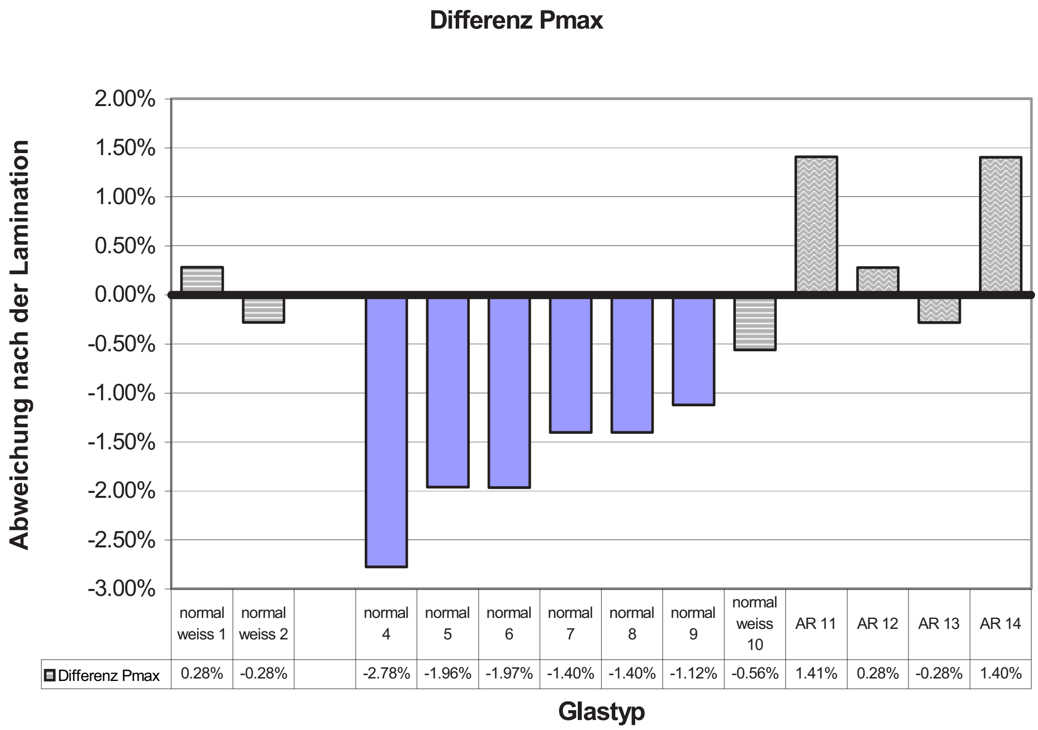


Abbildung 1 : relative Differenz der Leistung zwischen dem Zellennetz und dem laminierten Testmodul

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

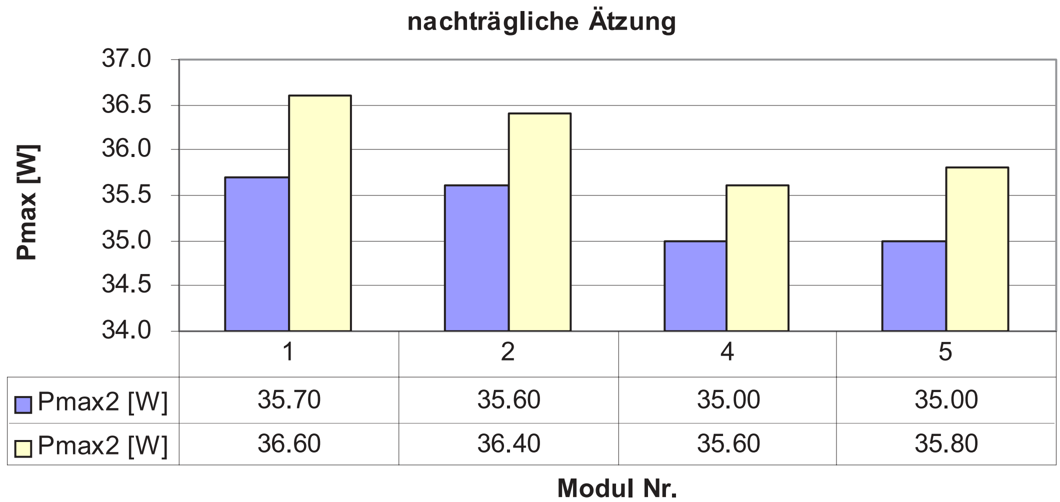
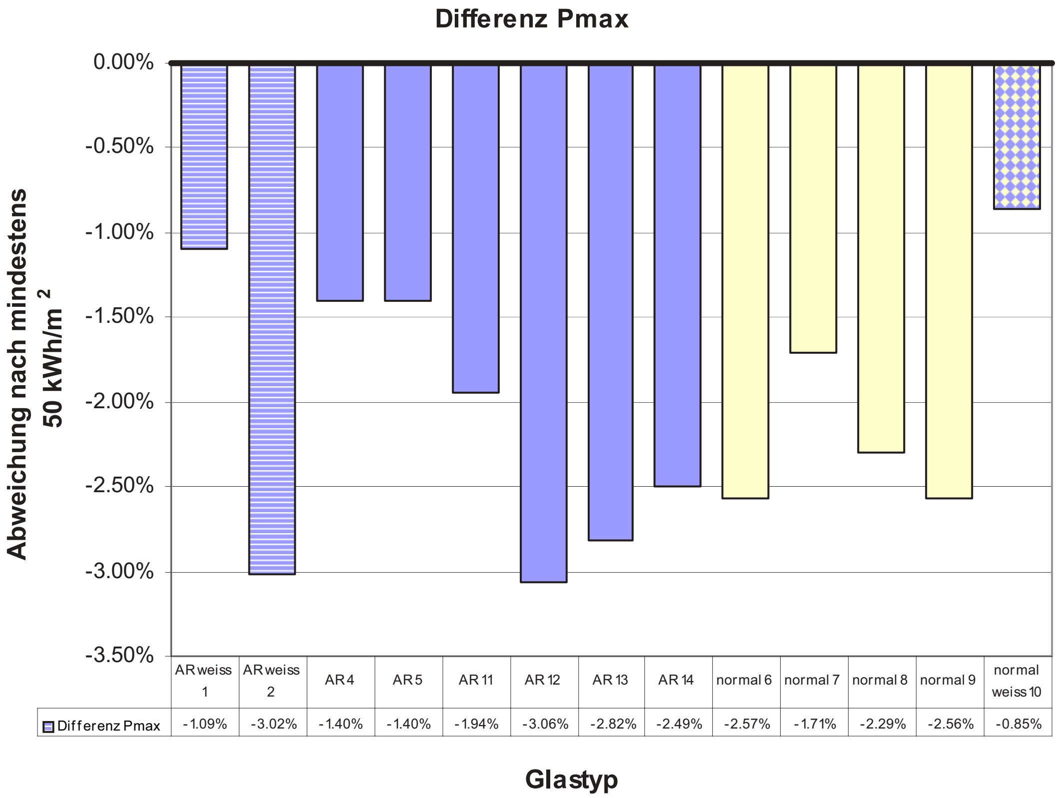


Abbildung 2 : absolute Differenz der Leistung bei nachträglicher Ätzung des Frontglases

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



	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%

Abbildung 3 : relative Leistungsabnahme nach mindestens 50kWh/m^2 Exposition im Freiland

Die Abminderung nach den ersten Betriebsstunden ist bei allen Modultypen etwa im Bereich von 1% bis 3%. Es kann kein signifikanter Unterschied festgestellt werden. Das Glas hat keinen Einfluss auf diesen Effekt.

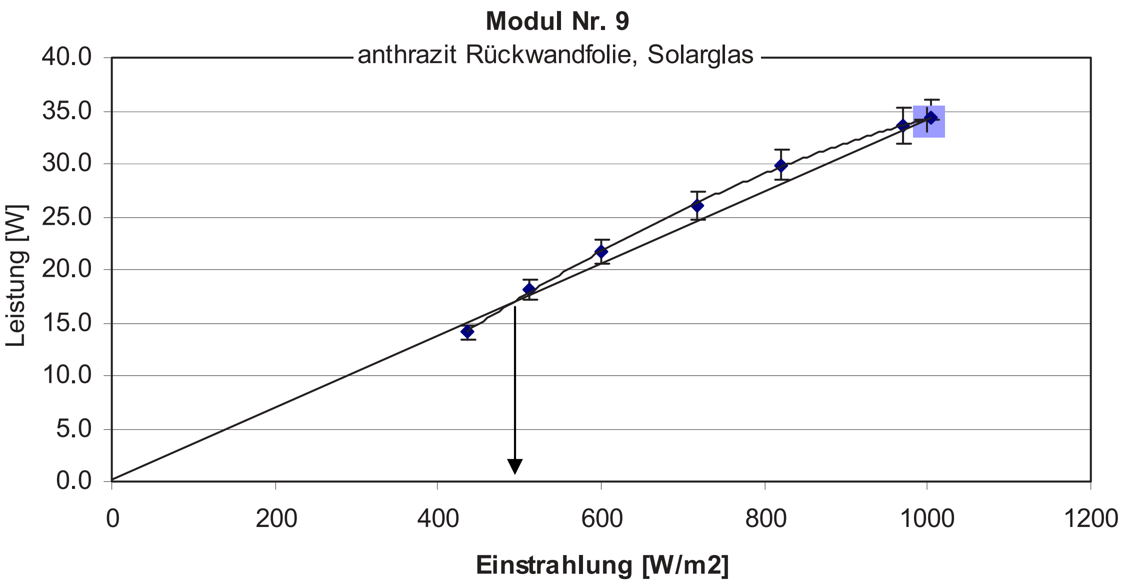


Abbildung 4 : Messung der Leistung im Freiland bei verschiedenen Einstrahlung, normales Glas

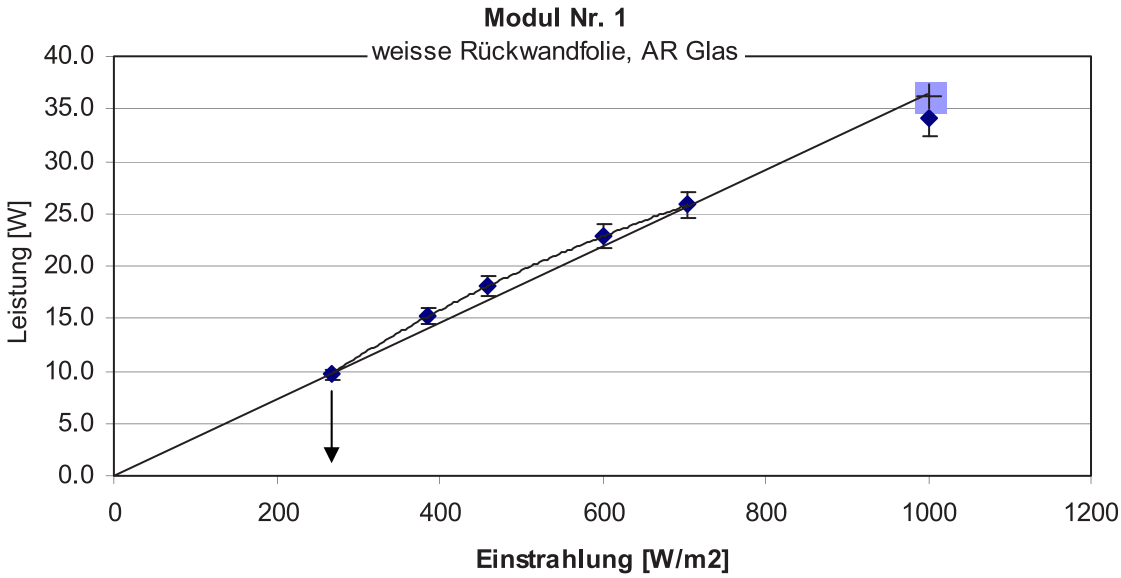


Abbildung 5 : Messung der Leistung im Freiland bei verschiedenen Einstrahlung, AR Glas

Mit Freiluftmessungen bei verschiedenen Einstrahlungswinkeln wurden das Verhalten der Leistung in Abhängigkeit der Einstrahlung gemessen. 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 normalem 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 von geätzten Antireflexgläsern mit normalem Solarglas zeigt einen Einfluss der Oberfläche auf die Leistung.

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 von Modulen zeigen eine Leistungssteigerung von mindestens 2% und bestätigen das erste Resultat.

Die Leistungsabnahme nach den ersten Betriebsstunden (gemessen nach 50kWh/m^2) ist nicht abhängig vom Glas. Zwischen den Vergleichsmodulen kann keine signifikante Tendenz festgestellt werden.

Bei den Freiluftmessungen bei verschiedenen Einstrahlungswinkeln zeigt sich, dass AR-Module den Grenzbereich mit flachem Einstrahlungswinkel noch besser ausnützen können. Ob diese Differenz wiederum die 2% sind, kann mit der angewandten Messtechnik nicht festgestellt werden. Interessant wäre eine Verifizierung der relativen Differenz bei vordefinierten Einstrahlungswinkeln.

Nationale / internationale Zusammenarbeit

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

Die Messungen der Netze und der Module werden in Zusammenarbeit mit der SUPSI (Scuola Universitaria Professionale della Svizzera Italiana) bzw. TISO ausgeführt.

Bewertung 2004

Der Leistungs- und Ertragsgewinn von mehr als 3% durch den Einsatz von antireflexgeätztem Glas kann nicht bestätigt werden. Hingegen ist eine deutliche Verbesserung von mindestens 2% erkennbar.

Weitere Untersuchungen im Bereich der Leistung vs. Einstrahlungswinkel kann zu einer weiteren Aussage über das Verhalten dieser Gläser führen.

Erfahrungswerte im Einsatz dieser Gläser sprechen sehr für den positiven Effekt der antireflexgeätzten Oberfläche. So ist eine 50 kW Anlage mit AR-Gläsern seit dem März 2004 in der Schweiz in Betrieb und liefert seither sehr gute Ertragswerte, welche über dem prognostiziertem Ertrag liegen.

Referenzen / Publikationen

[1] ***Higher efficiency from PV-modules using antireflective glass***, sunarc Technology A/S, Danmark

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

Annual Report 2004

AFRODITE Advanced facade and roof elements key to large scale building integration of photovoltaic energy

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Project- / Contract Number	NNE5-2000-00178/ ENK5-CT-2000-00345
Duration of the Project (from – to)	(1. April 2001); 1. october 2001 to 1. april 2004

ABSTRACT

The objective of this work was to improve the acceptability of building integrated renewable energy conversion by developing high performance photovoltaic building elements with a high visual appeal. After an exercise of translating the visual appeal into technical specifications, a number of novelties were introduced both on the level of the crystalline silicon solar cell structure, the required production equipment and for the module manufacturing. Supporting the development of the new products with both reliability testing and an extended outdoor performance evaluation, a number of highly efficient demonstrator building elements have been manufactured.

As a main outcome of the project, the developed back contact solar cells are now manufactured and marketed by the company Photovoltech in Belgium (www.photovoltech.be).

Einleitung / Projektziele

Hauptziel des Projektes ist die Entwicklung von rückkontaktierten, kristallinen Solarzellen, sowie deren produktionstechnisch und preislich optimale Verschaltung. Diese Zellen sind ästhetisch ansprechender als konventionelle Zellen, und sollen damit die Akzeptanz unter Architekten und Bauherren erhöhen.

Kurzbeschrieb des Projekts / der Anlage

Zur Erreichung der Projektziele wurde ein Team gebildet bestehend aus Entwicklern und Herstellern von Solarzellen, Photovoltaikmodulen, Produktionsequipment für Solarzellen, Produktionseinrichtungen, sowie dem Forschungsinstitut einer Universität.
Das Projekt ist in 5 Workpackages eingeteilt:

1. Konsultation von Architekten und Endverbrauchern zur Ermittlung der Anforderungen an ein allgemein akzeptiertes PV-Produkt.
2. Entwicklung und Demonstration der benötigten rückkontaktierten Zellen, der Zellverbindungstechnologie sowie des Siebdruckverfahrens.
3. Dieses workpackage verfolgt zwei Ziele: 1- Unterstützung der Entwicklung durch extensive Zuverlässigkeitstests und Nachprüfen der Produkteigenschaften; 2- Identifikation und Evaluation weiterer Vorteile der PV-Bauelemente
4. Demonstration der entwickelten Zell- und Verbindungstechnologie auf vorindustrieller Stufe, sowie detaillierte Kostenevaluation der Produkte
5. Erhöhung des Bekanntheitsgrades von kost engünstigen von Solarstrombauelementen im Bausektor.

2004 durchgeführte Arbeiten und erreichte Ergebnisse

Im Jahr 2004 standen die Umsetzung der Serienproduktion der rückkontaktierten Zellen im Vordergrund der Arbeiten. Von Swiss Sustainable Systems AG wurden diesbezüglich keine Arbeiten mehr durchgeführt. Von Swiss Sustainable Systems AG wurde lediglich ein Ersatzmodul für die Testfassade an der Uni Wroclaw geliefert.

Bewertung

Das Projekt kann als erfolgreich bewertet werden. Mit Photovoltech (www.photovoltech.be) konnte ein Industriepartner gewonnen werden, der diese Zellen bereits herstellt und vertreibt.
Die Aufgaben von Swiss Sustainable Systems AG waren Evaluation der neuen Zellen, Tests bei der Verarbeitung, sowie Herstellung von Mustern für die Tests, und wissenschaftliche Beratung bei den Tests. Die budgetmässige Hauptaufgabe mit der Entwicklung und Herstellung von Equipment für die Verbindung der rückkontaktierten Zellen ist dahingefallen, da am Markt bereits Equipment verfügbar ist, welches mit geringfügigen Modifikationen diese Aufgabe bereits wahrnehmen kann. Durch die rasche Kommerzialisierung wurden weite Teile der im Projekt festgelegten Ziele überholt. Die Arbeit von Swiss Sustainable Systems AG ist daher bedeutend kleiner ausgefallen als geplant.

Referenzen / Publikationen

- Emmanuel Van Kerschaver, C. Allebé, T. Szacsvay, L. Frisson, P. Renz, T. Zdanowicz, ***PHOTOVOLTAIC FACADE AND ROOF ELEMENTS WITH ADDED VALUE BY THE USE OF BACK CONTACTED SOLAR CELLS,*** PV conference in Rome, Oct. 2002
- E. van Kerschaver, j. Szlufcik & S. de Wolf-IMEC: ***High Performance Modules Based on Back Contacted Solar Cells***, PV conference in Osaka, May 2003

Annual Report 2004

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

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Project- / Contract Number	503777 / BBW 03.0046
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 el ements 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.

BFE OFEN UFE SFOE

Einleitung / Projektziele

Ziel des Projektes ist die Integration von Photovoltaik in die – insbesondere 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 Baustandards. Ebenfalls vorgesehen

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. Swiss Sustainable 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

Swiss Sustainable Systems AG ist dabei, ein neues Dachelement für die Gebäudeintegration zu entwickeln. Ein erster Prototyp ist vorhanden, eine provisorische Kalkulation sieht vielversprechend aus. Diese gilt es nun zu überarbeiten, und die Konstruktion des Prototyps anzupassen.

Bewertung 2004 und Ausblick 2005

Zahlreiche der Projektpartner sind in Deutschland domiziliert. Wegen dem dort herrschenden Boom im Bereich Photovoltaik sind diese teilweise sehr stark ausgelastet, was sich in einer etwas schleppenden Bearbeitung des vorliegenden Projektes widerspiegelt. Dennoch kommt das Projekt voran, gegenüber dem Zeitplan sind keine grossen Verschiebungen aufgetreten. Generell wird der Projektverlauf als ermutigend betrachtet.

Für Swiss Sustainable Systems AG steht für 2005 die Entwicklung des neuen Dachelementes im Vordergrund. Es wird erwartet, dass bis Mitte 2005 ein Prototyp zur Verfügung steht, sofern sich die ermutigenden Zahlen aus der provisorischen Kalkulation bestätigen sollten.

Annual Report 2004

CONSOL Connection Technologies for Thin-Film Solar Cells

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Telephone, Fax	+49 711 78 70 216 / +41 71 913 98 88
E-mail, Homepage	konrad.herz@zsw-bw.de / reinhard.zuest@telsonic.com http://www.zsw-bw.de / http://www.telsonic.com
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 metallic and semi conducting layers deposited onto a glass substrate. They are connected to the external electrical circuit via two metallic tapes on the Mo back contact and the ZnAlO front contact of the stack. In this project, two connection technologies for attaching the tapes are investigated: i) using conductive adhesives and ii) ultrasonic welding. These techniques will be applied and optimised for CIGS solar cells on conventional glass substrates as well as on flexible steel foils.

These activities pursue two main goals: i) to improve the corrosion resistance, stability, and processing of the bonded contact tapes, and ii) to decrease the manufacturing costs by optimising material components and process parameters, as well as rationalising and automating process steps used for bonding. Important goals are to maintain a low contact resistivity and a low degradation in the cell efficiencies due to contact corrosion when exposed to a damp-heat environment.

All adhesive formulations investigated in this project are 1 K adhesives with epoxy-based resins with silver content. A variety of such adhesives were applied for bonding Sn-plated Cu tapes to ZnO/Mo test layers deposited on glass, steel and polyimide substrates. The contact resistivity of tapes adhered by conductive adhesive remains far below 1 Tcm^2 during the damp-heat and thermo-cycling test.

In the case of ultrasonic welding, Al and Al-plated Ag tapes were bonded to Mo/glass and ZnO/Mo/glass test layers. These test structures were exposed to extreme environmental conditions. A good and reliable bond for the ultrasonically welded contact tapes can only be obtained with panels of the type Mo/glass, with the CIGS layer removed by scraping. For good adhesion, the welding areas must be thoroughly free of CIGS. Completely free of glass shelling was test module D with a good weldability on the Al/Ni layer additionally deposited. Further tests will be done with Al-plated Cu tapes. The 90° peel strength of ultrasonically welded tapes is significantly higher than for adhered tapes. Welded connections on Mo/glass showed an increase of the contact resistivity almost to 1 Tcm^2 after damp-heat test. The peel strength decreased after the damp-heat test in both cases, but the decrease was more pronounced for adhered tapes.

Executive summary

Objectives

CIGS solar modules consist of a stack of thin metallic and semi conducting layers (only a few µm thick) deposited onto a glass substrate. They are connected to the external electrical circuit via two metallic tapes on the Mo back contact and the ZnAlO front contact of the stack. In this project, two connection technologies for attaching the tapes are investigated: i) using conductive adhesives and ii) ultrasonic welding (Fig 1). These techniques will be applied and optimised for CIGS solar cells on conventional glass substrates as well as on flexible steel foils.

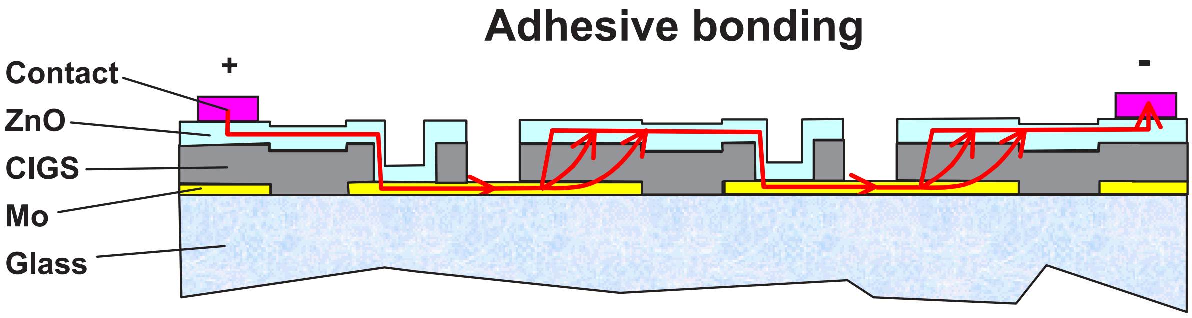


Fig. 1 Adhesive bonding

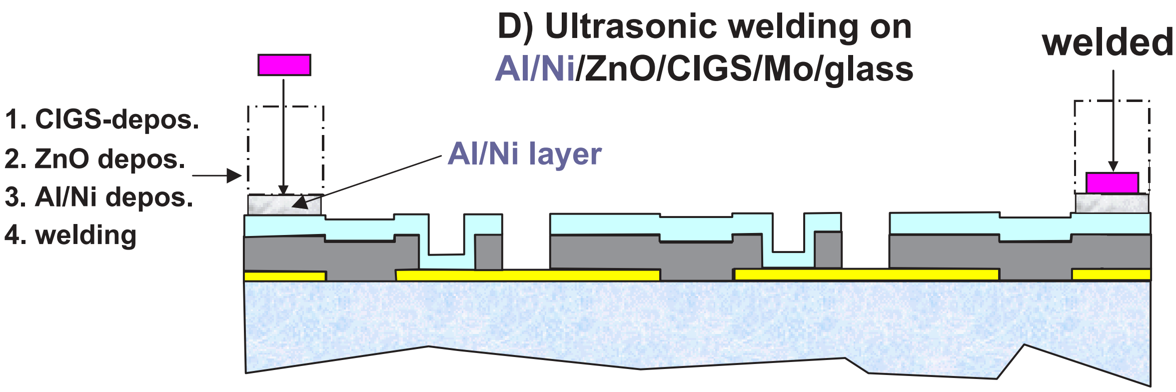


Fig. 2 Ultrasonic welding

These activities pursue two main goals: i) to improve the corrosion resistance, stability, and processing of the bonded contact tapes, and ii) to decrease the manufacturing costs by optimising material components and process parameters, as well as rationalising and automating process steps used for bonding. Important goals are to maintain a contact resistivity of Ω 1T cm^2 and a low degradation of <5% (rel .) in the cell efficiencies due to contact corrosion when exposed to a damp/heat environment with 85°C/85% humidity for 1000 hours and thermal cycling (-40°C/+85°C) for 200 cycles.

Work performed and achievements to date

All adhesive formulations investigated in this project are 1 K adhesives with epoxy-based resins and curing temperatures of about 150 °C. The silver content is between 70-75 weight%. A variety of such adhesives as well as some newly optimised formulations were applied for bonding Sn-plated Cu tapes to ZnO/Mo test layers deposited on glass, steel and polyimide substrates. In the case of ultrasonic welding (36 kHz), Al and Al-plated Ag tapes were bonded to Mo/glass and ZnO/Mo/glass test layers. 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 test modules 10 x 10 cm^2 on glass substrates contacted by adhesive bonding (configuration ZnO/CIGS/Mo) and ultrasonic welding (three different configurations) were tested in the DH test.

The contact resistivity of tapes adhered by the best conductive adhesive remains far below 1 Tcm^2 during the DH and TC test as demanded by the project goals. This was demonstrated for test layers on all substrate types. In case of test modules on glass substrates (other substrates in preparation) the contact resistivity sometimes exceeded this limit due to the increase of the ZnO sheet resistance during DH. Nevertheless the contact related power loss remained below 5%.

Corrosion effects are decreased by an inhibitor which is especially efficient for Sn coated Cu tapes. 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, fulfilling another important goal of the project. Another version of this best adhesive was developed with improved dispensing properties and a higher work life of 3 days at room temperature (instead of 1), but more bleeding. As bleeding does not affect the reliability of the connections, this version will be the preferred material.

A good and reliable bond for the ultrasonically welded contact tapes can only be obtained with panels of the type Mo/glass, with the CIGS layer removed by scraping. For good adhesion, the welding areas must be thoroughly free of CIGS. The 90° peel strength of ultrasonically welded tapes (1.6-15 N) is significantly higher than for adhered tapes (0.4-1.5 N). The peel strength decreased after the DH test in both cases, but the decrease was much more pronounced for adhered tapes. Welded connections on Mo/glass showed an increase of the contact resistivity almost up to 1Tcm^2 after DH 1000 h, caused by severe corrosion of the scraped Mo layer. In a later production process these areas must be protected by lamination and encapsulation. The increase of the contact resistance is much smaller during the TC test.

Most of the expected outputs 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. Furthermore, however, special results may also be licensed to other industries or interested parties if possible (depending on the competition of the respective customer).

Project partners

↓ ZSW, Zentrum für Sonnenenergie- und Wasserstoff-Forschung (D)

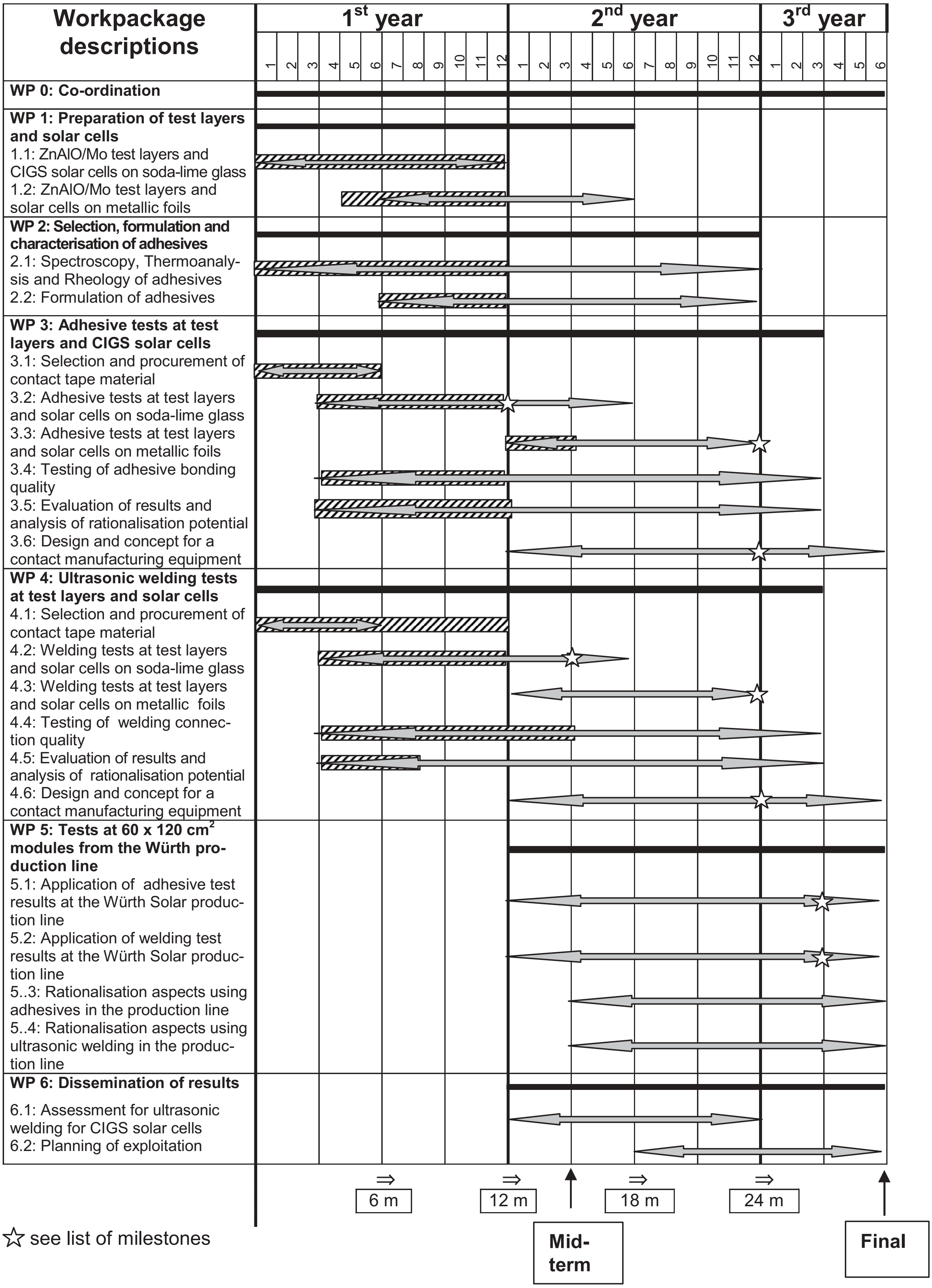
↓ ECUM, Emerson & Cuming, ICI Begium NV (B)

↓ IFAM, Fraunhofer-Gesellschaft zur Föderu ng der angewandten Forschung e.V./ Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung (D)

↓ TELS, Telsonic AG (CH)

↓ WS, Würth Solar GmbH (D)

Timetable


Workpackage descriptions
1st year
2nd year
3rd year
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6
WP 0: Co-ordination
WP 1: Preparation of test layers and solar cells
1.1: ZnAlO/Mo test layers and CIGS solar cells on soda-lime glass
1.2: ZnAlO/Mo test layers and solar cells on metallic foils
WP 2: Selection, formulation and characterisation of adhesives
2.1: Spectroscopy, Thermoanalysis and Rheology of adhesives
2.2: Formulation of adhesives
WP 3: Adhesive tests at test layers and CIGS solar cells
3.1: Selection and procurement of contact tape material
3.2: Adhesive tests at test layers and solar cells on soda-lime glass
3.3: Adhesive tests at test layers and solar cells on metallic foils
3.4: Testing of adhesive bonding quality
3.5: Evaluation of results and analysis of rationalisation potential
3.6: Design and concept for a contact manufacturing equipment
WP 4: Ultrasonic welding tests at test layers and solar cells
4.1: Selection and procurement of contact tape material
4.2: Welding tests at test layers and solar cells on soda-lime glass
4.3: Welding tests at test layers and solar cells on metallic foils
4.4: Testing of welding connection quality
4.5: Evaluation of results and analysis of rationalisation potential
4.6: Design and concept for a contact manufacturing equipment
WP 5: Tests at 60 x 120 cm2 modules from the Würth production line
5.1: Application of adhesive test results at the Würth Solar production line
5.2: Application of welding test results at the Würth Solar production line
5..3: Rationalisation aspects using adhesives in the production line
5..4: Rationalisation aspects using ultrasonic welding in the production line
WP 6: Dissemination of results
6.1: Assessment for ultrasonic welding for CIGS solar cells
6.2: Planning of exploitation
⇒ 6 m
⇒ 12 m
⇒ 18 m
⇒ 24 m
Mid-term
Final
☆ see list of milestones

Annual Report 2004

Exploitation Demosite 2003-2004

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Project- / Contract Number	37468
Duration of the Project	From 1/1/2003 to 31/12/2004

ABSTRACT

In 2004, DEMOSITE continued to promote and stimulate the development of Building Integrated Photovoltaic:

- Several groups visited the site on location in Lausanne, detailed explanations were given during the tours. Most visits also include a tour of several PV pilot installations on the EPFL site. Individual visits were also conducted, mainly with foreign architects (Jpn, Fr, Ger, USA)..
- A comprehensive leaflet with details on the various systems is handed to the participants
- The Website is maintained and answers are given to questions asked either by phone or e-mail

The 8 stolen modules on the SOLFACE pavilion at DEMOSITE 1, the part of the exhibition located on the parking lot, were not replaced as the pavilion will soon be used for a demonstration of a solar thermal system (SOLABS).

Routine maintenance has been conducted, pathways in front of the last 4 pavilions cleaned and grass cut down to allow for visits. Signs have been replaced.

Possible uses for Demosite within the upcoming Task 10 are still open.

Introduction / Buts du projet

Le but de Demosite reste de promouvoir le photovoltaïque intégré au bâtiment et de faire prendre conscience aux différents visiteurs des possibilités offertes par cette technologie. La possibilité de voir en vraie grandeur et sur site les nombreux systèmes exposés donne un impact particulier à ce centre. Les nouvelles tendances vers une approche plus globale (cités) des intégrations sont en cours d'investigation.

Brève description du projet / de l'installation

Le Demosite se compose actuellement d'un ensemble d'éléments:

- Un site sur un parking de l'EPFL, qui comprend 16 pavillons montrant des systèmes intégrés en toiture, en façade ou comme brise-soleil.
- Un second site situé sur une toiture plate du Département d'Electricité, exposant 8 différents systèmes de montage du photovoltaïque en toiture horizontale.
- Un site Internet qui présente les deux sites précédents aux visiteurs virtuels, ainsi que deux sections supplémentaires:
  - Un tutorial sur le photovoltaïque et son intégration au bâtiment
  - Une collection d'exemples architecturaux du monde entier
- Enfin un spécialiste pouvant orienter les personnes s'intéressant de plus près à la réalisation d'une installation.

Travaux effectués et résultats acquis

En l'an 2004, les travaux exécutés ont été les suivants:

- Organisation et conduite de visites guidés, individuelles et en groupes
- Présentation d'une contribution aux 5èmes. Journés Nationales Photovoltaïques, ETH Zürich, 25,26 Mars 2004: Ch. Roecker PVSyst3.3 - Un outil de planification pour architectes et ingénieurs.
- Maintenance du site Web, financement du nom de domaine.
- Maintenance des sites physiques et du système de fléchage:
  - Remplacement et remise en place de panneaux de signalisation vandalisés
  - Entretien régulier du chemin de visite des 4 pavillons sud de Demosite 1, tonte de l'herbe et nettoyage des objets abandonnés
- Participation à la 19ème. Conférence Europénne Photovoltaïque à Paris.
  Distribution de documentation Demosite.

Collaboration nationale et internationale

Demosite reste relié aux activités de l'AIE, notamment à travers les groupes qui le visitent (Tâche 3, Tâche 9), et sa possible utilisation dans le cadre de la future Tâche 10.

Une autre application internationale est prévue à travers le projet européen SOLABS, visant à développer des capteurs thermiques non-vitrés colorés afin d'en augmenter l'acceptabilité architecturale: un élément prototype sera installé sur un pavillon "façade" de Demosite (ex-Solface).

Évaluation de l'année 2004 et perspectives pour 2005

L'année 2004 a permis de réaliser les objectifs prévus pour cette période, et aucune activité n'est prévue pour l'instant concernant l'année suivante. Des discussions sont en cours avec la Direction de l'Ecole pour décider du sort de Demosite pour les prochaines années (maintien en l'état, démontage partiel, démontage total). Ces options dépendront en partie d'un financement minimal pour garantir un aspect correct des pavillons (image de l'EPFL)

Références et publications

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Sur invitation

Systemtechnik

Annual Report 2004

Centrale LEEE-TISO
Periodo VII : 2003-2004

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

ABSTRACT

During 2004 more than 2100 flashes have been performed with the indoor 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). In 4 years more than 10000 flashes have been performed. In April 2004 the fourth quality audit for the ISO17025 accreditation maintenance, supervised by the Swiss Accreditation Service, was successfully passed.

For the execution of measurements at different temperatures a thermostatic chamber, specially developed for the LEEE, was acquired. In the procedure for the temperature coefficients determination measurement of the I-V characteristic at 5°C intervals, from 25°C up to 60°C, are performed.

During 2004 the measures of test cycle 9 are concluded. Stabilised power P_{15} of c-Si module is on average 4.0% lower with respect to initial power P_a. The maximum power degradation was equal to -8.1%. The mean difference between the power of c-Si modules given by the manufacturer and the measured stabilized one is -6.9%, and all the modules are within the warranty limit.

The new Maximum Power Tracker for medium term outdoor test is under development with improved features.

In the BIPV field a first SUPSI internal workshop has been organized with 11 teachers and scientific collaborators in the architectural, civil engineering and electronic areas. A documentation research about architectural aspects of different PV integration typologies has been presented.

During 2004 the LEEE website layout has been completely revised to present a systematic vision of all projects (http://www.leee.supsi.ch).

BFE OFEN UFE SFOE

1 Introduction / Goal of the project

The aim of the project is the quality control of the photovoltaic modules most present on the Swiss market. The LEEE testing centre gives to designer and installers its experience about modules measurements (indoor and outdoor) and PV systems for a better quality of PV plants.

The goals for 2004 were:

- ISO17025 accreditation maintenance for I-V measurements with sun simulator.
- Acquisition of a thermostatic chamber for the determination of PV modules temperature coefficient. Execution of a series of test measurements at different temperatures.
- Performance measurements of module with high capacitances cells (direct measurement and multiflash method).
- Final tests on modules of test cycle 9.
- Design and development of a new MPPT prototype.
- Optimization of a method for the energy rating prediction (matrix method).
- Automation and optimization of sun-tracker measurement system
- Analysis of different PV integration typologies and internal workshop on architectural areas.

2 Description of the project

The "Test Centre LEEE-TISO" it is structured in the following main activities: indoor measurements with flash sun simulator accredited ISO 17025, outdoor analysis of the behavior of PV modules under environmental condition in short, medium and long term, photovoltaic building integration.

Since January 2000 at the LEEE-TISO a class A pulsed Sun Simulator has been operating for the I-V curve standard measurement of crystalline silicon module (IEC 60904-1); the measurement are accredited ISO 17025 by the Swiss Accreditation Service (SAS). With a stable and uniform thermostatic chamber it is possible to execute measurements at different temperatures. Investigation on indoor measurements of c-Si and thin film modules and at different irradiances 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. 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 for 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 Carried out work and achieved results

3.1 INDOOR I-V measurements (I)

During 2004 more than 2100 flashes have been 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). In 4 years more than 10000 flashes have been performed.

3.1.1 ISO 17025 accreditation

In April 2004 the fourth quality audit for the ISO17025 accreditation maintenance, supervised by the Swiss Accreditation Service, was successfully passed.

On behalf of the accreditation maintenance a series of calibrations and measurements have to be regularly executed. During 2004 the stability of accredited measurements was very good, remaining within the ∂1.0% range (mean annual variation).

In consideration of the measurements accuracy it has been decided to send both reference cells to the PTB (Physikalisch-Technische Bundesanstalt) for their calibration. Each reference cell is calibrated every 2 years. Once calibrated, it is used as reference for one year, and then replaced (for one year) by the other, just calibrated, cell.

3.1.2 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) have been performed. As “new” reference module, in substitution of the one lost last year during the shipping, has been chosen the same type.

International Intercomparison

An “International PV module measurement intercomparison” was organised between accredited laboratory by the National Renewable Energy Laboratory (NREL, Colorado, USA) in order to verify the consistency of the measurement. Only accredited measurement was considered, for the intercomparison and therefore only c-Si measurement. Indoor and outdoor performance measurements have been executed on 6 types of modules (1 sc-Si and 5 thin-films), while the concentrated device has not been tested for technical reasons. During the first months of 2005 all the data will be compared and results will be published in a Technical Report edited by NREL, and then presented at the IEEE PV Specialist Meeting (USA).

3.1.3 Service measurements for third-parties

In 2004 a total of 279 I-V measurements have been executed for third-parties (43 parties), including the control measurements committed by Canton Ticino within the subsidy program for the installation of grid-connected PV plant (6 parties – 30 measurement), and the “PV-Enlargement” project of the 5FP (8 parties – 95 measurement). The amount of third-party I-V measurements with the sun simulator is 150 measurement / year.

3.1.4 I-V measurements at different temperatures

In addition to the electrical characteristic measurement at Standard Test Conditions STC (25°C and 1000 W/m²) it has been decided to verify, with the sun simulator, the PV modules behaviour at different temperatures (Isc (Ŭ), Voc (ƅ) and Pm temperature coefficients) and irradiances.

For the execution of measurements at different temperatures the module temperature has to be stable and uniform; for this reason a thermostatic chamber, specially developed for the LEEE, was acquired. Unfortunately the device was delivered only in April 2004 (6 months late with respect to the due date) because of a series of delays of the manufacturer.

A series of test measurements have been executed, especially for determining the reference cell position (inside or outside the chamber). To assure a better irradiance uniformity it has been decided to put the reference cell PRC332 (inventory number C10-001-00) inside the chamber: knowing its Ŭ coefficient (0.0278 mA/°C) it has been possible to calculate the reference cell sensitivity at different temperatures.

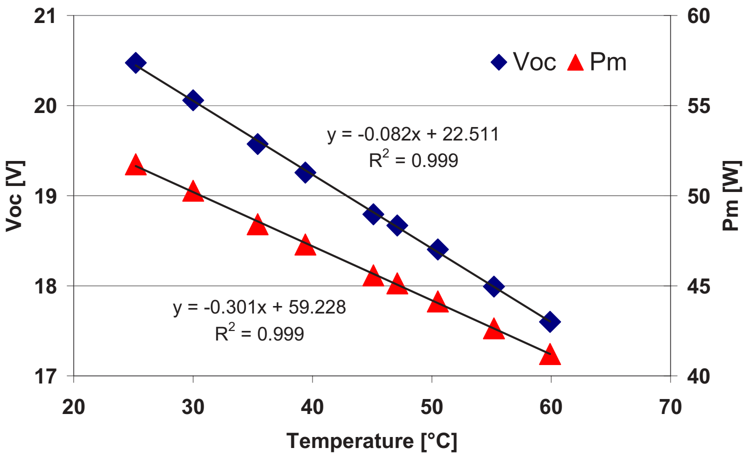


Figure 1: Example of temperature coefficients (module type SF75).

The procedure for the temperature coefficients determination has been defined as follow: measurement of the I-V characteristic at 5°C intervals, from 25°C up to 60°C (9 measurements). Measurements are performed gradually heating the module (not during its cooling), and when it has reached the required temperature for 5 minutes at least. In this test phase, temperature coefficients of 6 modules of previous test cycles (both c-Si and thin-films) have been determined.

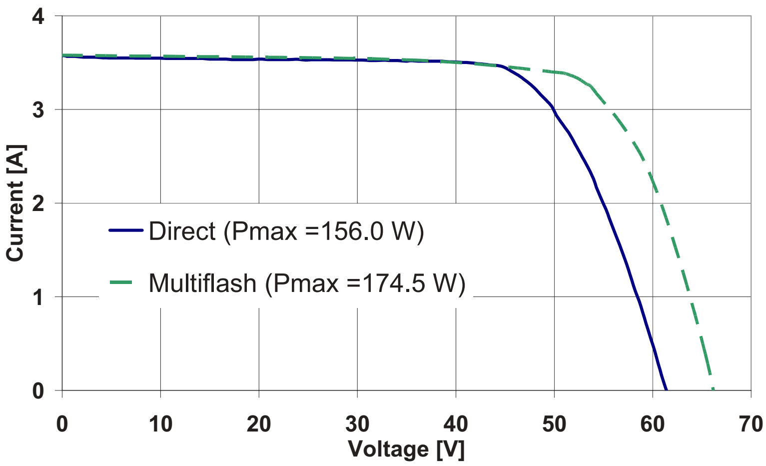
At present the LEEE offers the temperature coefficients determination of PV modules as service, and it is preparing the documents required for this test accreditation in 2005, on the occasion of the next quality audit.

3.1.5 I-V measurements at different irradiances

Investigation on measurements at different irradiances have been performed, from 200 to 1000W/m² (at intervals of 100 and/or 200 W/m²), on 18 different types of modules (c-Si and thin-film). Irradiance has been changed modifying the flash generator power, and this could lead to a spectrum variation at low irradiances (200 W/m²). However, results of the 18 series of measurements show a linear trend of the analysed electrical parameters Pm, Voc and Isc, both for c-Si modules and thin-films; therefore it is assumable that the lamp spectrum did not change at low irradiances. The main activities will be performed in 2005.

3.1.6 I-V measurements for high capacitance cell

The possibility of finding PV modules with high capacitances cells and high series resistances (see [1]), and so to obtain, with a pulsed sun simulator, bad results from the direct IV measurement, led the LEEE to perform multiflash measurements on all new PV module types.



Regarding service measurements, notable differences have been found in modules Atersa A-120 P5 (mean $\div Pm_{multi-direct}$ = 5.3%) and Webel WS115 (mean $\div Pm_{multi-direct}$ = 4.8%).

Sanyo HIP-J54BE2 modules (with cells made of one c-Si layer and a very thin a-Si film) presented a considerable capacitive effect (mean $\div Pm_{multi-direct}$ = 12.0%).

Figure 2: I-V characteristic of Sanyo HIP-J54BE2 module in direct and multiflash (dashed line) measurements.

3.2 Medium term OUTDOOR module characterisation (OA)

3.2.1 Test cycle 9

The modules were exposed for a total of 15 months so that a year at stable power would be completed after initial degradation. There exposed 14 types of modules (3 sc-Si, 9 mc-Si and 2 a-Si), while 3 types of modules had already been measured in the past (Siemens ST40, Würth Solar WS1007 e ASI16-2300).
During 2004 I-V measurements @STC were carried out every 3 months (P_0, P_3, P_6, P_9, P_{12}, P_{15}).

From this data it is possible to verify the:

- **initial degradation:** is the degradation in the first hours of exposure (20kWh/m^2 of insolation) at Voc.
- **first 3 month degradation:** is the degradation in the first 3 months at MPP.
- **secondary** and **annual degradation:** is the degradation during the stabilised period every 3 months and after one year.

× the respect of **warranty** through the comparison of the **stabilised measured values** with those guaranteed from the manufacturers

This last aspect does not have to be confused with the previous ones. The first three points are of technological nature, while the last one refers to marketing aspects.

MODULI		(P0-Pa)/Pa	(P3-P0)/P0	(P6-P3)/P3	(P9-P6)/P6	(P12-P9)/P9	(P15-P12)/P12	(P15-P3)/P3	(P15-Pa)/Pa
		Initial degradation (20kWh/m²)	First 3 months degradation	Secondary degradation				Annual degradation	Total degradation
Evergreen, EC-110	mc-Si	-1.5%	-1.7%	1.0%	-0.5%	-1.3%	-0.9%	-1.8%	-5.0%
Solterra, SOL140	sc-Si	-2.5%	-1.4%	0.4%	0.6%	-1.1%	-0.3%	-0.5%	-4.4%
(1) Atersa, A-120 P5	mc-Si	-0.9%	-2.3%	0.4%	-0.5%	-0.6%	1.2%	0.6%	-2.7%
RWE, ASE-100-GT-FT	mc-Si	-2.4%	-1.7%	0.8%	-1.9%	-0.4%	-0.3%	-1.8%	-5.8%
(2) Isofoton, I-106 *	sc-Si	-0.1%	-1.0%	n.a	n.a.	-1.5%	0.4%	0.5%	-0.6%
BP Solar, BP 5170	sc-Si	-1.8%	-0.5%	0.5%	0.0%	-1.0%	-0.9%	-1.3%	-3.7%
BP Solar, MSX120	mc-Si	-3.9%	-2.0%	0.7%	-0.1%	-1.4%	0.9%	0.1%	-5.7%
Kyocera, KC120-2	mc-Si	-2.7%	-1.6%	2.0%	-1.4%	-0.8%	-0.7%	-0.9%	-5.1%
Sharp, SB160	mc-Si	-2.2%	-2.9%	-0.1%	-0.5%	-1.1%	-1.6%	-3.2%	-8.1%
MHH, MHHplus 180	mc-Si	0.0%	-0.9%	0.5%	-0.4%	-1.0%	0.0%	-0.9%	-1.7%
Shell Solar, RSM 105	mc-Si	-1.1%	-0.2%	0.3%	-0.2%	-0.5%	0.2%	-0.1%	-1.4%
Axitec, AC165P/12	mc-Si	-2.5%	-1.1%	-1.0%	-0.7%	-0.2%	n.a.	n.a.	n.a.
Uni-Solar, US-116	a-Si	n.a.	n.a.	-1.1%	-1.3%	-3.7%	1.1%	-5.0%	-21.0%
Kaneka, K58	a-Si	n.a.	n.a.	3.8%	-3.8%	-7.5%	-1.6%	-9.1%	-33.2%

(1) multiflash measurement
(2) only one module

Table 1: Degradation of modules of cycle 9: initial (after 20kWh/m²); after 3 months; secondary degradation measured every 3 months; annual degradation and total degradation.

Initial degradation occur mainly in the first hours of exposure (20kWh/m² insolation) and it ranges from 0.0% to -3.9% (mean value: -1.8%) (see Table 1). In general, each measurement at STC of new c-Si modules must be preceded by a short period of exposure. For this test cycle, in particular, a further degradation occurred in the next 3 months (-1.4%, range from -0.2% to -2.9%).

Stabilised power P_{15} of c-Si module is on average 4.0% lower with respect to initial power P_a for this type of module and ranging from -0.6% and -8.1%.

In the standard modules with c-S cells, the average reduction after one year of exposure (from P3 to P15) in almost cases were within the reproducibility error limits of the measurements using the flash sun simulator.

Power measurements of thin film modules with pulsed solar simulator don't give reliable results; an outdoor characterisation has to be found.

The mean difference between the power of crystalline modules given by the manufacturer and the measured stabilized one is -6.9%, and all the modules are within the warranty limit.

3.2.2 Modification, improvement and substitution of electronic devices.

The electronic devices used for medium term photovoltaic module tests had been operating for 9 years under intense working and real environmental and meteorological conditions. In order to maintain a high reliability and to fulfil the new requirements of the PV modules market and research, it was decided to develop and realize a brand new device.

New features have been included in this new device for PV module testing, named "MPPT 3000", and moreover all main parameter ranges have been extended. Among these new features, there is the on-line scan of the I-V characteristic and the possibility to measure, independently from data loggers or external peripherals, the main meteorological parameters.

Features :	**Technical specifications :**	
Maximun Power Point Tracker (MPPT)	Pmax in :	250W
Simultaneous current and voltage measurement	Voc max :	150V selectable ranges
Scanning of the I-V characteristic	Isc max :	20A selectable ranges
Opto isolated UART RS485 communication	Vm min :	5V
Real Time Clock (RTC)	Operating temp. :	-20° - +70°C
Display and keyboard		
2 x temp.sense input + 2 x analog imput		
Vm + Im + 2 aux opto isolated analog output		

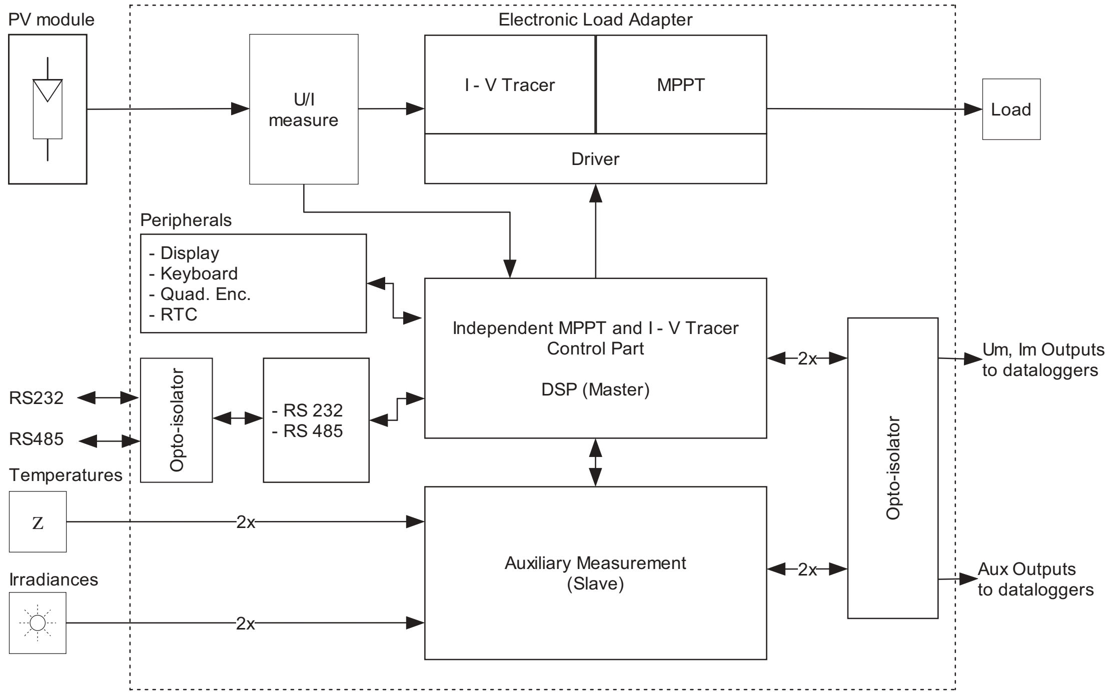


Figure 3: Block Diagram for the MPPT 3000.

The project is currently in the prototype assembling and programming phase. The Maximum Power Point Tracker function will be tested in association with the competent photovoltaic laboratory of the HTI engineering school in Burgdorf (CH).

3.3 Short term OUTDOOR module charact. with sun-tracker (OB)

The scope of the development of a new outdoor measurement system combined with a sun-tracker, is to respond to the need of a fast and flexible characterisation method under real operating conditions and to dispose of an alternative to our pulsed solar simulator for all the technologies, which can't be measured indoor with an acceptable accuracy.

The main objective is to realise a so far as possible automatic system, which does not only allow to measure the most important PV module and meteorological data, but also to immediately filter and analyse the acquired data.

Additionally to the common raw data, following data representations are foreseen: I-V curves @ STC; PV Module parameter (I_{sc}, V_{oc} , P_m, I_m, V_m, ɖ, FF) in relation to the main environmental variables (incident irradiance G_i, diffuse irradiance fraction G_{0diff}/G_0, ambient temperature T_a, module temperature T_{mod}, angle of incidence AOI, air mass AM, wind speed and direction, solar spectrum composition, etc.). e.g. P(G_i, T_a) and ɖ(G_i); frequency N of defined meteorological conditions e.g. N(G_i, T_a) and N(AM); module temperature in relation to the main environmental variables e.g. T_{mod}-T_a(G_i).

The PV module parameter which can be determined by these graphs are A) the module parameter I_{sc}, V_{oc} , P_m, etc. @ STC; B) the temperature coefficients ζ, η, etc. for different irradiances and C) the nominal operating cell temperature NOCT.

3.3.1 Progress in measurement system

A new software and improved electronic load is currently under development for our sun-tracker. To enhance the capacities of the old IVAQ (I-V AcQuisition) the electronic load had to be modified and a new NI data acquisition card (PCI-MIO-16E-4) to be implemented. The first prototype has been tested. Figure 4 shows the new measurement scheme.

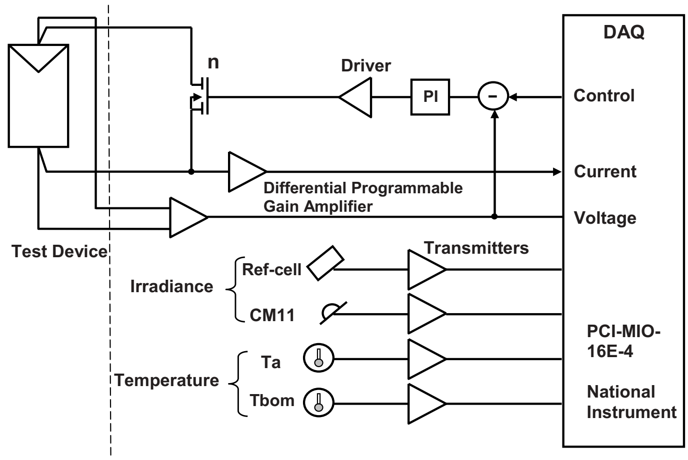


Figure 4: Block diagram of the sun-tracker outdoor measurement system under development.

The new load system allows to better control the on the module applied bias voltage and sweep speed. The major flexibility of the updated system consents for example to apply a triangle pulse to the module with the same sweep speed (2ms) and quality of the solar simulator system. In this way it is possible to investigate measurement artefacts caused by high PV module capacitances (see 3.1.6).

So far following main features have been integrated into the new outdoor characterisation system:

1. sun-tracker control via software allowing 3 different module positions (direct solar tracking - AOI=0°; user defined position (AZ, EL); same position as energy rating test stand (AZ= -7°, EL=45°))
2. calculation of the angel of incidence (AOI) and air mass factor (AM)
3. generation of the voltage signal to apply to the module (sweep times; signal type: single sweep forward, single sweep reverse*, triangle pulse, sinus, constant voltage, user-defined)
4. measurement of different irradiance and temperature sensors or I-V curve.
5. interpolation and calculation of module parameters I_{sc}, V_{oc} , P_m, I_m and V_m
6. STC correction by manually inserting the correction factors b and D (see next paragraph)
7. inter-comparison of declared, measured and calculated module parameter
8. creation of a file with all measured and calculated data
9. simultaneous measurement of up to nine different irradiance sensors (continuous measurement)

3.3.2 STC correction

An in the past for our portable IV-tracer system (PVCT - Solar Systeme Schutt) written I-V curve translation software has been overworked and tested on crystalline silicon technologies. The STC translation procedure used here is a modification of the Blaesser method [10-14] and is based on the determination of the two factors b and D. The objective is to further improve the software, to integrate it into the new sun-tracker program and to add the possibility to execute STC corrections to different kind of PV module technologies, by incorporating the respective correction procedures.

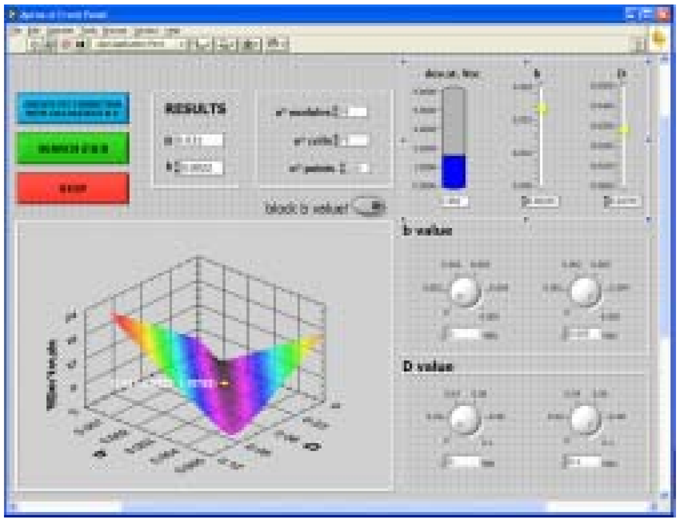


Figure 5 Software for the STC correction of outdoor measured I-V curves

3.4 Building integration (BIPV)

The two activities in the BIPV area, "Tests on safety and functionality" (B1) and "Additional solutions and assistance instruments" (B2) will be mainly carried out in the period 2005-2006. Nevertheless, the 12th November a first SUPSI internal workshop has been organized with 11 teachers and scientific collaborators in the architectural, civil engineering and electronic areas. A documentation research about architectural aspects of different PV integration typologies has been presented.

3.5 Homepage and tools (D)

During 2004 the LEEE website layout has been completely revolutionized to present a systematic vision of all projects. Structures and design have been defined for corresponding to the website school layout.

Figure 6 Homepage of the Laboratory of Energy Ecology and Economy (**http://www.leee.supsi.ch**)

The photovoltaic component will be enlarged to include, besides research results, design tools for engineers and architects.

4 National and International Collaboration

HTI Burgdorf, prof. H. Häberlin; Università di Lecce, prof. Vasanelli, Dr. Adriano Cola, Marco Pierro; JRC Ispra, Dr. Heinz Ossembrink, Dr. Ewan Dunlop, Robert Kenny, W. Zaaiman. Mr. Hiroshi KATO, Mr. Kengo MORITA, JET (Japan Electrical Safety & Environmental Technology Laboratories). Dr. Yoshiharu HISHIKAWA, AIST (National Institute of Advanced Industrial Science ant Technology). Mr. Hitoshi KUDO, NEDO (New Energy and Industrial Technology Development Organization).
From 28th to 30th April 2004, LEEE-TISO hosted the annual meeting of the WG3, TC82 IEC.

5 Prospect for 2005

All actions foreseen for 2005 will go on according to our time plan. All maintenance activities of the solar simulator will continue as before. First tests executed with the new thermostatic chamber, dedicated to temperature coefficient measurements, gave satisfactory results. The accreditation ISO 17025 of these tests is so expected for October 2005, together with our next audit. Further tests on indoor measurements of thin film modules will happen in parallel with outdoor measurements.

Begin of 2005 the new MPPT will be operational and a new measurement cycle will start. The matrix method will be further developed.

The safety and mechanical aspects as well as application possibilities of into a building envelope integrated PV module (BIPV) will be investigated and discussed within a by the laboratory organised public workshop. By architects needed tools will be identified.

The photovoltaic part of the LEEE homepage (http://www.leee.supsi.ch) will be extended to include, besides research results, design tools for engineers and architects.

(For more details see « Jahresarbeitsplan 2005 - Centrale LEEE-TISO – periodo VII : 2003-2006»)

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Annual Report 2004

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 this project; 32 PV demonstration systems with an overall generation capacity of more than 1,140 kWp will be installed in 10 different European countries. At this stage of the project, 712 kWp, corresponding to 62% of the total project capacity, are fully operational.

One of the main objectives of the whole project is to allow a scientific energy production inter-comparison in kWh/kW_p of all installations. For the achievement of this goal a quality control on module, system and monitoring level is essential.

The LEEE-TISO is responsible for accompanying scientific measures, more precisely for calibration activities and PV module power performance tests.

23 months have elapsed since the beginning of the project and 97 modules have been measured by our laboratory. The majority of the PV cell technologies actually present on the market in Europe are tested and compared within the framework of this project (mono-crystalline Si, EFG Si, poly-crystalline Si, amorphous Si, CdTe, CIS, hybrid cells, etc.).

The performance tests enable the difference between the purchased module power and the declared power (P_n) to be quantified and measures the possible degradation or recovery occurring during the first days of exposure.

A summary of the results obtained by the LEEE-TISO in 2004 will be given in this report. All technologies will be briefly discussed.

PV INSTALLATION STATUS 2004

Within this project, 32 PV demonstration systems (see Table 1) with an overall generation capacity of more than 1,140 kWp will be installed in 10 different European countries. At this stage of the project 712 kWp, corresponding to 62% of the total project capacity, are fully operational. Most of the other installations will be completed soon.

***Table 1:** List of PV installations - the yellow ones are completed*

Contractor	System Number	Country	Location	Name	Installed power, kWp	Type of PV technology installed	Integration type	PV system components purchased	Installation completed	Foreseen PV system start-up
2	1	DE	Munich	Gehrlicher, Parkdeck Messe München	470	PC, TF-CdTe, TF-CIS, TF-aSi	OR	Yes	Yes	operational
3	2	DE	Munich	FH Munich, 80 kWp PV System	80	MC	OR	Yes		10.2004
5	3	AT	Vienna	Vienna Univ., Naturhistorisches Museum	15	PC	RI	No		11.2004
5	4	AT	Hochschwab	Vienna Univ., Schiestlhaus	8	PC	FI	Yes		11.2004
6	5	AT	Mödling	Donau Univ. Krems, 'SOL4 Eichkogel' (replaces System at Univ. Krems)	29	PC	FI	No		09.2004
6	6	AT	St.Johann	Donau Univ. Krems, 'Troppmair'	53	PC	FI	Yes	Yes	operational
6	7	AT	Kriegerhorn	Donau Univ. Krems, Kriegerhornbahn Oberlech	10	PC	FFI	Yes	Yes	operational
6	8	AT	Wien	Donau Univ. Krems, ARSENAL research Wien	24	PC, TF-aSi	TBD	No		12.2004
6	9	AT	Baumkirchen	Donau Univ. Krems, Niedrigenergiehaus	3	PC	RI	No		12.2004
7	10	AT	Passau	Univ. Innsbruck, 'Haßlach'	30	PC	FRI	No		10.2004
8	11	AT	Mürzzuschlag	Viktor Kaplan Acadamy	25	TF	TBD	No		12.2004
9	12	BG	Gabrovo	TU Gabrovo, 10 kWp PV System	10	MC, TF-aSi	OR	Yes		09.2004
10	13	BG	Sofia	CL SENES,10 KWp AcadPV-Sofia	10	MC, PC	FRI	Yes		07.2004
12	14	CZ	Prague	Charles Univ. Prague, 20 kWp PV System	20	MC	OR	Yes	Yes	operational
13	15	CZ	Brno	Brno Univ. of Technology, 20 kWp PV System	20	MC	OR	Yes	Yes	operational
14	16	CZ	Ostrava	TU Ostrava, 20 kWp PV System	20	MC	OR	Yes	Yes	operational
15	17	CZ	Plzen	Univ. Plzen, 20 kWp PV System	20	MC	OR	Yes	Yes	operational
16	18	CZ	Liberec	TU Liberec, 20 kWp PV System	20	MC	OF	Yes	Yes	operational
17	19	EL	Pikerni	CRES, 40 kWp PV System	40	MC	OR, FRI	Yes	Yes	operational
18	20	EL	Athens	Agricultural Univ. of Athens, 15 kWp PV System	15	MC, PC,TF-CIS	OR, OF	Yes		06.2004
19	21	HU	Gödöllö	Szent Istvan Univ. Gödöllö	10	PC, TF-aSi	RI	Yes		07.2004
20	22	IT	Rom	Univ. of Rom, 'La Sapienza'	20	TBD	TBD	No		TBR
21	23	IT	Florence	Univ. of Florence	20	PC	FRI	Yes	Yes	operational
22	24	IT	Pistoia	Pontenuovo	19	TF-tripl.junc.	FRI	Yes	Yes	operational
23	25	PL	Warsaw	Warsaw Univ. of Technology	21	MC, TF	TBD	No		07.2004
24	26	PT	Oeiras	Instituto Superior Tecnico	50	TF	TBD	No		TBR
25	27	PT	Lisbon	Universidade Nova de Lisboa, UNL	50	MC	TBD	No		TBR
26	28	RO	Bucharest	Universitea 'Politehnica' din Bucuresti	31	MC, TF-aSi	OR + FL	Yes		09.2004
				Total (by contract 1.014 kWp)	1'142					

(1) In the column '**Type of PV Technology Installed**' the abbreviations stand for:
MC - mono crystalline Si
PC - poli crystalline Si
TF - thin film (TF-aSi for amorphous silicon, etc.)

(2) In the column '**integration Type**' the abbreviations stand for:
OR - On Roof Installation
RI - Roof Integration. PV system is part of building envelope
FRI - Full roof integration. PV system replaces roof
OF - On Facade installation
FI - Facade Integration. PV system is part of building envelope
FFI - Full facade integration. PV system replaces facade of building

TBD - To be defined
TBR - To be replaced

LEEE-TISO OBJECTIVES IN 2004

Introduction

One of the main objectives of the whole project is to allow an energy production inter-comparison in kWh/kW_p of all installations, but not only by considering the nominal power declared by the manufacturer but especially by looking at the real installed module power. For this reason it has been decided to test a selection of 6-8 modules from each PV plant for their power. Depending on the technology, different indoor and/or outdoor IV-measurements are performed. A final check of the total installed power will be done by measuring the strings of all installations and by translating them to STC. A combination of laboratory measurements, on-site string measurements and monitoring data will be used for the final energy output analysis.

Note: From a statistical point of view 6-8 modules per installation are not significant enough to predict the total installed power of a plant, but it gives an idea of the quality of power declarations as well of the magnitude of error introduced by these. It would be very time consuming to test a larger number of modules and the shipping costs would not be acceptable.

Within this project the LEEE-TISO laboratory is responsible for most accompanying scientific measures and more precisely for all calibration activities and PV module power performance tests.

Objectives

1. In the first test phase, 210 randomly selected modules (6-8 of each installation) will be measured by the LEEE-TISO. The objective is to determine the stabilised power of the modules through indoor and/or outdoor measurements and light soaking tests. This test phase should be completed during the first half of 2005.

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

3. All PV systems will be equipped with one or more silicon sensors for in-plane irradiance measurements. To assure a high and reproducible measurement precision and to satisfy the EC JRC guidelines for PV system monitoring, the sensors will be calibrated indoors by the LEEE-TISO.

4. An analysis of the I-V measurements will be made for all technologies and first conclusions will be drafted. First degradation occurring during light soaking and deviation from the nominal power will be reported together with the inter-comparison of different indoor and outdoor measurement techniques applied to the different PV technologies.

LEEE-TISO WORK PROGRESS IN 2004

State of module performance tests

Table 2 shows the list of modules to be measured during the first test cycle. Until now, 97 modules have been delivered to our laboratory. Some other modules will arrive in the next few months. The majority of the PV cell technologies actually present on the market in Europe will be tested and compared within the framework of this project (mono-crystalline Si, EFG Si, poly-crystalline Si, amorphous Si, CdTe, CIS, hybrid cells, etc.). Not all modules to be tested could be defined until now as there are still some installations missing (see Table 1) and some PV installations planned initially had to be replaced by others due to national funding problems.

Test procedure

Before starting with the real power measurement, each module type is checked for possible measurement difficulties due to high cell capacitances. All modules showing capacitive effects will be characterised indoor with a single point IV-measurement procedure (multi-flash meas.) instead of our faster and more commonly used sweeped IV-measurement procedure (single-flash meas.). This guarantees correct measurements with an accuracy of ±2% for all c-Si technologies. For these module technologies, where the indoor measurement accuracy of ±2% cannot be guaranteed due to the non availability of matched reference cells or to technology specific measurement difficulties, additional outdoor measurements at near to AM1.5 conditions are carried out.

The general test procedure for the modules consists of an initial power measurement at standard test conditions (STC), and a second measurement after an outdoor exposure with a cumulated insolation of at least 20 kWh/m². The first measurement gives information about the difference between the module power and the declared power (P_n), while the second measurement gives information about the degradation occurring during the first days of exposure.

Table 2: *Modules to be tested in the first test cycle – the yellow ones are completed*

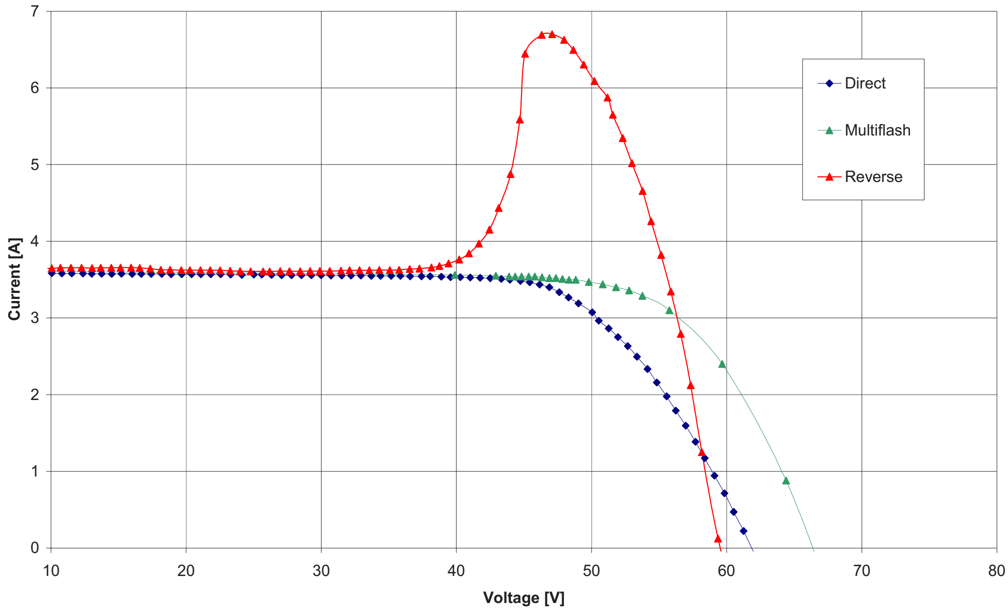
	partner name	*module technology*		*origin*	*n°*	*tested*
1.	**Università degli studi di Firenze**	**- Photowatt PW1250**	**c-Si**	**F**	**6**	**Yes**
2.	**Gehrlicher**	**- Antec ATF43**	**CdTe**	**D**	**14**	**Yes**
		- RWE ASI-F 32/12	**a-Si**	**D**	**6**	**Yes**
		- Shell ST40	**CIS**	**D**	**6**	**Yes**
		- Solon M210/6	**c-Si**	**D**	**6**	**Yes**
		- Würth WS11007/70	**CIS**	**D**	**6**	**Yes**
		- Sanyo HIP-J54BE2	**c-Si**	**J**	**6**	**Yes**
		- Isofoton CER50	**c-Si**	**ES**	**6**	**Yes**
		- First Solar FS55	**CdTe**	**USA**	**6**	
		- RWE ASE	**c-Si**	**D**	**6**	
		- Shell SQ	**c-Si**	**D**	**6**	
		- TBD				
3.	**ATB**	**- RWE ASE 300**	**c-Si**	**D**	**6**	**Yes**
		- Fischer/ Power cell	**c-Si**	**D**	**1**	**Yes**
4.	**Solartec**	**- Solartec Radix72 dark blue**	**c-Si**	**CZ**	**8**	**Yes**
		- Solartec Radix72 marina blue	**c-Si**	**CZ**	**8**	**Yes**
5.	**Agri. University of Athens**	**- Shell S115C**	**c-Si**	**D**	**6**	**Yes**
		- Shell SQ150	**c-Si**	**D**	**6**	**Yes**
		- Shell ST40	**CIS**	**D**	**6**	**Yes**
6.	Szent Istvan University Gödöllö	- Dunasolar DS40	a-Si	HU	6	
		- RWE ASE100	c-Si	D	6	
7.	Centre for Renewable Energy Sources, CRES	- Solarfabrik SF115	c-Si	D	6	
		- Conergy 105L	c-Si	D	6	
8.	FH München	- Solarfabrik SF115 - TBD	c-Si	D	6	shipped
9.	Warsaw University of Technology	- TBD				
10.	Bucharest Politechnical University	- TBD				
11.	TU Gabrovo	- TBD				
12.	CL Senes Sofia	- TBD				
13.	Roma Energia	- Kaneka CSA211	a-Si	J	6	
		- S.E. Project SEM90-M	c-Si	I	6	

Test results of crystalline silicon modules

Capacitive effects

Among the modules tested until now, only one module showed capacitive effects. All modules of this type have been measured with our multi-flash measurement method, where the steady state I-V curve is determined point by point and not by a voltage sweep of approx. 2 ms. Figure 1 shows the test results of one of these modules. In the curves obtained with the sweeped method a clear hysteresis is visible due to the high internal capacitance.

Figure 1: *Sweeped I-V curve measurement (direct and reverse) and steady state I-V curve measurement (multiflash) of a module with high cell capacitance.*



During this year (2004) 53 crystalline silicon modules of 8 different types have been tested. One module was found to have a broken cell and had to be replaced by the manufacturer. Table 3 summarises the on the label declared nominal power (P_n) and tolerance (t) of each module type together with the average initial divergence of the purchased module power from the nominal power and the average degradation in the first days of outdoor exposure. This eventual initial degradation occurs only at the beginning of the module life cycle. It is expected that afterwards the power will remain generally quite stable, except for a very small annual degradation of approximately 0.3%.

Table 3: *Average results for each c-Si technology*

	Avg. initial difference to Pn	*Avg. degradation after light soaking (>20kWh/m²)*
1.	-9.4%	-0.9%
2.	-7.8%	-1.0%
3.	-7.5%	-
4.	-4.4%	-1.3%
5.	-2.0%	0.1%
6.	-1.3%	-3.3%
7.	-3.0%	-1.6%
8.	+9.6%	-0.3%
9.	-0.80%	-0.10%
10.	+3.40%	-0.70%

Purchased power

Considering the evaluation of the purchased power as well the measurement accuracy of ±2%, we can state that half of the studied c-Si modules shows an average initial power which is lower than the nominal power ($P < P_n$-2%) declared by the manufacturer. The maximum difference is -9.4%. From these module types, three resulted even lower than the acceptable minimum power P_{min}, defined as the nominal power P_n minus the declared tolerance t and minus the measurement accuracy (±2%). The other 7 module types respected the tolerance limits given by their data sheets.

The module with the highest positive power difference (+9.6%), is a non-standard glas-glas module constructed for building integration. No labelling or official data sheet was available. Moreover, compared to the other modules, from which at least 6 were available for testing, only one module has been sent to our laboratory for measurements. For these reasons it cannot really be compared with the other modules.

Power after first light soaking

After an outdoor exposure of at least 20kWh/m², the initial degradation of c-Si was determined. The degradation ranged from 0 to -3.3%. The average degradation of all c-Si technologies was of -1.2% and stayed within the range of measurement accuracy. A negative trend is clearly visible, but the values were all smaller than 2% apart from one. All tested modules will be integrated into the installations and some of them will be measured again towards the end of the project to verify if a further degradation has occurred. If there are no major problems the further degradation should not exceed 0.3%/year.

Note: It should be mentioned, that it is not always possible to know if the modules arriving at our laboratory for testing have been previously exposed to light and if they are already totally or partially degraded.

Note: For one module type, only the measurement of the purchased power is available and no conclusion about the first degradation could be made. A verification regarding the stabilised power will be carried out in the second test phase at the end of the project.

Test results of thin-film modules (CIS, CdTe, a-Si)

38 thin-film modules have been measured for this project until now. The test samples include, 2 different CIS technologies (ST40 from Shell Solar and WS11007 from Würth Solar), 1 CdTe technology from Antec and 1 a-Si technology from RWE Schott Solar. Other thin-film modules will be delivered for testing during the next few months. The module types already defined are, 1 other CdTe type from First Solar and 2 other a-Si technologies (DS40 from Dunasolar and CSA211 from Kaneka). Some others still have to be defined. The most important CIS and CdTe manufacturers and the majority of a-Si module producers will be so included in the study.

Due to material related measurement effects, a reading of the thin-film module measurement results obtained until now is very difficult. As a result, at this stage of the project only a summary of the main observed module behaviours will be given. The final measurement results together with a detailed analysis will be reported towards the end of the project when all monitoring and measurement data are available.

Capacitive effects

None of the tested thin-film modules showed capacitive effects with an I-V curve sweep speed of 2ms.

Purchased power and power after first light soaking

The purchased power of all modules has been determined via indoor and outdoor measurements. Various measurement and technology related difficulties have to be considered. The following observations have been made, distinguishing by module technology.

CIS The ST40 and WS11007 modules showed different behaviours. A comparison of indoor and outdoor measurements has shown, that the Shell technology (ST40) cannot be measured indoors with our standard measurement system. The measured STC power indoors remains 10% to 20% lower than the outdoor measured power. This difference cannot only be explained by a slightly higher spectral miss-match factor compared to c-Si, but by the fact that there must be another effect influencing the measurements. One explanation seems to depend on the history of the module, or more precisely on the amount and spectral composition of the irradiance absorbed by the module just before the measurement. The WS11007 modules seems to be much less influenced by irradiance history; in fact, the indoor and outdoor measured powers are closer to each other and almost within the range of measurement uncertainty.

Concerning the production tolerance, it can be roughly concluded that the tolerance of CIS modules is visibly higher than the typical crystalline silicon production tolerance. The ±10% tolerance declared for CIS modules corresponds more closely to reality than that for c-Si modules.

Note: For c-Si, the actual production tolerance seems to be lower than the declared one. A ±3% can be frequently observed for standard crystalline silicon modules even if ±10% is declared.

The initial power of all CIS modules is most of the time within the range of ±10% of the nominal power with a tendency for the Würth modules towards negative differences. After an outdoor exposure of approximately 1 month, all Würth modules showed a more or less pronounced (2-13%) increase in power, reaching final values higher than the declared nominal power. Conclusions for the ST40 modules are so far not possible.

CdTe Up to now, only one of the two CdTe technologies existing on the market could be tested. The Antec modules delivered to our laboratory consisted of 8 modules which had been taken from an already existing installation and 6 new modules. Both modules are from the same type (ATF43) but from different periods of production.

The spectral responsivity of CdTe modules does not allow assurance of the same high measurement accuracy as obtained for c-Si technologies. The miss-match factor of the indoor measurements with a c-Si reference has to be determined and correction applied. A spectral response system for PV modules, not available at the LEEE-TISO laboratory, would be needed for this kind of correction. For this reason, the IV-measurements of two modules were repeated outdoors at near to STC conditions after 1 month of outdoor exposure. Both modules have remained at our laboratory for further characterisation and degradation studies.

a-Si Amorphous silicon modules generally have an initial power which is higher than the declared stabilised power. After a period, which can vary from 3 to 12 months, depending on the kind of material, the power reaches its stabilised value. The only amorphous silicon technology tested here showed an initial degradation but did not reach the final stabilised value, due to the limited exposure time (approx. 1 month). At least 3 months would be needed for an almost complete stabilisation (90% of the initial degradation). After 1 month, the tested modules were still higher than the stabilised power. The modules will be measured again in the second test cycle to verify their stabilised power output. The final measurements have been done outdoor at near to STC conditions. As for CdTe, a miss-match correction should be applied to all indoor measurements.

Irradiance sensor calibration

All PV systems have to be equipped with one or more silicon sensors for in-plane irradiance measurements. The sensors will be manufactured especially for the project by Solartec and calibrated by LEEE-TISO. Already 2 prototypes have been delivered to our laboratory for calibration. The calibrated prototypes have been mounted on one of the PV-Enlargement installations for initial tests. After some minor modifications, the final layout of the sensors could be defined (see Figure 2). It is expected that by the end of the year 2004, all sensors (approx. 50) will be ready for calibration. Distribution to the single partners will be possible in the first month of 2005.

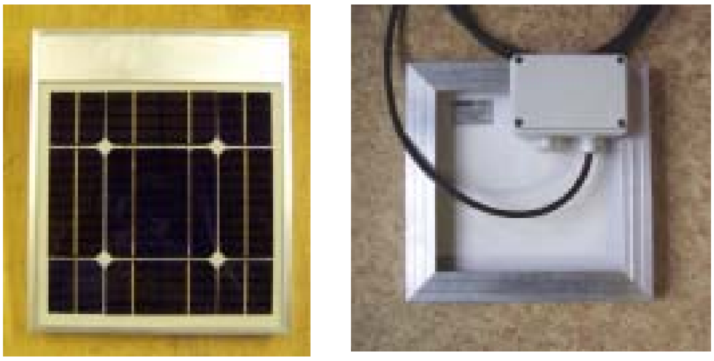


Figure 2: *irradiance sensor (front view and back side view)*

PROSPECTS FOR 2005

In 2005, all PV installations will be operational and the first phase of STC performance measurements will be definitely completed. The silicon irradiance sensors will be calibrated and distributed with their certificates to all partners at the beginning of 2005. The installations will be equipped with the scientific monitoring equipment needed for the project and data acquisition and evaluation will start. First results will be published at the next European PV conference in Barcelona (June 2005). Because of organisational problems and non-convenient air mass conditions, IV-tracer inter-comparison (WIP/LEEE-TISO) has been postponed to spring 2005. Initial energy production inter-comparisons will be made by combining the power values measured by LEEE-TISO, with the on-site string measurements and monitoring data. Further necessary measurements will be repeated on single modules or installations. Detection of eventual degradation effects and resolution of some of the technology related measurement difficulties will be attempted. The modules measured in the first test phase will be integrated into the original installations. To see if a further degradation has occurred, a selection of these will be measured again in 2006, towards the end of the project. The organisation of the second test phase will probably start at the end of 2005. The results will be discussed with the relevant partners and manufacturers before being published.

Publications 2004

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Annual Report 2004

Photovoltaik-Systemtechnik 2003-2004 (PVSYTE)

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Project- / Contract Number	100451
Duration of the Project (from – to)	01.01.2003 – 31.12.2004 (31.12.2006)

ABSTRACT

Purpose and Goals of the project during 2004

- 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 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 2004

- Extended semi-automated tests performed at several new inverters (NT4000, IG30, IG40, SMA Mini Central 6000) with the new PV array simulators on 3 to 5 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 vs. power can be determined.
- PV array simulators: Significant extension of voltage range to 20 V – 800 V instead of 75 V – 750 V and development of new hardware for the control circuits for the smaller PV array simulator of the PV laboratory of HTI in Burgdorf to be prepared better for tests of inverter with unusual specifications.
- To increase measurement accuracy of MPP-tracking efficiency η_{MPPT} further, it is now also possible to use *measured* P_{MPP}-values for each power level for determination of η_{MPPT} instead of extrapolated I-V-curves.
- Introduction of a new quantity $\eta_{tot} = \eta \cdot \eta_{MPPT}$ that can describe overall behaviour of grid-connected PV inverters much better than only DC-AC conversion efficiency η.
- In course of the investment program of the University of Applied Science Bern (BFH) for 2004, a programmable AC/DC source of 3 × 5kW (0-2.5kHz) and an IR-camera could be ordered and commissioned, which will extend the test possibilities of the PV laboratory considerably in the future.
- Continuation of long-term monitoring of PV plants. Realisation of automatic data transmission to HTI by means of a GSM modem for the last plant with analytical monitoring with manual readout. Planning of monitoring equipment and its overvoltage protection for large PV plant Wankdorf in Bern.
- (Mandatory) change of computer network and operating systems to XP on most PC's used in the project.
- Staff change: 3 new assistants taking over the project work and responsibility from former assistants.
- 4 conference contributions at the 19th EU PV Conf. in Paris, an oral presentation at the Swiss national PV conference in Zurich and 2 publications in scientific newspapers on different project results.

Projektziele für 2004

- Ausgedehnte halbautomatische Tests mit der neuen Mess-Software zum Solargenerator-Simulator 25 kW, 750 V, 40 A an einigen neuen Wechselrichtern mit weitem Eingangsspannungsbereich bei je mindestens 3 verschiedenen DC-Spannungen. Dabei weitgehend automatische Aufnahme aller relevanten Daten (DC-AC-Umwandlungswirkungsgrad, MPP-Tracking-Wirkungsgrad, Oberschwingungsströme, cos π).
- Solargenerator-Simulatoren: Überarbeitung der Steuerelektronik des kleinen Simulators von 7,5 kW auf PC-Steuerung. Durchführung der auf Grund der Wechselrichter-Messungen notwendigen Erweiterungen/Anpassungen der Messsoftware/Messverfahren bei beiden Geräten.
- Fortführung des Langzeit-Monitorings an allen Anlagen des Projektes LZPV2 (mit kristallinen und Dünnschichtzellen-Modulen). Umbau aller Anlagen mit Feinmessung auf automatische Datenübermittlung an die HTI sowie Planung der Messeinrichtung der PV-Anlage Wankdorf.
- Durchführung weiterer Tests an Dünnschichtzellen-Solarmodulen (Verhalten bei ungewöhnlichen Betriebszuständen (Teilbeschattung) und Blitzstromempfindlichkeit).
- Mitarbeit im Nationalen Kompetenznetzwerk BRENET (Gebäudetechnik / erneuerbare Energien).

Kurzbeschreibung der 2004 durchgeführten Arbeiten

Die im Herbst 2004 vorhandene Steuer- und Mess-Software für den Solargenerator-Simulator wurde in den Jahren 2003 und 2004 stark verbessert. Statt der 2003 im Vordergrund gestandenen, mathematischen Extrapolation der I-U-Kennlinie aus den gemessenen Daten hat sich bei den praktischen Messungen im Jahre 2004 jedoch gezeigt, dass eine direkte Messung der I-U-Kennlinie auf jeder Leistungsstufe doch vorteilhafter ist, denn die automatische Extrapolation ist bei kleinen Leistungen nicht immer möglich und Fehler bei der Extrapolation können sich unter Umständen doch recht stark auswirken. 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. Für Schnelltests ist die automatische Extrapolation aber natürlich weiterhin verfügbar.

Zur Gewinnung von Testresultaten von neueren Wechselrichtern erfolgten 2004 auch ausgedehnte Tests an einigen neuen Geräten (Sunways NT4000, Fronius IG 30 und IG 40 sowie Sunny Mini Central 6000 von SMA). Dabei wurden auf nunmehr 23 Leistungsstufen alle U, I und P auf der DC- und AC-Seite, der DC-AC-Umwandlungswirkungsgrad ξ, der statische MPP-Tracking-Wirkungsgrad ξ_{MPPT}, die Oberschwingungsströme und der cos π auf der entsprechenden Leistungsstufe gemessen. Im Laufe von 2004 wurde zudem die neue Grösse „totaler Wirkungsgrad ξ_{tot}" eingeführt, die eine noch bessere Charakterisierung des Verhaltens von Netzwechselrichtern ermöglicht. Einige der getesteten Wechselrichter weisen gegenüber früheren Geräten eine deutliche Steigerung des Umwandlungswirkungsgrades auf, der zudem oft deutlich von der verwendeten DC-Spannung abhängt

Um für zukünftige Tests zwei computersteuerbare Simulatoren zur Verfügung zu haben, wurde im Jahre 2004 auch die Steuerelektronik des kleinen Simulators (7,5 kW / 12 A) komplett überarbeitet und der Arbeitsspannungsbereich von 75 V bis 750 V auf 20 V bis 800 V erweitert. Damit wurde dem auf dem Markt zu beobachtenden Trend zu immer weiteren Eingangsspannungsbereichen für PV-Netzwechselrichter Rechnung getragen.

Im Rahmen dieses Projektes wurde auch das Langzeit-Monitoring der im vorangegangenen Projekt gemessenen Anlagen mit insgesamt 55 Wechselrichtern fortgesetzt. Dabei wurde auch die älteste mit einer Feinmesstechnik ausgerüstete Anlage in Burgdorf mit einer automatischen Datenübertragung via GSM Modem ausgerüstet. Auch die Planung der Messtechnik der PV-Anlage Wankdorf wurde in Angriff genommen. Da die Wartung der über 10 Jahre alten Datenkonversions-Software, die noch auf einem unter DOS laufenden PASCAL-Programm beruht, immer mehr Probleme bereitete, wurde eine externe Firma mit der Erstellung eines neuen, Windows-kompatiblen Programms beauftragt. Die Ausfallrate bei den Photovoltaik-Wechselrichtern war 2004 etwa gleich gross wie im Vorjahr. Wie schon 1998 wurden auch 2004 bei einigen Anlagen wiederum Mängel an der DC-seitigen Verkabelung festgestellt. Die im Herbst 2003 durchgeführte thermische Isolation der Anlage Newtech 3 scheint sich zu bewähren, jedenfalls hat sich die weitere Degradation dieser amorphen Anlage deutlich verlangsamt. Dagegen wurden 2004 erstmals Anzeichen einer beginnenden Degradation der 2001 erstellten CIS-Anlage Newtech 1 festgestellt, die bisher sehr stabile Produktionswerte aufwies.

Im Jahre 2004 erfolgten auch viele Wechsel unter den am Projekt beteiligten Assistenten. Nach dem Austritt eines ersten Assistenten im Herbst 2003 erfolgten in der ersten Hälfte 2004 zwei weitere Austritte. Die Verantwortung für das Teilprojekt Langzeit-Monitoring ging von Herrn Ch. Renken an Herr Ch. Geissbühler über. Den Ausbau der Simulator-Steuerelektronik übernahm Herr U. Zwahlen, der zusammen mit Herrn M. Kämpfer Messungen an Netzverbund-Wechselrichtern durchführt. Im Sommer 2004 musste auf Grund übergeordneter Weisungen der Schule zudem das ganze Computernetzwerk der Schule auf ein neues System umgestellt werden und alle Anwendungen von Windows 98, NT oder 2000 auf XP umgestellt werden. Diese Umstellung war teilweise sehr zeitintensiv und konnte trotzdem nicht ganz bei allen Applikationen im PV-Labor durchgeführt werden, d.h. für einige Geräte müssen die Steuerprogramme unter alten Betriebssystemen weiter betrieben werden. Durch diese unvermeidlichen Wechsel und Umstellungsarbeiten ging leider viel wertvolle Arbeitszeit verloren.

Aus Zeitgründen wurden deshalb die eigentlich für 2004 geplanten weiteren Untersuchungen an Dünnschichtzellen-Modulen zurückgestellt und erst ab November im Rahmen einer Semesterarbeit weitergeführt. Dazu konnten zu den bereits vorhandenen älteren CIS-Modulen ST20 und ST40 von Shell auch 5 Module von Würth beschafft werden.

Andererseits bot sich 2004 im Rahmen eines Investitionsprogrammes der Berner Fachhochschule die erfreuliche Gelegenheit, eine programmierbare AC/DC-Quelle von 3 × 5 kW (0 – 2,5 kHz) zu beschaffen, welche die kontrollierte Erzeugung von Störungen auf der Netzseite gestattet. Diese Quelle wurde Ende Oktober 2004 geliefert. Damit können (kurzzeitige) Über- und Unterspannungen, Rundsteuersignale, Frequenzvariationen und Spannungs-Transienten erzeugt werden sowie Messungen der von Wechselrichtern erzeugten Stromoberschwingungen unter Normbedingungen durchgeführt werden. Damit soll in Zukunft auch gezielt der Einfluss der Verhältnisse auf der Netzseite auf das Wechselrichterverhalten untersucht werden und entsprechende Testverfahren entwickelt werden. Im Rahmen dieses Investitionsprogramms konnte auch eine Thermografiekamera beschafft werden, die für Feldmessungen und Fehlersuche an PV-Anlagen gute Dienste leisten wird.

Die Aktivitäten im Rahmen des nationalen Kompetenznetzwerks BRENET (Gebäudetechnik und erneuerbare Energien) waren im Berichtsjahr eher bescheiden. Immerhin fand die diesjährige Generalversammlung in Burgdorf statt und die interessierten BRENET-Partner hatten die Gelegenheit, die vorhandene PV-Infrastruktur des Photovoltaiklabors zu besichtigen.

Teilprojekt Wechselrichter-Tests: Erste Ergebnisse der neuen Tests

DC-AC-Umwandlungswirkungsgrad

Wie bereits in früheren Publikationen erwähnt, ist der Umwandlungswirkungsgrad von Netzverbund-Wechselrichtern von der DC-Spannung abhängig. Auf den folgenden Bildern 1-4 werden die Ergebnisse der Tests des NT4000 von Sunways, des Sunny Mini Central 6000 von SMA sowie des IG30 und IG40 von Fronius gezeigt.

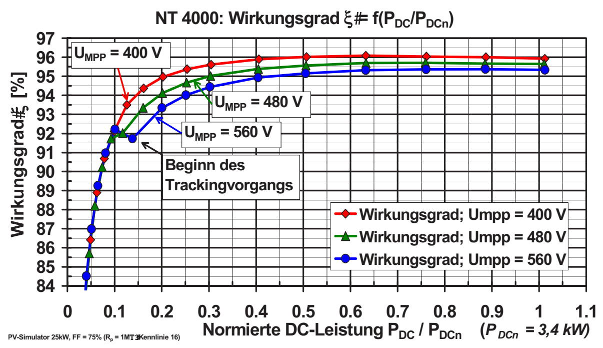


Bild 1: Umwandlungswirkungsgrad eines trafolosen Wechselrichters NT4000 bei verschiedenen DC-Spannungen (P_{DCn} = 3,4kW). Das Gerät hat den bisher höchsten gemessenen Wirkungsgrad.

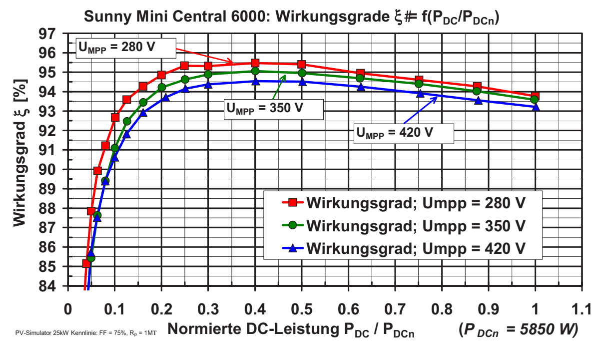


Bild 2: Umwandlungswirkungsgrad des neuen Wechselrichters Sunny Mini Central 6000 mit galvanischer Trennung bei verschiedenen DC-Spannungen (P_{DCn} – 5,85 kW). Der Wirkungsgrad ist für ein Gerät dieser Leistungsklasse mit galvanischer Trennung beachtlich hoch.

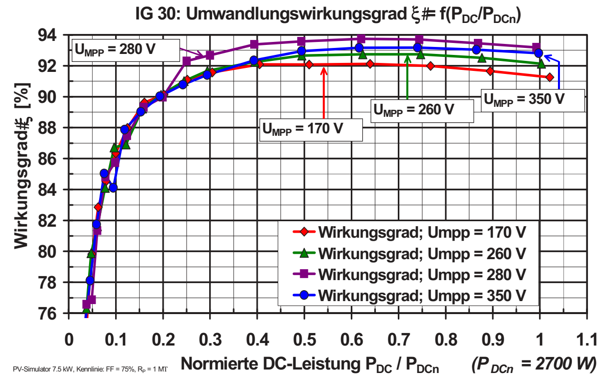


Bild 3: Umwandlungswirkungsgrad des Wechselrichters IG30 mit galvanischer Trennung (und deshalb etwas geringerem ξ) bei verschiedenen DC-Spannungen (P_{DCn} – 2,7 kW).

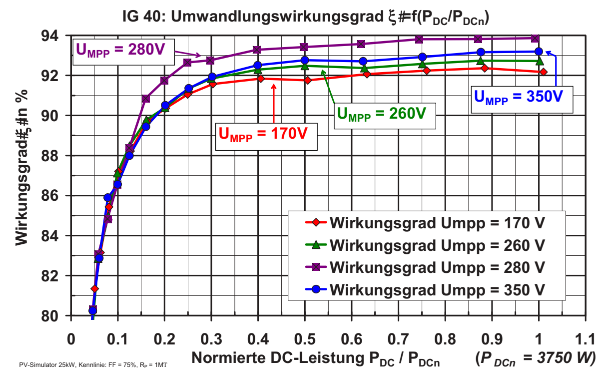


Bild 4: Umwandlungswirkungsgrad des Wechselrichters IG40 mit galvanischer Trennung (und deshalb etwas geringerem ξ) bei verschiedenen DC-Spannungen (P_{DCn} – 3,75 kW).

Messung des statischen MPP-Tracking-Wirkungsgrades ξ_{MPPT}

Die Definition und die Probleme bei der Messung des MPP-Tracking-Wirkungsgrades wurden bereits in vielen früheren Publikationen, u.a. im Jahresbericht 2003 dieses Projektes [8] behandelt.

Um das genaue MPP-Tracking-Verhalten eines Wechselrichters bei verschiedenen Leistungen zu zeigen, ist es zweckmässig, ξ_{MPPT} in Funktion der MPP-Leistung darzustellen und im gleichen Diagramm auf der zweiten Achse einerseits den wahren, gemessenen Wert von U_{MPP} und andererseits den Mittelwert der vom Wechselrichter auf der Kennlinie effektiv eingestellten DC-Eingangsspannung anzugeben (Bild 5 + 6).

Da die Eingangsgrösse für das MPP-Tracking die vom Solargenerator zur Verfügung gestellte MPP-Leistung P_{MPP} ist, wird ξ_{MPPT} zweckmässigerweise in Funktion von P_{MPP} dargestellt. Um das Verhalten von Wechselrichtern verschiedener Grösse zu vergleichen, ist es zudem günstig, diese MPP-Leistung auf die DC-Nennleistung des Wechselrichters P_{DCn} zu normieren, also wie in den Bildern 5 bis 8 ξ_{MPPT} in Funktion von P_{MPP}/P_{DCn} darzustellen.

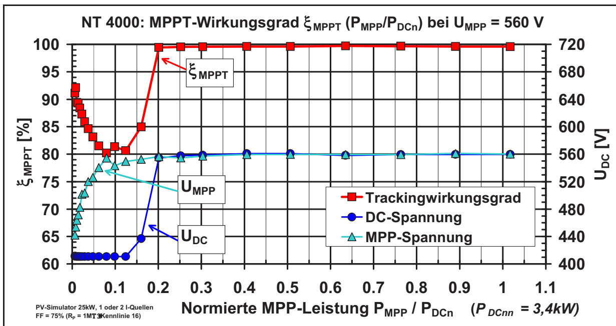


Bild 5: MPP-Tracking-Wirkungsgrad ξ_{MPPT} eines NT4000 in Funktion von P_{MPP}/P_{DCn} bei U_{MPP} – 560V. Da das Gerät bei kleinen Leistungen bei der tieferen Spannung U_{DC} – 410 V arbeitet, ist ξ_{MPPT} dort tief. ξ_{MPPT} steigt bei höheren P_{MMP} gegen 100%, da U_{DC} – U_{MPP}.

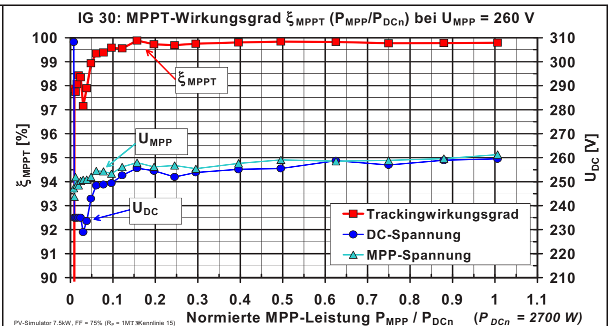
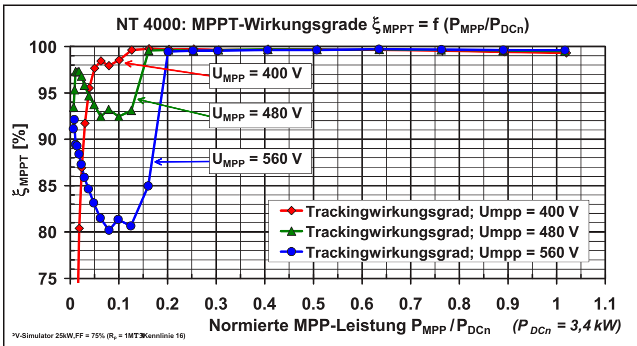


Bild 6: MPP-Tracking-Wirkungsgrad ξ_{MPPT} eines IG30 in Funktion der normierten MPP-Leistung P_{MPP}/P_{DCn} bei U_{MPP} – 260V. U_{DC} weicht auch bei kleinen Leistungen nur wenig von U_{MPP} ab, das statische MPP-Tracking-Verhalten ist auch dort sehr gut.

Wie in Bild 5 zu erkennen ist, arbeiten viele Wechselrichter bei kleinen Leistungen auf einer fixen Spannung, da die Störungen durch ihre interne PWM-Schaltfrequenz die Erkennung des bei kleinen Leistungen kleinen Stromsignals und damit das korrekte Auffinden des MPP erschweren. Durch diese Strategie ist somit bei kleinen Leistungen immer noch ein sinnvoller Betrieb möglich. Allerdings wird dadurch bei kleinen Leistungen, je nach Lage der effektiven MPP-Spannung U_{MPP}, mehr oder weniger Energie verschenkt, denn die vom PV-Generator angebotene Energie wird nicht vollständig ausgenützt, besonders wenn diese Festspannung wie in Bild 5 weit vom effektiven U_{MPP} liegt. Besser wäre es vermutlich, bei kleinen Leistungen auf beispielsweise dem 0,8-fachen der vorher gemessenen Leerlaufspannung U_{OC} zu arbeiten.

Der in Bild 6 gezeigte Wechselrichter hat dagegen ein wesentlich besseres statisches MPPT-Verhalten, seine Arbeitsspannung U_{DC} ist auch bei kleinen Leistungen nur wenig unterhalb von U_{MPP}, was wesentlich geringere Leistungsverluste und damit einen höheren ξ_{MPPT} zur Folge hat.

Bild 7 und 8 zeigen den statischen MPP-Tracking-Wirkungsgrad ξ_{MPPT} eines NT4000 und eines IG30 in Funktion von P_{MPP} bei drei verschiedenen MPP-Spannungen. Bei kleinen Leistungen ist das MPPT-Verhalten des IG30 eindeutig besser.



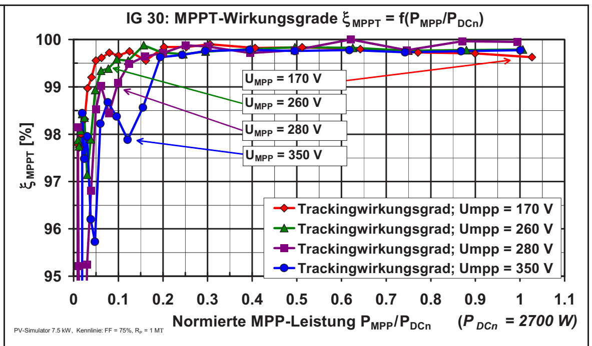


Bild 7: MPP-Tracking-Wirkungsgrad ξ_{MPPT} eines NT4000 in Funktion der normierten MPP-Leistung P_{MPP}/P_{DCn} bei drei verschiedenen MPP-Spannungen. Da das Gerät bei kleinen Leistungen fest bei U_{DC} – 410 V arbeitet, ist ξ_{MPPT} je nach Lage von U_{MPP} dort mehr oder weniger kleiner als 100%.

Bild 8: MPP-Tracking-Wirkungsgrad ξ_{MPPT} eines IG30 in Funktion der normierten MPP-Leistung P_{MPP}/P_{DCn} bei vier verschiedenen MPP-Spannungen. Gegenüber Bild 7 ist der ξ_{MPPT}-Massstab stark gedehnt. Das statische MPP-Tracking-Verhalten ist auch bei kleinen Leistungen sehr gut.

Einführung des totalen Wirkungsgrades ξ_{tot}

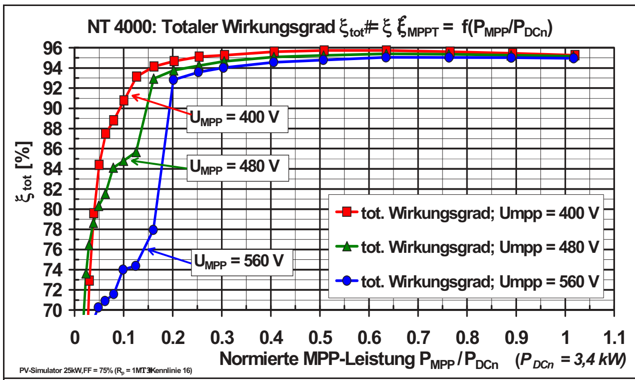
Ein Solargenerator stellt auf Grund der aktuellen Einstrahlung G und Temperatur T eine bestimmte Leistung P_{MPP} zur Verfügung. Der Wechselrichter verwertet im stationären Betrieb davon aber nur $P_{DC} = \xi_{MPPT} \cdot P_{MPP}$ und erzeugt daraus $P_{AC} = \xi \cdot P_{DC}$. Somit kann man eine neue Grösse definieren:

Totaler Wirkungsgrad eines Wechselrichters: $\boldsymbol{\xi_{tot} = \xi \cdot \xi_{MPPT} = P_{AC} / P_{MPP}}$

Damit gilt im stationären Fall :

$$\boldsymbol{P_{AC} = \xi \cdot P_{DC} = \xi \cdot \xi_{MPPT} \cdot P_{MPP} = \xi_{tot} \cdot P_{MPP}}$$

Bild 9 und Bild 10 zeigen den so berechneten totalen Wirkungsgrad ξ_{tot} der beiden Wechselrichter NT4000 und IG30 in Funktion der normierten MPP-Leistung P_{MPP}/P_{DCn} bei drei verschiedenen MPP-Spannungen.



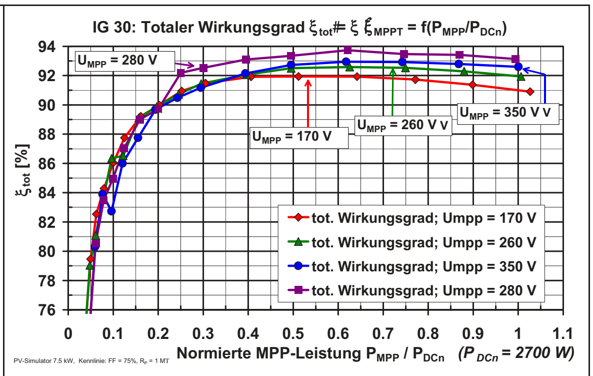


Bild 9: Totaler Wirkungsgrad ξ_{tot} eines NT4000 in Funktion von P_{MPP} bei drei verschiedenen MPP-Spannungen. Wegen des relativ schlechten ξ_{MPPT} bei kleinen Leistungen und höheren U_{MPP} hat das Gerät dort trotz des hohen Wirkungsgrades ξ ein relativ kleines ξ_{tot}.

Bild 10: Totaler Wirkungsgrad ξ_{tot} eines IG30 in Funktion von P_{MPP} bei vier verschiedenen MPP-Spannungen. Bei kleinen Leistungen macht der IG30 bei ξ_{tot} durch das gute MPP-Tracking den schlechteren Umwandlungswirkungsgrad ξ wett.

Der totale Wirkungsgrad eines Wechselrichters ist somit ein direktes Qualitätsmerkmal, das eine höhere Relevanz für die Praxis aufweist als der reine Umwandlungswirkungsgrad ξ. Wie ξ und ξ_{MPPT} hängt natürlich auch ξ_{tot} von P_{MPP} und U_{MPP} ab und muss durch geeignete Messungen bestimmt werden. Für weitere Details zum totalen Wirkungsgrad muss aus Platzgründen auf weitere, Anfang 2005 erscheinende Publikationen verwiesen werden.

Um mit einem einzigen Wert das Verhalten eines Wechselrichters kurz zu beschreiben, kann auch für ξ_{tot} und ξ_{MPPT} ein Durchschnitts-Wirkungsgrad (z.B. Europäischer Wirkungsgrad) berechnet werden (siehe Tabelle 1). Beachte: $\xi_{tot\text{-}EU}$ ist nicht genau $\xi_{EU} \cdot \xi_{MPPT\text{-}EU}$, da ξ_{EU} nicht auf P_{MPP} bezogen ist.

	NT 4000			SMC 6000			IG 30				IG 40			
U_{MPP}	400V	480V	560V	280V	350V	420V	170V	260V	280V	350V	170V	260V	280V	350V
ξ_{EU}	95,3%	94,8%	94,3%	94,6%	94,2%	93,7%	90,9%	91,4%	92,0%	91,5%	91,1%	91,4%	92,4%	92,0%
$\xi_{MPPT\text{-}EU}$	99,5%	99,0%	98,0%	99,5%	99,4%	99,7%	99,7%	99,8%	99,9%	99,5%	99,9%	99,0%	99,6%	99,6%
$\xi_{tot\text{-}EU}$	94,9%	93,9%	92,5%	94,2%	93,7%	93,3%	90,7%	91,2%	91,7%	91,0%	91,0%	90,6%	92,1%	91,6%

Tabelle 1: Durchschnitts-Wirkungsgrade für ξ, ξ_{MPPT} und ξ_{tot} (Gewichte nach Formel für den Europäischen Wirkungsgrad) für NT4000, SMC6000, IG30 und IG40 bei verschiedenen Spannungen.

Teilprojekt Langzeitverhalten von Photovoltaik-Anlagen

Wechselrichter-Ausfall-Statistik

Die seit 1992 geführte Ausfallstatistik wurde auch 2004 weitergeführt. Im Jahr 2004 blieb die Ausfallrate auf 0,13 WR-Defekte pro WR-Betriebsjahr (Stand Oktober 04, hochgerechnet auf Ende Jahr) und lag damit im Bereich der Vorjahre. Die Anzahl überwachter Wechselrichter blieb bei 55 Stück.

Fünf von sechs Ausfällen betrafen trafolose Wechselrichter. Es waren dies 3 Solarmax S und 2 Convert 4000. Alle konnten vom Hersteller repariert werden und sind wieder in Betrieb. Bis auf einen EdiSun200 sind alle gegenwärtig überwachten trafolosen WR vom Typ Solarmax S (16 Stk.) oder Convert 4000 (8 Stk.). Der ausgefallene Wechselrichter mit galvanischer Trennung war ein TopClass 4000/6 Grid III. Das Netzfilter war defekt und hat auf der Netzseite einen Kurzschluss verursacht.

Die grosse Ausfallrate der trafolosen Wechselrichter Jahr 2004 hat uns veranlasst, die Ausfallstatistik etwas zu verfeinern und zusätzlich auch noch eine nach Wechselrichtern mit und ohne galvanische Trennung aufgeteilte Statistik zu erstellen. Bei der Interpretation gibt es einige Punkte zu beachten:

- Die hohe Ausfallrate der WR ohne galvanische Trennung im Jahre 1996 wurde hauptsächlich durch mehrere Ausfälle eines EcoPower20 verursacht (1998 nach weiteren Ausfällen ersetzt).
- Die hohe Ausfallrate der WR mit galvanischer Trennung im Jahre 1999 wurde durch Ausfälle einiger älterer Solcon-Geräte hervorgerufen, die dann durch andere Geräte ersetzt wurden.
- Der Ausfall-Peak bei den trafolosen WR im Jahr 2001 wurde wahrscheinlich durch Überspannungen (naher Blitzeinschlag bei einer Anlage mit mehreren Wechselrichtern) verursacht.

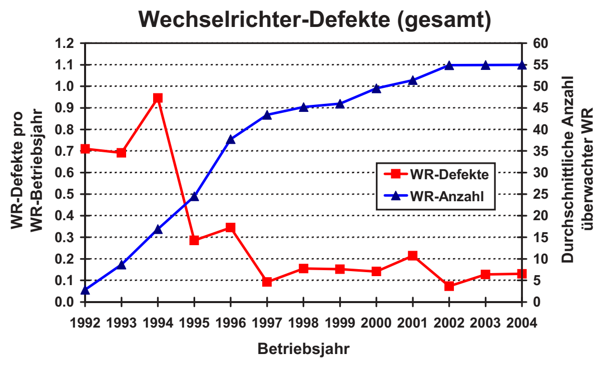


Bild 11:
Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr und durchschnittliche Anzahl von der HTI Burgdorf überwachter Wechselrichter (Hochrechnung Stand Ende Oktober 2004).

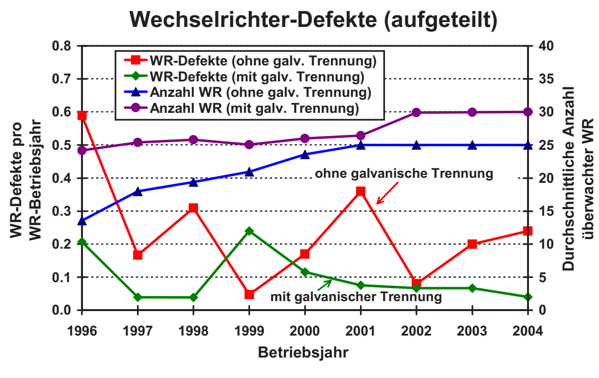


Bild 12:
Wechselrichter-Defekte pro Wechselrichter-Betriebsjahr aufgeteilt nach Wechselrichtern mit und ohne galvanische Kopplung (Hochrechnung Stand Ende Oktober 2004).

Allgemein kann gesagt werden, dass im Mittel die Wechselrichter mit einer galvanischen Trennung weniger Ausfälle erleiden. Sie scheinen gegen netzseitige Störungen oder in Bezug auf bei nahen Blitzeinschlägen zwischen Solargenerator- und Netzanschlussleitungen auftretende Spannungsdifferenzen robuster zu sein. Bei dieser Folgerung muss aber beachtet werden, dass praktisch alle überwachten trafolosen Wechselrichter vom selben Hersteller stammen. Die grösseren dreiphasigen Wechselrichter des gleichen Herstellers erwiesen sich dagegen bisher als sehr zuverlässig. Das Durchschnittsalter aller Wechselrichter, welche im Moment (Stand Ende 2004) im Monitoring-Programm sind, beträgt ca. 7,8 Jahre.

Um die Wechselrichterausfallstatistiken und die Ertragsausfälle der Burgdorfer-PV-Anlagen weiterhin seriös erfassen zu können, wurden in diesem Jahr einige Ledan-Erfassungsgeräte (Restposten von Medatec) gekauft und einige defekte Geräte repariert. Somit ist gewährleistet, dass die Grobmessungen an den Energiezählern, trotz den altersbedingten sporadischen Ausfällen der Ledan-Geräte, weitergeführt werden können.

Durch die geplante Erneuerung der Daten-Konvertierungssoftware (Umstellung eines nur unter DOS lauffähigen alten PASCAL-Programms auf ein Windows-kompatibles Programm) ist auch auf dieser Seite wieder ein sicherer Betrieb der Auswertungen möglich. Auch das Hinzufügen von neuen überwachten Anlagen (z.B. Wankdorf) wird wesentlich vereinfacht.

Alterungsbedingte Mängel auf der Gleichstromseite von PV-Anlagen

Wie bereits 1998 (siehe www.pvtest.ch, Publikation [64], S. 14) wurden auch 2004 bei verschiedenen, nunmehr etwa 10 Jahre alten Anlagen sicherheitsrelevante Mängel auf der DC-Seite festgestellt (lose Kabel der Solarmodulverdrahtung infolge gebrochener Kabelbinder). Es ist deshalb unerlässlich, dass nicht nur die AC-Seite, sondern auch *die DC-Seite von PV-Anlagen periodisch kontrolliert* wird.

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 (Details siehe z.B. [5] und [9].

In Bild 13 werden die Monats-DC-Nutzungsgrade, in Bild 14 die Generator-Korrekturfaktoren $k_G = Y_a/Y_T$ der drei Newtech-Anlagen und von zwei Anlagen mit kristallinen Siliziumzellen verglichen. In Bild 13 ist zu erkennen, dass die amorphen Technologien im Sommer 2002 zunächst einen nur geringen Abfall des Wirkungsgrades aufweisen, dass dieser in den kalten Wintermonaten dann aber deutlich absinkt, sich aber im Sommer 2003 wieder mit steigenden Temperaturen weitgehend, aber nicht vollständig, regeneriert. Um diesen Regenerations-Effekt zu verstärken und die Degradation im Winter zu verringern, wurden im Herbst 2003 die Module von Newtech 3 hinten mit ca. 2 cm dicken Styrofoam-Platten isoliert.

Bild 13:

Monats-DC-Nutzungsgrad der drei Newtech-Anlagen im Vergleich zu zwei Anlagen mit mono-c-Si (alpine Anlage mit η# 90° auf 2670m).

Ein Jahr nach der thermischen Isolation von Newtech 3 ist nun (verglichen mit Newtech 2) sichtbar, dass der Abwärtstrend der DC-Monatsnutzungsgrade gestoppt werden konnte. Der Ausreisser im Januar 04 ist auf eine längere Schneebedeckung zurückzuführen.

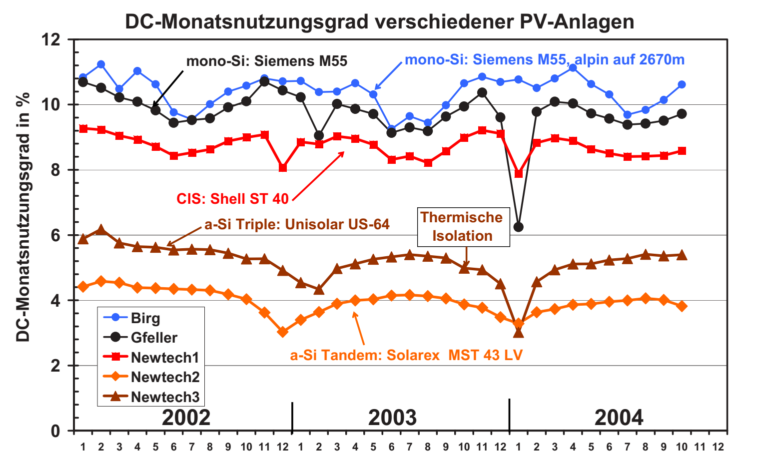
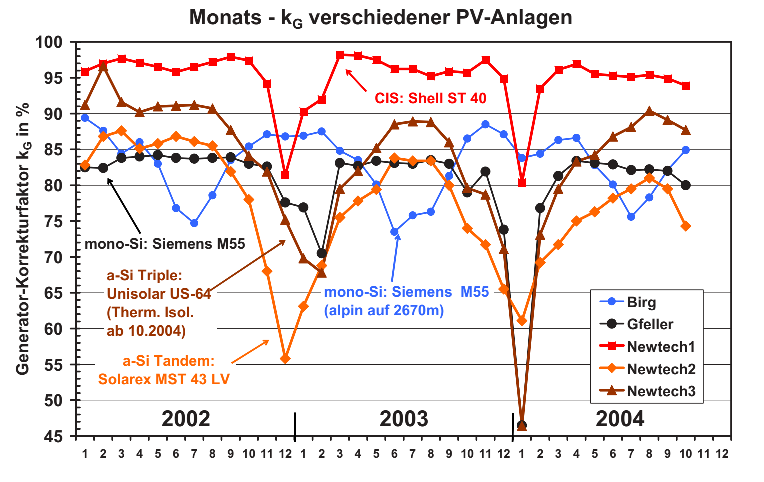


Bild 14: Monats-Generator-Korrekturfaktor k_G der drei Newtech-Anlagen im Vegleich zu zwei Anlagen mit mono-c-Si (alpine Anlage mit η = 90° auf 2670m). Ein Jahr nach der thermischen Isolation von Newtech 3 im Oktober 2003 ist nun (verglichen mit Newtech 2) zu erkennen dass auch der Abwärtstrend der Monats-Generator-Korrekturfaktoren k_G gestoppt werden konnte. Der Ausreisser im Januar 2004 ist auf eine längere Schneebedeckung zurückzuführen.



Nationale und internationale Zusammenarbeit

- Ausführliche Tests eines NT 4000 von Sunways, eines IG30 und IG40 von Fronius und eines Sunny Mini Central 6000 von SMA.
- Mitarbeit im NKN BRENET.
- Auslieferung der bestellten Stromquellen und Dokumentationen für den Lizenzbau zweier Solar-generator-Simulatoren nach Australien.

Bewertung 2004 und Ausblick 2005

Ausser bei den Tests von Dünnschichtzellen-Modulen konnten alle Ziele für 2004 erreicht werden. Die Sputnik AG wird Ende 2004 verbesserte Versionen des Solarmax 3000 und 6000 zur Verfügung stellen und im Frühling 2005 neue, verbesserte 20 - 30 kW Versionen der dreiphasigen Solarmax-Reihe herausbringen. Die ASP AG plant im Frühling 2005 eine neue Generation von Netzverbund-Wechselrichtern (SATIS, 4 kW, später auch zwei kleinere Varianten) herauszubringen. Es ist geplant, all diese Geräte im Jahre 2005 eingehend zu testen. Im Rahmen des Monitoring-Teilprojektes soll 2005 die Messtechnik der Anlage Wankdorf sobald als möglich fertiggestellt und in Betrieb genommen werden. Auch die Untersuchungen von Dünnschichtzellen-Modulen sollen 2005 wieder intensiviert werden. Es ist auch vorgesehen, im bisherigen Rahmen im NKN BRENET mitzuarbeiten.

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[7] H. Häberlin: ***"Hochalpine Photovoltaikanlagen – Langzeiterfahrungen mit Fassadenanlagen"***. Elektrotechnik 6-7/2004

[8] H. Häberlin: ***Jahresbericht 2003 zum BFE-Projekt "Photovoltaik-Systemtechnik 2003-2004"***

[9] C. Renken und H. Häberlin: ***Jahresbericht 2003 zum BFE-Projekt "Newtech – Vergleich 3 x 1kWp Dünnschichtzellenanlagen"***

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 2004

Energy Rating of Solar Modules

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Project- / Contract Number	47456 / 87538
Duration of the Project (from – to)	Jan. 2003 – Dec. 2003

ABSTRACT

The Performance Matrix forecasts the electric power of a solar module against solar irradiance and ambient temperature. To determine the performance matrix of a solar module, first its power is measured at different irradiances and temperatures; then a mathematical model is used to fit a plane through the power data.

In this project the suitability of different measurement methods and mathematical models to create a Performance Matrix was analysed. For this purpose 3 modules BP580 (monocrystalline) and 3 Kyocera modules (polycristalline) were measured indoor and outdoor. These measurement data were used to create Performance Matrices of the modules with different mathematical models.

It revealed that the measurement data have to cover a broad range of temperatures and irradiances to build a reliable basis for the creation of a Performance Matrix. Therefore indoor measurements where any temperature and irradiance can be adjusted are very adequate. But with indoor measurements various external factors like diffuse irradiance, wind, albedo and ambient temperature are missing. Outdoor measurements on the other hand are appropriate to build a Performance Matrix, if the measurement can be done automatically and for a sufficient time (weeks to months). Compared to measurements with a suntracker, the measurements on a fixed rack include angle of incidence variations. If the instantaneous power at maximum power point is measured instead of the whole I-V curve, at varying weather conditions MPPT errors occur. These have to be excluded from the final analysis.

The analysed mathematical models differ in complexicity, required input values, compressibility and physical background. With exception of a very simple linear model, they all showed similar results and uncertainties.

The Performance Matrices of the 6 modules were used to forecast the specific energy yield for different standard days and the yearly specific energy yield for the locations Zurich, St.Moritz and Lagos. All Kyocera modules achieved in average up to 4.2 % higher specific yields than the modules BP580. It is not sure yet, if this difference is significant enough in relation to the until now obtained uncertainty of the yearly specific energy yield prediction of approximately ± 3%. The difference between the two module types is much smaller if the energy predicition is based on indoor measurements, which could be due to different behaviour under outdoor conditions. But this has to be analysed further.

Introduction / Project goals

Up to now, the quality of solar modules has been judged by means of the STC-value. But it's known from experience that modules with the same STC-value can show significant differences in their yearly energy yield, even if they are mounted at the same location. An approach to this problem is to prognose the yearly energy yield of a module at a certain location with the so called "Performance Matrix". The Performance Matrix forecasts the electrical power of a solar module against solar irradiance and ambient temperature. To determine the performance matrix of a solar module, first its power is measured at different irradiances and temperatures; then a mathematical model is used to fit a plane through the raw power data.

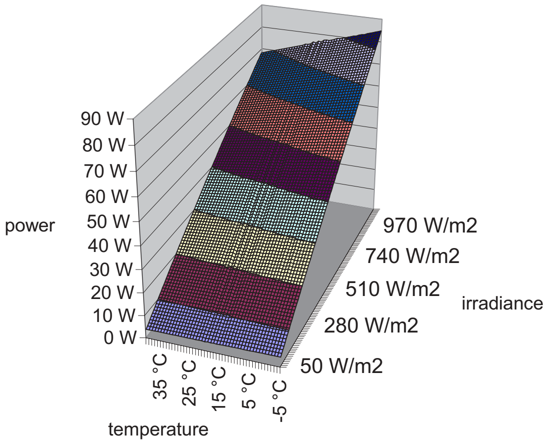

Figure 1: typical performance matrix of a solar module

The goal of this project is to prove the suitability of the performance matrix for predicting the energy yield of solar modules. Furthermore, different mathematical models and measurement methods will be compared to give inputs for an improvement of the performance matrix with the long-term objective to standardize this procedure.

The following institutions and persons participated in this project:

- Joint Research Institute ISPRA: Dr. Robert Kenny
- LEEE-TISO: Gabi Friesen; Domenico Chianese
- Paul Scherrer Institut: Dr. Wilhelm Durisch
- Gesellschaft Mont Soleil/Minder Energy Consulting: Dr. Rudolf Minder
- ISET Kassel: Dr. Christian Bendel
- Enecolo AG: Sandra Stettler; Robert Kröni

The project accomplished thanks to the financing and the partial take over of the costs of sales by the following institutions:

- Swiss Federal Office of Energy: financial contribution
- Gesellschaft Mont Soleil: financial contribution
- Joint Research Institute ISPRA: goods on own account
- LEEE-TISO: goods on own account, modules
- Paul Scherrer Institut: goods on own account
- ISET Kassel: goods on own account
- Edisun Power AG: modules

Short description of the project

To prove the suitability of the performance matrix to characterize solar modules, 6 solar modules (3 monocrystalline BP580 and 3 polycristalline Kyocera modules, see table 1) were measured in a round robin test by ISPRA, PSI and LEEE-TISO. Every measurement institute has its own measurement methods (see table 2) which differ in the measured parameters (I-V-curve versus direct performance measurement), but also in the location of the module (outdoor measurements on a fixed rack or with a suntracker or indoor measurements with a solar simulator). Furthermore, the number of measurement points at different irradiances and temperatures that could be measured in the given time span varied substantially between the different methods, depending on the frequency of measurements and the available irradiance and temperature conditions. At ISET in Kassel an additional module was measured with the same measurement method that was used at LEEE-TISO.

Table 1: characteristics of the measured modules. The module BP90 wasn't yet degraded at the measurement at JRC ISPRA

	module	**type**	**serial number**	**STC-measurement at LEEE-TISO**	**STC-measurement at JRC ISPRA**
BP20	BP580	monocrystalline	683520S	79.21	78.23
BP22	BP580	monocrystalline	683522S	78.58	78.18
BP90	BP580	monocrystalline	680790S	77.31	80.16*
Kyo03	Kyocera	polycristalline	94308103	47.01	45.98
Kyo04	Kyocera	polycristalline	94308104	46.68	46.90
Kyo05	Kyocera	polycristalline	94308105	46.48	45.49

Table 2: Measurement Methods

Method	**Description**	**Measured modules**
PSI Outdoor	Manual outdoor measurements of the I-V-curve on a suntracker at PSI [1]	All 6 modules
TISO Outdoor	Outdoor measurements on a fixed rack at LEEE-TISO. The module runs at MPP. The power is measured every minute [2]	All 6 modules
ISPRA Outdoor	Outdoor measurements on a fixed rack at JRC Ispra: automated periodically measurement of the I-V-curve, in the meantime the module runs at MPP [3]	BP20
ISPRA Indoor	Indoor measurement with a sun simulator at JRC Ispra: Temperature is varied from 25 to 60 °C, irradiance from 50 to 1000 W/m². A grid with a mesh of 100 W/m² and 5°C is measured [3]	All 6 modules

To acquire the performance matrix based on the measured raw data, different mathematical models were evaluated. The models vary in their complexity, needed input parameters (Isc, Uoc, FF, Pmax, Impp, Umpp) and physical background (see table 3).

Using the different sets of measurement data and the mathematical models, for every module several performance matrices can be created. The quality of these performance matrices depends on the quality of the measurement data and of the mathematical model. A calculation of the uncertainty of the different performance matrices is used to judge the quality of the performance matrix. As additional quality control the measured power at certain irradiances and temperatures is settled with the corresponding power in the performance matrix. By comparing the performance matrices of the monocristalline BP580 modules with the matrices of the polycristalline Kyocera modules furthermore it shall be demonstrated, if the performance matrix is useful to detect differences in the specific yearly energy yield of two different types of modules.

Table 3: Description of the different mathematical models for the calculation of the performance matrix

Model	**Description**
ISPRA	By regression, the variables of the following three equations are determined: Isc = a1 + a2*G + a3*Tcell Uoc = b1 + (b2 + b3*Tcell)*LN(G) - b4*Tcell FF = c1 - ((c2*G + c3)/LN(G)) - Tcell*(c4*G + c5) The power at a certain irradiance and temperature then is accomplished by multiplicating these three equations [4, 5, 6].
Linear interpolation	The measurement data are filled in a matrix of irradiance and temperature with a mesh of 10W/m2 and 1°C . Matrix fields with high standard deviations are excluded from the subsequent calculation. Then a linear regression Pmax = f1(T) and consecutively a quadratic regression Pmax = f2(G) are used to fill every line and row of the matrix, thus completing the performance matrix [2, 7]
TISO	Impp and Umpp depend from irradiance and module temperature as follows: $Impp = Im \cdot (G/1000) + Im \cdot alpha \cdot deltaT \cdot (G/1000)^2 + Im \cdot alpha \cdot (G/1000) \cdot (T_{amb}-25)$ $Umpp = Um + C0 \cdot ln(G/1000) + C1 \cdot (ln(G/1000))^2 + beta \cdot deltaT \cdot (G/1000) + beta \cdot (T_{amb}-25)$ The parameter Im, alpha, deltaT, Um, C0, C1 and beta are calculated with a regression of the measurement data. The power of the module at a certain irradiance and temperature then is calculated by multiplicating Impp and Umpp [8].
PSI efficiency	By regression of the measurement data, the variables of the following equation are determined: $efficiency = a*(G/G0) + b*(G/G0)^{0.5} + c*(G/G0)^{(1/3)} + d*(G/G0)^{(1/4)} + e*(G/G0)^{(1/5)} + f*Tcell/(T0-1)$ The power of the module at a certain irradiance and temperature then is calculated by multiplicating the efficiency with the irradiance and the area of the module [1, 5, 9].
PSI power	By regression of the measurement data, the variables of the following equation are determined: $Pmax = P1*G^2 + P2*G^{(3/2)} + P3*G^{(4/3)} + P4*G^{(5/4)} + P5*G^{(6/5)} + P6*G*Tamb$ The power of the module at a certain irradiance and temperature then is simply calculated with this equation [10].

Executed work and achievements in 2004

The measurements and calculations of the performance matrices were already done in 2003. In 2004, some performance matrices were recalculated with slightly modified conditions, to make the different performance matrices better comparable. Important calibration factors were:

- To calculate the specific energy yield, the energy yield was normed to the average of the STC values measured at LEEE-TISO and JRC Ispra for each module
- To convert between cell and ambient temperature, the formula Tcell = Tambient + k * irradiance. For all Kyocera modules a k value of 0.0277 was used, for all BP modules a k value of 0.0344. This corresponds to the average of the measured k value of the modules
- Especially the over a longer period executed outdoor measurements on a fixed rack produce a higher scatter of the data. For all mathematical models an elimination mechanism for outliers was used.

Using the performance matrices then the energy yield for several American standard days [11] and for one year at Zurich was calculated. Furthermore the quality of the performance matrix was checked in different ways:

- The uncertainty of the performance matrix was calculated with theory of errors
- The measured power at certain irradiances and temperatures was compared with the corresponding power in the performance matrix

The evaluation of the performance matrices clearly showed that the quality and distribution of the raw data, as a base of the performance matrix, is crucial. If the measurement data is insufficient, even the best mathematical model won't be able to calculate a reasonable performance matrix. Insufficiency of the measurement data not only means the accuracy of single measurement points but also the distribution of the data over different irradiances and temperatures. This is very clearly shown with measurement data PSI Outdoor, which was performed manually and for reasons of time only a few measurement points at a very limited number of irradiances and temperatures could be measured. Although the accuracy of the single data points is very high, for several modules it was not possible to calculate a reasonable performance matrix because the different parts of the performance matrix just were not covered by a sufficient number of measurement points (see figure 2). Now the method PSI Outdoor has been automated. Therefore it will be possible in future to measure enough data with reasonable personnel costs.

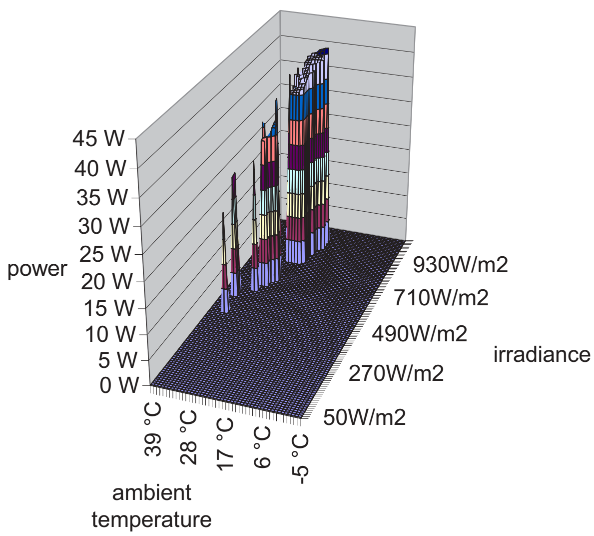

Figure 2: measured raw data of the module Kyo04 with measurement method PSI Outdoor

Figure 3 shows the caculated yearly specific energy yields. The calculated values of approximately 1100 to 1200 kWh/kW are very reasonable, as it is the brutto energy yield of the modules, without any energy losses due to the inverter or the cables. The energy yields based on PSI Outdoor data show a lot of outliers which are produced due to the insufficient number of measurement data and therefore unreliable performance matrices. In figure 3 it can also be seen that the measurement data TISO Outdoor produces clearly lower yearly energy yields for BP modules than for Kyocera modules. It revealed that all BP modules at LEEE-TISO were measured with defect electric measuring instrument. Therefore the results of the BP modules measured TISO Outdoor had to be excluded from the study. By comparing the different mathematical models it attracts attention that it was not possible to calculate the yearly energy yield of some modules wit the method Linear. The method resulted to be inadequate to describe the real outdoor behaviour of a module, not reducible to single equations and incapable to fit most data sets. Especially for PSI Outdoor data, the basis was too small to calculate the performance matrix. The other mathematical models, even the quite simple model PSIpower, show very similar results.

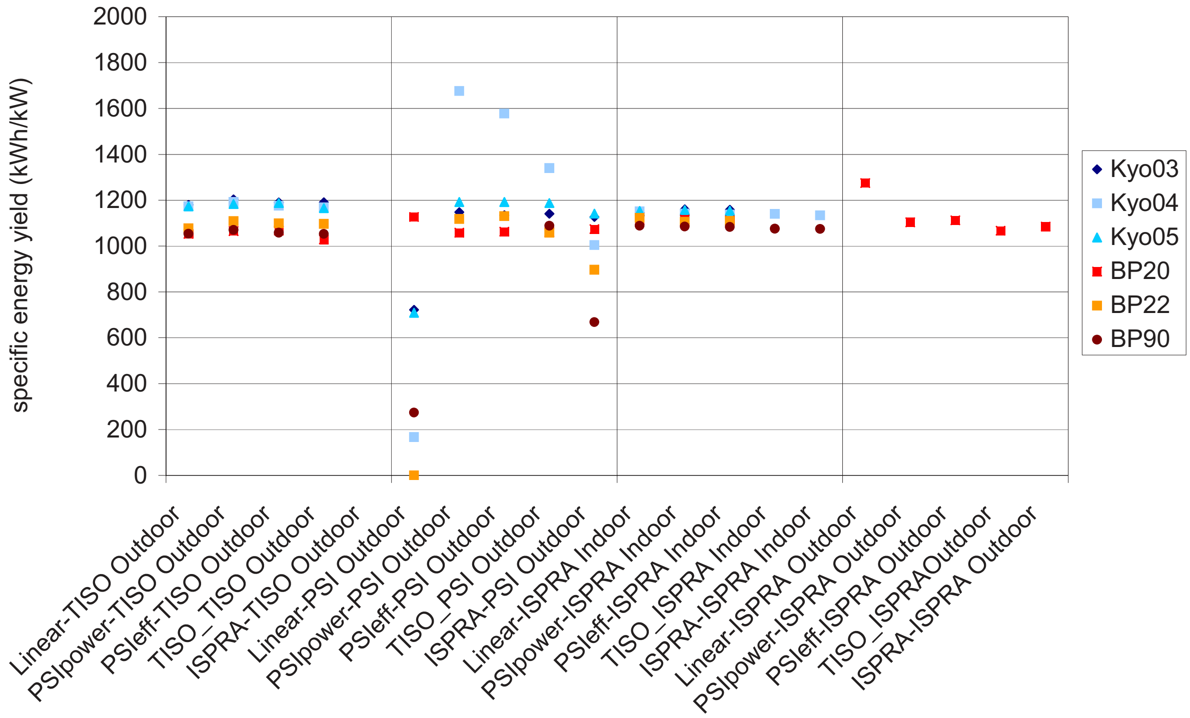

Figure 3: yearly energy yield at Zurich calculated with the different performance matrixes and with hourly meteorological data from meteonorm for an inclination angle of 20°.

If the specific yearly energy yields of the measurement data TISO Outdoor were calculated with the method TISO, there were slight different results, depending on whether Enecolo or LEEE-TISO determined the performance matrix. These differences are due to two a slight discrepancy in calculation: Outliers were excluded in a different way. The measurement data TISO Outdoor has a higher scatter (see figure 4) due to changing weather conditions, low inclination angles and measurements in 1 minute intervals over longer periods and over the whole day.

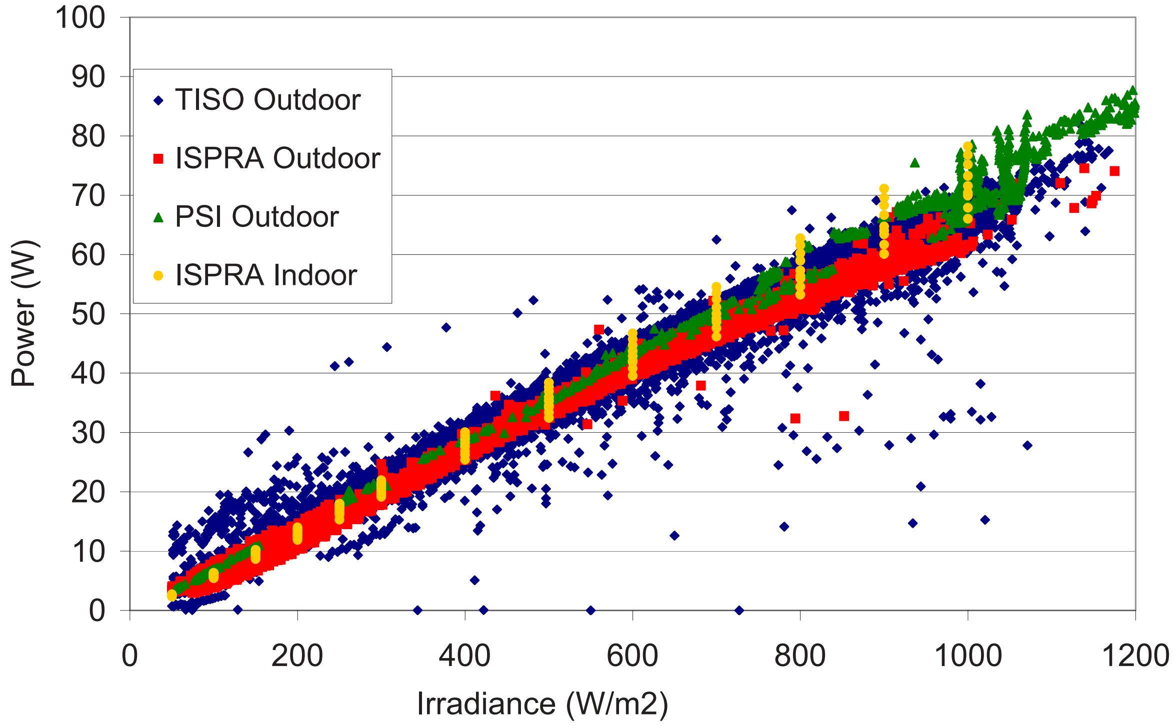

Figure 4: measured raw data of the module BP20 (monocristalline BP580 module)

National / international collaboration

In Switzerland there was a collaboration between Enecolo AG/Edisun Power AG, LEEE-TISO, Paul Scherrer Institut and Gesellschaft Mont Soleil.

On international level, there was an intensive collaboration with JRC ISPRA. Additionally there was a collaboration with ISET Kassel, Prof. Bendel and GENEC/CEA Philippe Malbranche.

Evaluation 2004 and outlook 2005

The project is finished and the final report is in preparation. In January 2005 a workshop with all project members will take place to discuss the results of the project.

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[12] W. Durisch[1)], B. Bitnar[1)], J.-C. Mayor[1)], K.-H. Lam[2)], J. Close[2)]. **E*fficiency of Selected Photovoltaic Modules and Annual Yield at a Sunny Site in Jordan.*** World Renewable Energy Congress VIII (WREC 2004), Proceedings, Elsevier Science Ltd. ISBN 008-044470 9. [1)] Paul Scherrer Institut, PSI, 5232 Villigen PSI [2)] The University of Hong Kong, Dept. of Architecture, Pok Fu Lam Road, Hong Kong, China

Annual Report 2004

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.

Short 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**).*

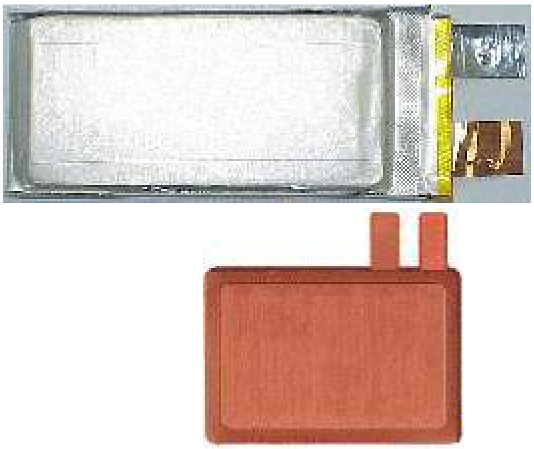
The polymer solar cell:

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 most advanced battery technology. This battery 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 2^{nd} 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.

Solaronix SA is active in the development of a substrate terminal with electrical interconnections and assembly of both the battery and the solar cell into a prototype tandem module.

Work performed and results achieved

Works done at **Solaronix** during the second project year.

WP 4.1 Low-voltage converter "PowerDot"

a) Converter components

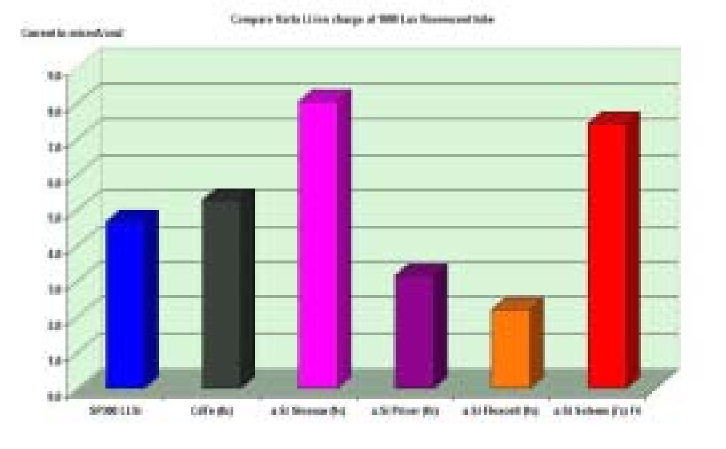
Results 2004

 Two types of converter/charging circuits	Converter/charge controller for PoliFlex batteries: Adjustable charging voltage ~4.2 V Maximum power point tracker for optimal solar power usage Size: 35 x 10 x 2 mm Tested with various solar cells to charge Varta PoliFlex battery

WP 4.2 Interface prototyping

 LED driven through flexible interface	Identification of *solderable* a printable conductive material, allows flexible design to make circuits in prototypes with fast turnaround. Prototyping of polyimide based electrical circuitry made by screen printing of Ag-paste, fired at high temperature to get mechanical stability. Conductive "via-hole" made by YAG-laser tested successfully in combination of Ag-print.

Test electrical performance of converter charging the PoLiflex Varta Li-ion battery with various solar cells.



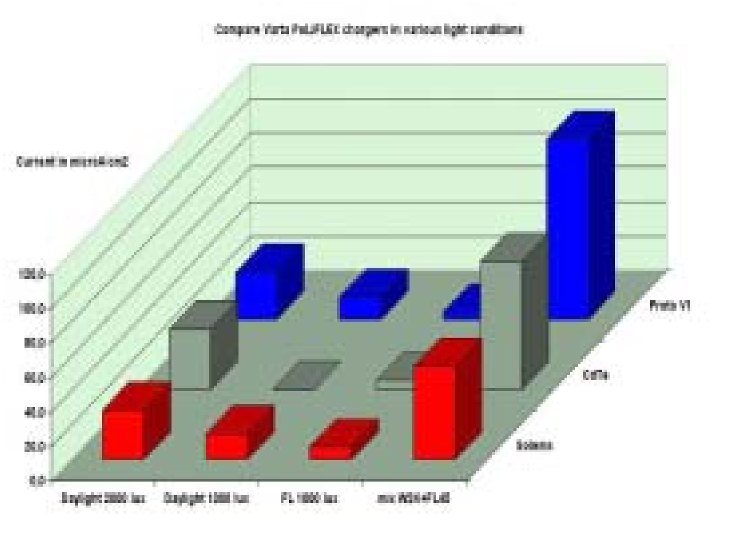
Compare charging current into a 26 cm^2 sized PoLiFlex Varta battery at 4.2 V

The light is here a 1000 lux fluorescent tube.

Amorphous silicon cells are best suited, followed by CdTe and “low-light” silicon developed by Solaronix.

The best cell gives about 0.2 mA for a surface of 26 cm^2 in these conditions.

Test electrical performance of converter charging the PoLiflex Varta Li-ion battery with various solar cells and various light sources.



The amorphous Si cell works best in low daylight (1000 & 2000 lux) conditions, and “low-light” silicon works best in incandescent bulb light of 2500 lux.

For a EURO-PSB product, the light conditions and the solar cell have to be matched carefully to get optimal charging currents.

WP5.1 Prototype assembly

Assembled prototype (Proto v1) with Varta PoLiflex battery, converter/charging circuit and a semi-flexible “low-light” silicon module as temporary solar power source, used before the organic solar cells are ready

	
“loose-wire” version of Proto v1, with battery, converter and solar cell	Assembled prototype Proto v1 (wires are provided to measure charging conditions)

National and International Cooperation

The coordinator of **EURO-PSB** will be **CEA-Saclay, France**. Since rechargeable lithium-polymer batteries are now a mature technology we will 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 will be 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 will be developped by a swiss SME **Solaronix S.A.**, **Switzerland**. Prototype assembly will be performed by **CEA-Saclay**, **Linz University** and **Tallinn University**. Application needs and industrial exploitation plan will be essentially under the responsability of a french SME **Solems S.A.**, **France**. Finally, as the coordinator of **EURO-PSB**, **CEA-Saclay** will be in charge of management.

Evaluation of 2004 and perspectives for 2005

The mid of 2004 was the period of the Mid-Term Assessment and the first integration of the complete system using the available state-of-art was be completed, and tested in various light conditions. Several types of solar cell modules were adapted to the prototype to understand spectral sensitivity.

The organic solar cells from University Linz have been prepared on glass substrates and are now in evaluation. A workshop together with the Tallinn Technical University (TTU) was held at Solaronix in November to improve the printing process for the back contact of the TTU «monograin »CIGS solar cells. These CIGS cells will also be tested in 2005 together with the organic cells (later-on on also with flexible substrates).

More prototypes with improved integration will be available during 2005.

References and Publications

No publication yet submitted

Patent application under investigation.

Diverse Projekte und Studien

Annual Report 2004

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 report for year 2003 presented rather in details the goals of the project, to which the interested reader should refer. In the present report, essentially the results of the year 2004, as well as the perspectives for year 2005, 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

Until now, the definition phase (WP 1, 2 and 3) has been completed, as well as a significant part of the other workpackages, except WP 7 (Application, case studies) which has been left for the end of the project. The status of each of the work packages is the following:

Work package 4 (Data acquisition): The default values for the simulation parameters (iDefaults, Intelligent Default values) have been collected by all the partners and is therefore available for every participating country. The dataset for validation of models, especially stochastic models, has been delayed but will be available at the beginning of year 2005.

Work package 5 (Prototype models): A first version of the models has been developed and programmed. Concerning the stochastic models, for which the LESO-PB is responsible, 4 models have been already developed, programmed and partially validated (occupancy, window opening, blind and electric lighting use, and electric appliance use); the remaining 2 models (water, waste) are not yet available. A prototype solver, including all the available models, has been written by BDSP for demonstration purposes.

Work package 6 (Graphical interface, Educational tool): both parts of that work package are already available as prototype versions, not including all the possibilities planned for the final tool. For the time being, the parts of the whole project have not yet been tested together, but this should be done at the very beginning of year 2005.

International and national collaborations

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 (CSphere, 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.

Perspectives for 2005

The perspective for year 2005 at the Swiss level include the following:

- The continuation of the model development (completing of the implementation of stochastic models);
- The continuation of data collection for missing data (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.

At the project level, the main objective for 2005 is the completion of the prototype tool and its testing by selected users. Each participant will be using the tool and providing feedback on it.

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.esoft.gr/suntool/***

[2] 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

[3] 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

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

Annual Report 2004

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

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Duration of the Project (from – to)	November 2002 until November 2005

ABSTRACT

The PVSAT2 project is the followup of the EU-Joule 3-project PVSAT1, which was successfully concluded in 2001. A practical application was realised with Satwatch in Germany, where the solar irradiation data provided by the Meteosat satellite is used to predict the energy yield of PV systems. This allows the operator of the PV system to compare with the effectively produced energy yield and therefore to check the performance of its PV system. There are two main differences respectively novelties in PVSAT2 compared to PVSAT1: First, the accuracy of the irradiance calculation is improved by using reference values from ground measurements (the so called kriging method) and by changing to data of the new MSG satellite instead of the old Meteosat satellite. Second, energy production of the PV system is measured on site and sent to a central server which automatically checks the performance of the PV system by comparing this data with the calculated energy yield. In case of insufficient performance, a failure detection routine searches for possible malfunctions of the PV system and informs the operator. This performance check runs automatically and doesn't require regular personal support.

Therefore PVSAT2 will establish a low cost, reliable and easy-to-use performance check of photovoltaic systems. This will significantly increase the operational availability of PV systems and thus increased power production and income can be expected. Average cost reductions of about 2-5 % in both system maintenance and power production are expected. By introducing a unique two-way communication structure between the PV system and a central intelligent system, PVSAT2 provides a basis for a variety of management and control activities for production statistics, utilities information and later on also production forecast. In addition, PVSAT2 will help to open the renewable energy sector to new information and communication structures by introducing satellite-derived radiation data and new Information and Communication Technology (ICT)-based decision making techniques. This lets PVSAT2 contribute to a successful integration of PV into future energy distribution structures by increasing the value of information and - correspondingly - the energy efficiency.

Introduction / Project goals

Because the energy yield of PV systems is not constant but strongly depends on irradiance, a detailed performance check is very difficult. Therefore a former project (PVSAT1) implemented a calculation scheme to predict the expected energy yield of PV systems with the help of irradiance data provided by a satellite and site specific information about the PV system. The operator of the PV system himself then had to compare the predicted energy yield with the effectively produced energy yield and to decide about the performance of its PV system. PVSAT2 aims to prepare hardware, software and tools for a procedure, which not only predicts the energy yield of PV systems but also registers the effectively produced energy yield. Supplied with these information, the automatic data processor will be able to detect malfunctions of the PV system and search for possible failure reasons. It further includes the adequate information of the system operator and owner.

Short description of the project

The main components of PVSAT2 are:

- Development of a 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 PVSAT2 application more easy to use.
- Improvement of the irradiance calculation scheme. Accuracy will be increased 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.
- Development of a central knowledge-based decision making system, which will analyse the performance of the PV systems on a daily basis, and will be able to detect system failures and their possible causes.

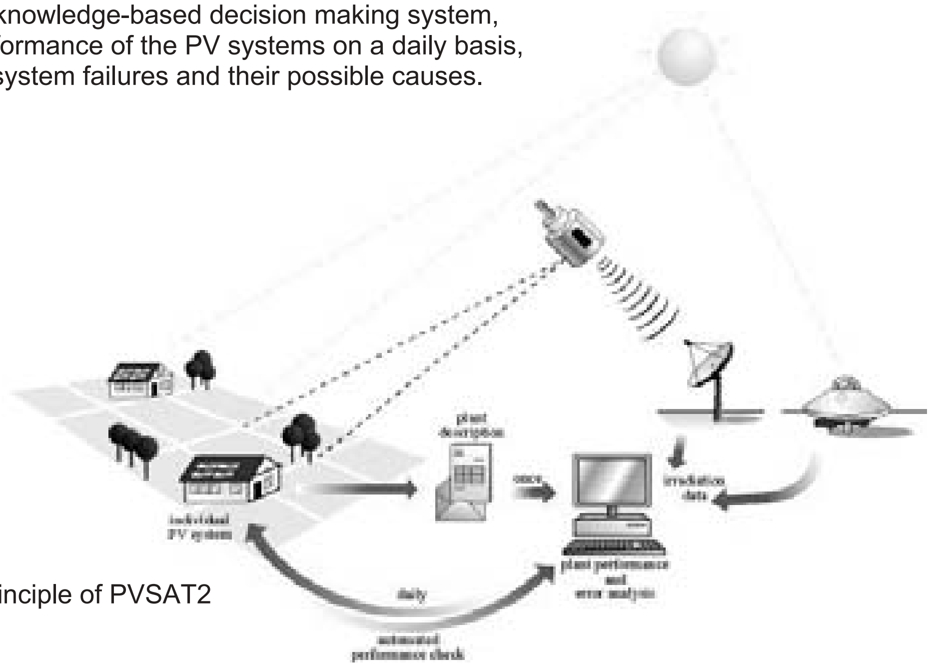

Figure 1:
Functional principle of PVSAT2

The consortium combines expertise from both Earth observation and solar energy research in order to exploit synergies between these fields and to realise a new approach for solar resource management. Customers and users are also represented as partners in PVSAT2. The PVSAT2 procedure will be tested in a one year field test with 100 PV systems in Switzerland, Germany and the Netherlands and thus be prepared to bring it on the broad market.

Executed work and achievements in 2004

Most improvements and developments are completed or soon will be completed and the test phase is in full preparation. The low cost hardware device is tested in the different countries and will be installed in the test PV systems in December. The improvements of the irradiance calculation, including the ground measurement data, are finished. Data of the new MSG satellite will be available as of January 2005.

The main Swiss contribution to the project is the development of the central decision making system. Enecolo developed a decision tree which allows to check automatically the performance of a PV system by comparing the predicted and the measured energy yield of the PV system. In case of an insufficient energy yield, the decision tree allows to analyse different attributes of the energy loss (e.g. duration, extent, correlation with daytime) that refer to different malfunctions of PV systems and therefore allow to determine, which malfunction most probably caused the energy loss. As a basis for programming the computer tool, an elaborate application flow scheme of every method was developed, including a defined set of variables and constants and all necessary calculation steps. After a submission, finally Meteocontrol AG was mandated to programme the decision making system. The programming will be finished in November 2004.

The test phase will start in January 2005 with 25 PV systems in the Netherlands, 50 PV systems in Germany and 25 PV systems in Switzerland. To coordinate the test phase and inform the partners about the status of the different work packages, several meetings were organised.

Automated Failure detection routine and decision support tool

The goal of the Decision Support Tool is to deliver information about the functioning of its PV system to the operator of a PV system. On the basis of this information the operator shall be able to decide, which type of maintenance is necessary for the PV system: Is there a severe problem which needs a specialist to repair the PV system, is it only a minor problem that can be solved by untrained (e.g. the housemaker) or is the PV system functioning properly and doesn't need any maintenance at the moment? Furthermore, the Decision Support Tool helps the operator to decide, e.g. which tool kits and materials are needed for the repair. To be able to decide, the operator mainly needs one information: Which failure or malfunction occurred in the PV system? Therefore, the Decision Support System computer tool is a routine which calculates probabilities for different failures. Hence, the Decision Support Tool is a failure detection routine. Figure 2 gives an overview on the Decision support tool, which includes the footprint method developed at Fraunhofer Institute [2], several failure analysis methods and a calculation scheme for the probabilities of different frequently occurring malfunctions.

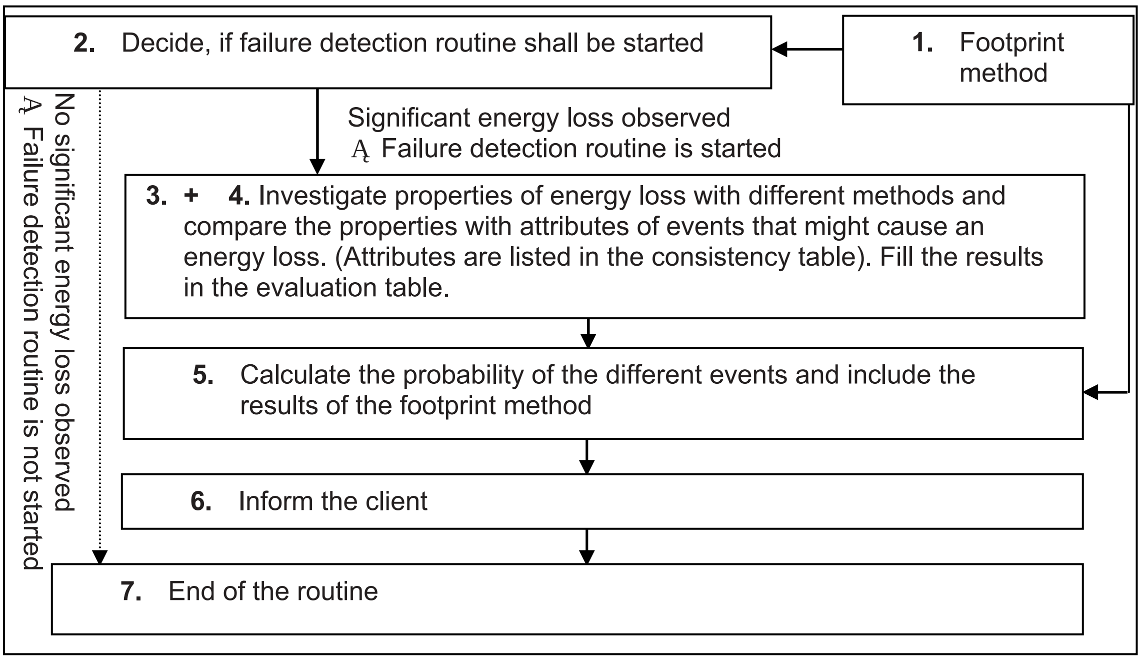

Figure 2: Overview Decision Support System

1. Footprint method: How did the energy loss correlate with irradiance and daytime?
This method was developed at Fraunhofer Institute [2] and runs every day, independent whether an energy loss occurred or not. It investigates the long term behaviour of the energy loss, analysing not only the investigated day but also the last 7 and the last 30 days. In case of an energy loss, the results of the footprint method are used later on in the daily and monthly failure detection routine.

2. Decide, if failure detection routine must be started
The failure detection routine is only started if a significant energy loss at certain hours of the day or on the whole day occurred. This method compares the simulated and the measured daily and hourly energy yield of the PV system at the investigated day. Because low energy losses caused by shading or permanent failures are only detectable in a long term analysis, secondary the results of the footprint method are used to decide about the starting of the failure detection routine.

3. Investigate properties of energy loss
If a significant energy loss is detected, the properties of this energy loss are investigated with several methods:

- **Daily energy loss:** How large was the daily energy loss?
- **Hourly energy loss:** How large was the maximum observed hourly energy loss for that day?
- **Temperature:** Which temperature prevailed during the last 3 days?
- **Spatial dimension:** Did neighbouring PV systems as well suffer from energy losses that day?
- **Changes of energy loss:** Is the energy loss constant in time?
- **Duration of event:** For how long did the energy loss occur?

4. Compare properties of energy loss with attributes of events that might cause an energy loss
The findings of the methods “daily energy loss”, “hourly energy loss”, “temperature”, “duration of event”, “changes of energy loss” and “spatial dimension” are compared with the attributes of several common events causing energy losses. The properties of these events are defined in the “consistency table” (see appendix 1). In this table the following events are specified:

- **Permanent errors:** Degradation / module over rating, soiling
- **Meteorology related errors:** shading, high temperature, snow cover
- **Module defect**
- **String defect**
- **Inverter failure:** high losses at low power, MPP tracking
- **Total blackout:** grid outage, defect inverter, defect control devices

For every event in the consistency table, the following attributes of each event are specified:

- **Maximum daily energy loss:** How large is the maximum daily energy loss that can be caused by this event? (e.g snow cover : 100%)
- **Minimum daily energy loss:** How large is the minimum daily energy loss that is caused by this event? (e.g snow cover : 0%)
- **Maximum hourly energy loss:** How large is the maximum hourly energy loss that can be caused by this event (e.g. snow cover: 100%)
- **Minimum hourly energy loss:** How large is the minimum hourly energy loss that is caused by this event? (e.g. snow cover: 0%)
- **Temperature dependency:** at what temperatures can this event occur? (e.g. snow cover: < 5 °C during the last 3 days)
- **Spatial dimension:** Is it a spacious event? Can this event affect several neighbouring PV systems at the same time? (e.g. snow cover is a spacious event)
- **Changes of energy loss:** Does the energy loss caused by this event remain constant or is it changing? (e.g. snow cover: may change or remain constant)
- **Maximum duration of event:** How long can the energy loss caused by this event appear at most? (e.g. snow cover: longer than a month)

Every attribute of every event is compared with the results of the failure detection methods. In the “evaluation table” (see appendix 2) the probability is recorded whether a property of an event is complied. There are 5 different probabilities from 0 (impossible) to 4 (very likely).

5. Analyse the probability of different errors

On the basis of the “evaluation table” the probability of every event is determined. Events that were rated with one or even more “0” in the “evaluation table” are not possible. Their probability is 0. For all other events, the points in the “evaluation table” are summed up. Those events with the highest score are the most probable ones.

The probability of the different events is the ratio between the score of this event and the maximum possible score.

The footprint method generates probabilities of different events, too. The probabilities of the footprint method and of the failure detection method are then averaged to get the final probability of the events (see figure 3). If the probability of one event by either the footprint method or by the failure detection routine is zero, the probability of the event is zero (instead of the average of the probabilities).

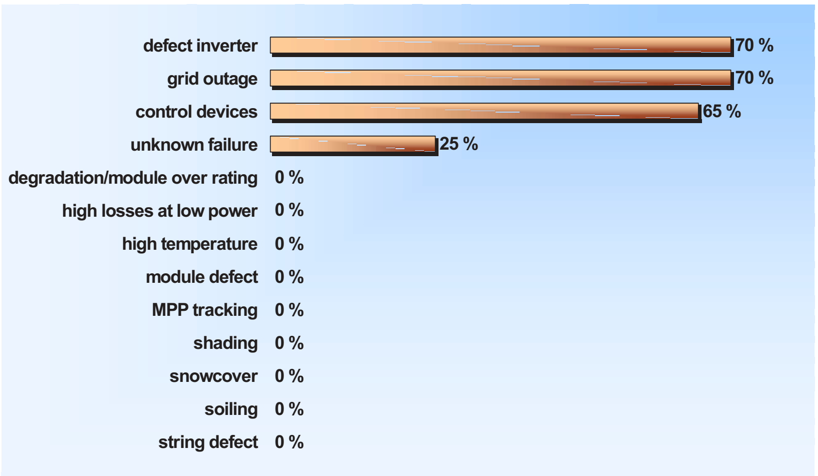

Figure 3: Example of a result of the Decision Support System

6. Inform the client

The result of the failure detection routine is recorded on the homepage and thus made available for the client. Furthermore, the client is instantly informed per email about the observed energy loss, if the observed significant energy loss exceeds a threshold and if the energy loss can be eliminated by a technician.

7. End of the routine

At the end of the routine, the results of the failure detection analysis are stored on the server.

National / international collaboration

The following partners are, beside Enecolo, members of the project team:

- University of Oldenburg, Oldenburg, DE, Project coordination and FH Magdeburg as subcontractor
- Fraunhoferinstitut für Solare Energiesysteme (ISE) in Freiburg, DE
- University of Utrecht, Utrecht, NL
- Meteocontrol, Augsburg ,DE

In addition, the following swiss companies were involved in PVSAT2

- Zühlke Engineering AG, Schlieren (Zürich), CH
- Ergonomics AG, Zürich, CH
- Leanux.ch, Böbikon, CH
- Meteotest, Bern, CH

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

Evaluation 2004 and outlook 2005

The test phase has been delayed from September 2004 to January 2005 because the hardware device doesn't function yet. This will also allow to include the new MSG satellite in the test phase, because these data will be available as for 2005. The transfer of the Decision Support System into a computer code has been subcontracted to Meteocontrol (DE). The project progress is according the schedule, except the delivery of the local data acquisition. PVSAT can benefit from other projects such as Heliosat 3, the new MSG and ENVISOLAR.

In 2005 the test phase will start with totally 100 PV systems. The failure detection routine will be tested with historic and actual measured data. In parallel, the marketing is going to be initiated. For that purpose, Enecolo and Meteocontrol plan to participate in two conferences (intersolar 2005 and 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, 6 – 10 June 2005).

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[1] Anja Drews, ***Internetseite des Forschungsprogramms*** **www.pvsat.de** , University Oldenburg.

[2] D 2.2 ***Footprint recognition algorithm***, Fraunhofer Institut für solare Energiesysteme (FhG-ISE)

[3] D 2.3 ***Report on Decision Support System computer code***, Enecolo AG

[4] ***A robust model for the MPP performance of different types of PV-modules applied for the performance check of grid connected systems***; EUROSUN 2004 (ISES Europe Solar Congress) Freiburg 20.6.-23.6. 2004

[5] ***Accuracy Improvement of Irradiation Data by Combining Ground and Satellite Measurements***; Poster at EUROSUN 2004 (ISES Europe Solar Congress) Freiburg 20.6.-23.6. 2004

[6] ***Intelligent Performance Check of PV System Operation Based on Satellite Data***; EUROSUN 2004 (ISES Europe Solar Congress) Freiburg 20.6.-23.6. 2004

[7] ***Identification of a General Model for the MPP Performance of PV-Modules for the Application in a Procedure for the Performance Check of Grid Connected Systems***; 19th European Photovolatic Solar Energy Conference & Exhibition, Paris 7.6.-11.6.2004

[8] ***PVSAT-2: Intelligent Performance Check of PV System Operation Based on Satellite Data***; 19th European Photovolatic Solar Energy Conference & Exhibition, Paris 7.6.-11.6.2004

[9] ***PVSAT-satellitengestütztes Monitoring von netzgekopelten Solaranlagen***; Poster an der 5. Nationale Photovolatik - Tagung, ETH Zürich 25.03.-26.03. 2004

[10] ***Ertragsberechnung für PV-Anlagen in Brasilien über das PVSAT Verfahren***; 19. Symposium Photovoltaische Solarenergie, Staffelstein 11.3.-13.3. 2004

[11] ***Satellitengestützte Ertragsüberwachung mit automatischer Fehlererkennung für kleine und mittere Photovoltaikanlagen***; 19. Symposium Photovoltaische Solarenergie, Staffelstein 11.3.-13.3. 2004

[12] ***Satellitengestützte Ertragsüberwachung mit automatischer Fehlererkennung für Photovoltaikanlagen***; Poster am 19. Symposium Photovoltaische Solarenergie, Staffelstein 11.3.-13.3. 2004

[13] ***Satellitengestützte Ertragsüberwachung mit automatischer Fehlererkennung für Photovoltaikanlagen***; Poster am 19. Symposium Photovoltaische Solarenergie, Staffelstein 11.3.-13.3. 2004.

Appendix

1. Consistency table
2. Evaluation table

Appendix 1: Consistency table

		event / failure	daily energy loss		hourly energy loss		temperature dependancy	spatial dimension Sp_i	changes	maximum duration MD_i	footprint
			minimum mEV_d_i	maximum MEV_d_i	minimum mEV_h_i	maximum MEV_h_i					
permanent errors		degradation / module over rating	0%	20%	0%	20%	no	no	no	800 h	FPp
		soiling	0%	20%	0%	20%	no	yes	no	800 h	FPp
non permanent errors	meteorology related errors	shading	0%	35%	0%	90%	no	no	yes	5 h	FPs
		high temperature	0%	15%	0%	15%	> 20°C	yes	yes	24 h	FPl
		snow cover	0%	100%	0%	100%	< 5°C	yes	yes or no	720 h	
	module related errors	module defect	0%	35%	0%	35%	no	no	no	800 h	FPp
	string related errors	string defect	25%	25%	25%	25%	no	no	no	800 h	FPp
	inverter failure: power limitation	high losses at low power	0%	50%	0%	50%	no	no	yes	24 h	
		MPP tracking	0%	20%	0%	20%	no	no	yes	24 h	FPl
	shutdown; total blackout	grid outage	0%	100%	0%	100%	no	yes	yes or no	100 h	
		defect inverter	100%	100%	100%	100%	no	no	no	800 h	FPp
		control devices	100%	100%	100%	100%	no	no	no	800 h	FPp
	diverse errors										

legend Appendix 1

daily energy loss; minimum	What is the minimum daily energy loss due to this event? (in %)
daily energy loss; maximum	What is the maximum daily energy loss due to this event? (in %)
hourly energy loss; minimum	What is the minimum hourly energy loss due to this event? (in %)
hourly energy loss; maximum	What is the maximum hourly energy loss due to this event? (in %)
temperature dependance	Does the energy loss depend on temperature?
spatial dimension	Has the event a spatial dimension? Can neighbouring PV systems be influenced by the same event?
changes of energy loss	Does the energy loss remain constant or is it changing?
duration of energy loss; minimum	After how many hours changes the amount of energy loss earliest?
duration of energy loss; maximum	After how many hours changes the amount of energy loss latest?
footprint	Which probability of the footprint method corresponds to the event? FPp: Probability for permanent power loss FPs: Probability for shading FPl: Probability for power limitation

Appendix 2: Evaluation table

The evaluation table contains the results of the different methods of the failure detection method. In the column “temperature dependency” only results for the failures “high temperature” and “snow cover” are calculated. The column “frequency of event” indicates, how often this event occurs in PV systems. The points in this column are determined once and for every PV system the same.
The score is the weighted sum of all points of a failure. It is used to calculate the probability of the failures without accounting for the footprint method. The probabilities of the footprint method and of the failure detection routine are weighted and averaged to get the final probability of the events.

Importance of method	1	1	1	1	2	1	1	1	1		1	1	1	2	
methods m	daily		hourly		temperature dependency	spatial dimension	changes	maximum duration	frequency of event	score S	probability without footprint	footprint			probability with footprint
events/failures i	min mEV_d_i	max MEV_d_i	min mEV_d_i	max MEV_d_i								1d	7d	30d	
degradation / module over rating									4		%	%	%	%	%
soiling									2		%	%	%	%	%
shading									1		%	%	%	%	%
high temperature									1		%	%	%	%	%
snowcover									3		%	%	%	%	%
module defect									1		%	%	%	%	%
string defect									3		%	%	%	%	%
high losses at low power									3		%	%	%	%	%
MPP tracking									2		%	%	%	%	%
grid outage									3		%	%	%	%	%
defect inverter									3		%	%	%	%	%
control devices									1		%	%	%	%	%

points
0 event not possible
1 event very unlikely
2 event might be possible
3 event possible
4 event surely possible

Annual Report 2004

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

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Project- / Contract Number	ENK5-2000-00332
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. The expected quality of the solar irradiance data will be a substantial improvement with respect to the available methods and will better match the needs of customers of the resulting products.

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)

Short description of the project

It is expected that the MSG data in combination with the new calculation schemes increases significantly the accuracy of the calculated surface solar irradiance. Other benefits will be the high spectral resolution, the enhanced information about the spatial structure of solar irradiance and the angular distribution of the diffuse light.

Work performed and results achieved

The project started in June 2001. The satellite was successful launched in 2002 and the first routine data are accessible since March 2004. The first validation against ground data acquired in Geneva are very promising, the standard deviation of the modelled irradiances turn around 80-120 [W/m^2] for 15 min data, and for both the beam and the global components.

Perspectives for 2005

Due to the late launch of the satellite, the end of the project was postponed to February 2005. A workshop will be held in Freiburg (Germany) at the end of February.

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Annual Report 2004

PV Catapult

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Project- / Contract Number	n° EU: 502775 (SES6) – Coordination Action
Duration of the Project (from – to)	01.12.2003 – 31.01.2006

ABSTRACT

The potential for the EU solar electricity (PV) industry to contribute to a clean energy system are enormous. However, a great co-ordinated effort is needed to ensure that the sector fully benefits from the expansion of the PV market. In PV Catapult industry consultants and research institutes work therefore together to give a boost to the EU solar energy.

The consortium aims to accelerate market development by means of various strategic actions. In the first step the strengths, weaknesses, opportunities and threats for the PV sector will be identified. The Consortium also aims to optimise the transfer process from the research laboratories to mass production. As the integrating of PV in buildings is a major market potential in Europe, the consortium will engage the construction industry to strengthen the PV market.

In this project new financial instruments will be exploited for the industry and the end-consumer to decrease the cost of PV. This will be done for different regions: the current EU-members, Newly Associated States and emerging/developing countries.

The simultaneously production of solar electricity and thermal energy (PVT) has the potential to reduce cost significantly. This project aims at bringing together all the key players in the R&D and industrial PVT field in Europe, to collect the knowledge, to structure it and to make it accessible. The gathering of key players will result in a strong network and have positive influence on the R&D effectiveness.

A grown up PV-marketed needs reliable standards and energy yield predications. To increase the understanding of the measurement of PV the same panels will be measured in different laboratories. This so called robin test will be made available to the PV community through a variety of means. Non EU-members are at the moment taking the lead for new standards, with the risk that EU interests are neglected. By exchange knowledge within the EU PV-community a good preparation for this process is made.

Project description

6th FW Coordination Action "PV-Catapult"

PV Catapult will run over 2 years and will involve more than 70 partners from the European industry, the research community and other major stakeholders of the PV sector.

The objective of PV Catapult is to coordinate activities in the field of photovoltaic (PV).

The main areas of work that will be developed are:

- Design alternative strategies for European PV sector according to the main stakes for the industry
- Facilitate the transfer of results from the European Research to the European PV industry
- Determine PV market potentials and develop a roadmap
- Engage the construction sector to enhance uptake of photovoltaics
- Address socio-economic and financial issues relevant to the PV sector
- Identify opportunities and barriers in a changing European Market
- Identify opportunities and barriers in export markets
- Work on measurement standards and prediction of the performance of PV modules
- Cross-fertilize and disseminate results to the whole sector

Dissemination of results

The outcomes of all work packages will be disseminated by means of workshops, reports, handbooks and web sites. The official project website informs the public about events and available publications. http://www.pvcatapult.org

Work packages

PV Catapult consists of 11 work packages (WP). LEEE is involved in the work package WP8+ WP9. Solstis is involved in the work package WP3.

WP 1 Identification of the results of existing State-of-the Art analysis and performing a SWOT – Strengths/Weakness, Opportunity/Threats

WP 2 Crystallizing the fruits of the European RTD + D efforts

WP 3 PVT Market and R&D Roadmap

WP 4 Engaging the Construction Industry in PV

WP 5 Socio-economic and financial issues

WP 6 Opportunities, Perspectives, Potentials and Hurdles in the enlarged EU market

WP 7 Emerging Economies and economies in developing countries

WP 8 PV and PVT Performance measurement

WP 9 PV and PVT Performance prediction

WP 10 Realisation of Cross Fertilisation Potentials

WP 11 Dissemination of the results

PV-Catapult activities in which the LEEE is involved (WG8 and WG9)

A grown up PV-marketed needs reliable standards and energy yield predictions. By exchange of knowledge within the EU PV-community a good preparation for this process has to be made. The following two workgroups (WG8 and WG9) will deal with these topics.

Workgroup 8 (PV performance measurement)

There are significant differences in the measurements reported by various calibration institutes. The dissimilarities between indoor and outdoor measurement is even more startling. Information about the actually used measuring equipment and measurement techniques for PV module performance measurements will be gathered through detailed questionnaires. These will be distributed as well to external groups. The work will be additionally supported by round robin tests of PV modules with different cell technologies. Particular attention will be paid to new cell technologies as current measuring procedures were developed mainly for crystalline silicon cell technology and therefore do not automatically include requirements for new cell technologies and materials such as multi-junction cells (a-Si), thin-film cells (CIS, CdTe) and hybrid cells (a-Si/σc-Si). Results will be made available through best practise guides in which possible error sources and technology related difficulties will be listed.

Workgroup 9 (PV performance prediction)

The evaluation of device performance needs also to be carried out theoretically and a reliable prediction method needs to be validated. Today a significant number of approaches is available within the European Research Area, based on very different approaches and simplifications, mostly validated for a very limited number of data sets and locations. It is important to evaluate the accuracy of these different approaches as well as generate some proven sets of data to carry out the validation procedure. In this context it is important to investigate the validity of the international standard (IEC 61853) currently under discussion, which on the current state of work is not based on extensive measurement campaigns.

The work in this work package is meant as a preliminary study, which focuses on: reviewing existing methods and defining the inputs needed for them, carry out round robin tests of different energy prediction methods including as far as possible all available methods, reporting the lessons learned and defining best practice guidelines for future round robins.

PV-Catapult activities in which Solstis is involved (WG3)

Workgroup 3 (PVT Market and R&D Roadmap)

A photovoltaic/thermal (PVT) module combines photovoltaic cells with a solar thermal collector, so that more solar energy is generated per unit surface area when compared to separate photovoltaic panels and solar thermal collectors. In addition, the integration of a solar thermal collector with PV leads to potential savings in material use and in production and installation costs. Finally, PVT modules have an aesthetic advantage: only one building element is required to produce both forms of solar energy, leading to a more homogeneous roof or façade appearance.

The aim of PVT Forum is to lay the foundations for a large-scale introduction of PVT technology in Europe. This is achieved in two steps. As a first step, PVT experts, PV and solar thermal industries and other stakeholders were brought together in two workshops, connected to the PVSEC 2004 in Paris and the Eurosun conference 2004 in Freiburg, to identify drivers and barriers for PVT. The results of these two workshop reports, were used as input for the roadmap.

As a second step, the PVT roadmap is written, formulating the necessary steps that should be taken on short, medium and long term in order to enlarge the market for PVT products. The chapters of the roadmap are written and reviewed by the various institutes participating in PVT Forum. These participants have been chosen on the basis of their contribution to PVT development over the last years.

The aim of the roadmap is to identify promising markets for PVT, and identify the economical, policy, legislative and technical bottlenecks. In addition, the roadmap wants to inform the parties in the market on PVT. The roadmap thereby targets a broad range of professionals, including policy makers, solar manufacturers, installers and researchers.

The roadmap, which is currently being drafted, will be finished in March 2005. The findings and conclusions of this roadmap will be presented at several conferences, especially the possibilities that PVT creates for a further strengthening of the European solar thermal market.

Workprogress (WG8 and WG9) in 2004

Most of the work of WG8 and WG9 is planned for the second half of the project. In 2004 questionnaires has been prepared and the WG8 and WG9 round robins defined. First results will be published at the next European PV Conference in Spain, Barcelona (June 2005).

Internationale Koordination

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Schweizer Beitrag zum IEA PVPS Programm, Task 1

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Project- / Contract Number	11427 / 11058
Duration of the Project (from – to)	1.1.04 – 31.12.04

ABSTRACT

The Swiss contribution to the PVPS Task 1 Work Programme included:

- **National Survey Report**, a summary of developments in the market and political areas. The report's data is integrated into the IEA PVPS **International Survey 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 July and December, including an article on the PV-house in Dottikon, Switzerland
- Two **Task 1 meetings** in Daejon, South Korea, and Port Macquarie, Australia

Work still to be done:

- To include more details of the PV value chain in the trends report 2004
- Organize a Workshop at the PV conference in Barcelona (June 2005)

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 2003), 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 Task 1 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 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 Programmes, Publizieren von Marktstatistiken.

IEA PVPS-Workshop Juni 2004, Paris

Durchgeführte Arbeiten und erreichte Ergebnisse

National Survey Report NSR

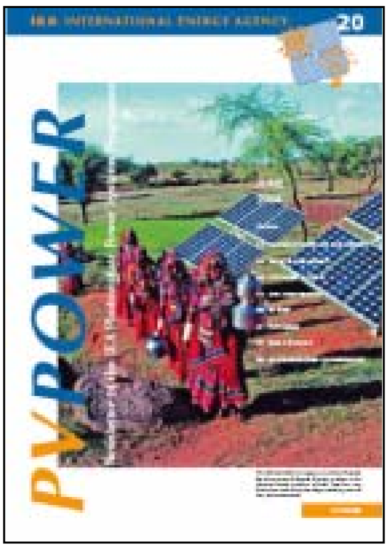
Der NSR bildet die Grundlage für den jedes Jahr erscheinenden "**Trends Report**". Als Grundlage für die Statistiken dienen einerseits die jährlichen Erhebungen des Sonnenenergie Fachverbandes SOLAR, andererseits die VSE-Statistik zu den netzgekoppelten PV-Anlagen. Die nachfolgende Tabelle gibt einen Überblick über die erhobenen Marktzahlen.

Sub-market/ application	31.12. 1992 kW	31.12. 1993 kW	31.12. 1994 kW	31.12. 1995 kW	31.12. 1996 kW	31.12. 1997 kW	31.12. 1998 kW	31.12. 1999 kW	31.12. 2000 kW	31.12. 2001 kW	31.12. 2002 kW	31.12. 2003 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*
off-grid non-domestic	70	100	112	143	162	184	190	200*	210*	220*	230*	260*
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
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
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

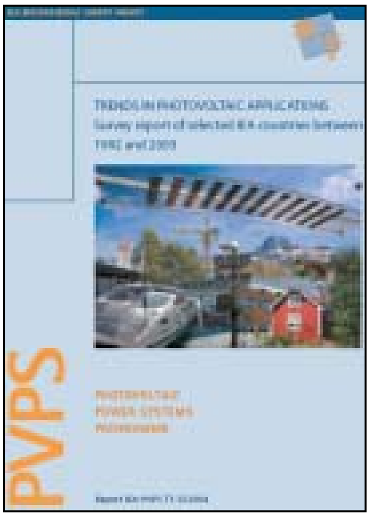
* Author's estimates. Exact figures for the proportion of off-grid power for domestic and non-domestic applications are not available.

PV Power

PV Power wurde im Berichtsjahr 2 mal ausgeliefert (Mai und Dezember).
In der Mai-Ausgabe wurde termingerecht auf die Europäische PV-Konferenz in Paris produziert.
Neu in 2004 sind in jeder Ausgabe kurze Länderinfos zu Regierungsprogrammen, speziellen P & D – Anlagen und sonstige Aktivitäten von weltweitem Interesse.



Trends Report



Basierend auf den Daten des "National Survey Reports" wurde Mitte September der Trends Report publiziert. Dieser Report ist international sehr anerkannt, da er unabhängig von der Industrie Daten zu Produktion und Markt in 20 Ländern liefert.
Die wichtigsten Daten aus dem Report sind auch im Internet unter www.iea-pvps.org [3] einsehbar. Der ganze Report wie auch einzelne Tabellen können als PDF-Dokumente heruntergeladen werden.
Die aktuellen Zahlen sind in der nachfolgenden Tabelle aufgeführt.

Trends Report 1992 – 2003: Installed PV power in reporting IEA PVPS countries as of the end of 2003

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 2003 (kW)	Grid-connected PV power installed in 2003 (kW)
	domestic	non-domestic	distributed	centralized				
AUS	13 590	26 060	4 630	1 350	45 630	2,29	6 500	1 730
AUT	2 173		13 507	1 153	16 833	2,05	6 492	6 327
CAN	4 539	6 886	405	0	11 830	0,37	1 833	37
CHE	2 740	260	16 440	1 560	21 000	2,88	1 500	1 300
DNK	55	170	1 675	0	1 900	0,35	310	300
DEU	19 700		390 600		410 300	4,97	133 000	130 000
ESP	18 820		9 180		28 000	0,68	8 000	6 500
FIN	3 022	237	118	32	3 409	0,66	357	22
FRA	11 924	5 332	3 817	0	21 072	0,35	3 832	1 875
GBR	172	542	5 189	0	5 903	0,10	1 767	1 621
ISR	313	200	6	14	533	0,09	30	0
ITA	5 300	6 400	7 600	6 700	26 000	0,45	4 000	3 980
JPN	1 101	77 792	777 830	2 900	859 623	6,74	222 781	216 535
KOR	461	4 549	1 427	0	6 438	0,13	1 028	666
MEX	13 565	3 536	10	0	17 111	0,16	950	0
NLD	4 678		38 759	2 480	45 917	2,83	19 591	19 545
NOR	6 175	365	75	0	6 615	1,44	231	7
PRT	1 152	520	397	0	2 069	0,20	401	5
SWE	2 814	573	194	0	3 581	0,40	284	36
USA	67 900	93 700	95 600	18 000	275 200	0,94	63 000	38 000
Estimated total[1]	**158 084**	**249 232**	**1 347 269**	**54 379**	**1 808 964**		**475 887**	**428 486**

[1] 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.

Industry Workshop 8. Juni 2004, Paris

Anlässlich der Europäischen Photovoltaik-Konferenz in Paris organisierte Task1 einen Workshop: **IEA PVPS meets with industry .**
Der Anlass wurde hauptsächlich durch die Schweizer PVPS-Delegation organisert.
Als Feedback gab es wertvolle Hinweise für die zukünftige Task 1 Arbeit: Was braucht die Industrie vom PVPS-Programm, wie können die Tasks besser mit der Industrie zusammenarbeiten? usw.

Nationale / internationale Zusammenarbeit

Im Berichtsjahr fanden 2 Task 1 Meeting statt:

März 2004	Dajeon, Süd-Korea Planung für den Industrie-Workshop in Paris (Juni 04) Festlegen der erweiterten Kapitel für den Trends Report 92-03 (Mehr Information zu nicht IEA-Ländern wie China und Indien, Produktionszahlen zu Ingots und Wafer)
Sept. 2004	Port Macquarie, und Sydney, Australien Auswertung des Industrie-Workshops von Paris Planung eines weiteren Workshops anlässlich der Europ. PV-Konferenz in Barcelona (Juni 2005) Beschluss 2005 nur 1 Task 1 Meeting durchzuführen Workshop in Sydney zusammen mit dem Australischen Business Council for Sustainable Energy: P. Hüsser **Vortrag zu PV in Switzerland**

Bewertung 2004 und Ausblick 2005

2 wichtige Publikationen aus der Bankenwelt beziehen sich stark auf die von Task 1 publizierten Daten zum Marktgeschehen. Der „Solar Power Sector Outlook der Credit Lyonais (Hongkong) bezog sich auf die Zahlen des 2002 – Trends Reports.

Für den aktuellen Solar Report der Bank Sarasin (Nov. 2004) konnten bereits die aktuellen Daten von 2003 einbezogen werden.

Task 1 will den Trends Report weiter ausbauen und gutes, aktuelles Datenmaterial möglichst entlang der ganzen Wertschöpfungskette erheben.

Referenzen / Publikationen

[1] P. Hüsser, A. Hawkins ***National Survey Report on PV Power Applications in Switzerland 2003***, Mai 2002

[2] ***Trends in Photovoltaic Applications in selected IEA countries between 1992 and 2003***, IEA, PVPS, Task I – 13:2004

[3] ***Internet site www.iea-pvps.org***

[4] P. Hüsser ***A Decade of Trends in Photovoltaic Applications***
Results from the latest surveys in selected IEA PVPS countries
Vortrag an der Europ. PV-Konferenz, Juni 2004, Paris

Annual Report 2004

IEA PVPS Programm, Task 2 (Schweizer Beitrag 2004)

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Project- / Contract Number	14805 / 151057
Duration of the Project (from – to)	1. January 2004 - 31. December 2004

ABSTRACT

Switzerland has committed itself to take part in the Photovoltaic Power Systems (PVPS) programme of the International Energy Agency (IEA), Task 2. The aims of the IEA-PVPS-Task 2 are outlined in the IEA PVPS Implementing Agreement of April 1994.

The overall objectives of the Task 2 is to provide technical information on operational performance, long-term reliability and sizing of PV-Systems to target groups.

Submissions have ben made to the Executive Committee of the IEA PVPS for the extension of Task 2 for another four years.

Subtask 1: Performance Database,
Subtask 2: Evaluation of Photovoltaic Power Systems (terminated in phase 2),
Subtask 3: Measuring and Monitoring (terminated in phase 1),
Subtask 4: Improving Photovoltaic Systems Performance (terminated in phase 2).

New activities:

Subtask 5: Technical Assessments and Technology Trends of PV Systems,
Subtask 6: PV System Cost over Time,
Subtask 7: Dissemination Activities.

The work of the Task work consists now mainly in the preparation and the dissemination of results to the target groups via the Task 2 homepage (http://www.iea-pvps-task2.org/).

This annual report gives an overview of the Task 2 main activities for the year 2004, mainly:

- IEA PVPS Performance Database
- Dissemination of results
- Implementation of new activities

Duration of Task 2 activities, phase III: 2004 to 2007

This project is supported by the Swiss Federal Office of Energy.

Einleitung / Projektziele

Das çPhotovoltaic Power Systemè (PVPS) Programm der Internationalen Energie Agentur (IEA) wurde in Zusammenarbeit von 15 Mitglied Staaten Anfangs 1993 gestartet. Im April 94 ist das çImplementing Agreementè von allen 15 Staaten unterzeichnet worden. Mittlerweile sind 21 Länder am PVPS Programm beteiligt. Das Ziel des Programms ist die internationale Zusammenarbeit und der Informations-Austausch im Bereich Forschung und Entwicklung von Photovoltaik- Anwendungen im Netzverbund und Inselbetrieb. Die einzelnen Forschungs-Projekte sind jeweiligen Taskgruppen unterstellt. Die Schweiz hat sich unter anderem zu einer Zusammenarbeit beim Task 2 verpþichtet.

Die Ziele von Task 2 sind:

Å Weiterleitung von technischen Informationen zur Performance, Langzeitverhalten und Auslegung von PV-Systemen an die Zielgruppen.

Å Die Zielgruppen sind, andere PVPS Tasks und PV Experten, Forschungsstellen, Elektrizitª tswerke und Hersteller von Komponenten, System Entwickler und Installateure, Normenverbª nde und Berufsschulen.

Mitglieder des Task 2 sind folgende Lª nder:

Deutschland (Taskleitung) ÅFrankreich ÅItalien ÅJapan Å¥ sterreich ÅSchweiz
neu sind: Kanada ÅSchweden ÅUSA dazugekommen
und ÅEuropª ische Union ÅPolen Åsind als Beobachter vertreten,
nicht mehr aktiv beteiligt sind: Israel ÅNiederlande.

Task 2 beýndet sich in der dritten Phase (2004 - 2007).

Task 2 ist ein technischer Task mit der Aufgabe Informationen an die ¿brigen Tasks von PVPS und an PV-Experten zu vermitteln. Informationen zum Betrieb und Unterhalt sowie Langzeitverhalten von PV Anlagen und deren Komponenten sind ein wesentlicher Aspekt der Aktivitª ten.

Kurzbeschrieb des Projekts

Um die notwendigen Informationen ¿ber die Performance und das Langzeitverhalten von PV-Systemen zu erhalten wurde eine Internationale Datenbank (IEA PVPS Performance Database) aufgebaut und den Zielgruppen zugª nglich gemacht. Die Anlage- und Betriebsdaten wurden wª hrend den letzten Jahren von den Mitgliedern des Task 2 eingesammelt, aufbereitet und weitergeleitet. Die meisten Daten stammen aus nationalen Projekten der Task 2 Mitgliedlª nder.

Durchgef¿hrte Arbeiten und erreichte Ergebnisse

Arbeiten des Task 2:

Å Zwei Task Meetings
Erlenbach, Schweiz. Mª rz 2004
Ispra, Italien, September 2004

Å Ausbau der Datenbank mit:
Integration neuer Betriebsdaten schon aufgenommener Anlagen
Integration neue Anlagen in die Datenbank

Å Unterhalt der Task 2 WWW-Homepage

Å Aufbereitung und Analyse der Messdaten

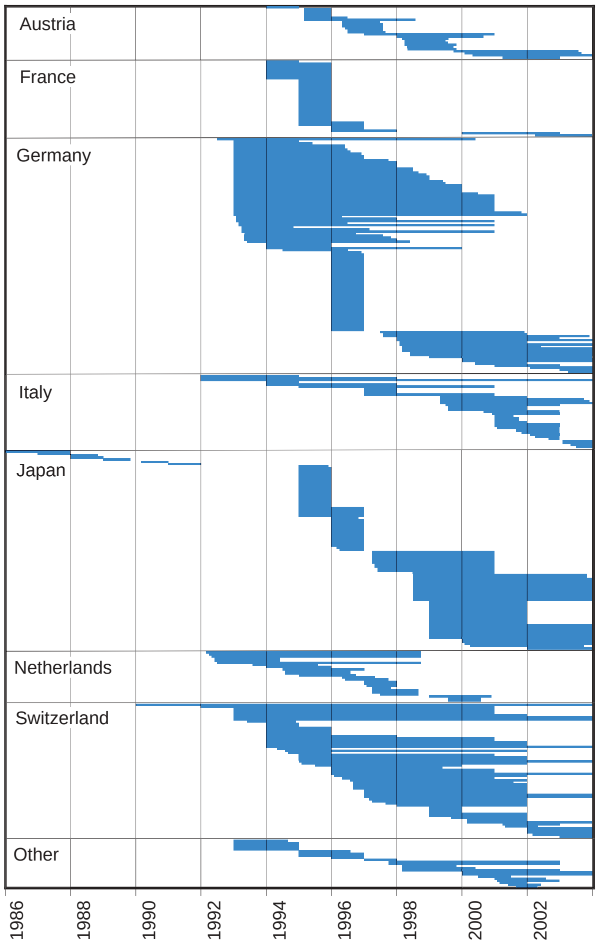
Å Deýnition und Ausf¿hrung von neuen Aktivitª ten

Å Ausarbeitung des ÄWorkplansñf¿r die Verlª ngerung des Task 2, Phase III

Internationale Datenbank

Die neueste Auþage der ĂIEA PVPS Performance Databaseñ[9] vom May 2004 enthªlt 414 PV-Systeme aus 21 Lªndern von insgesamt 12 MWp Nennleistung und 15ó149 Monats-Betriebsdaten von 1986 bis 2003.

Die ĂIEA PVPS Performance Databaseñ ist in englischer Sprache erhªltlich. Vorgesehen sind franzºsische, italienische und japanische ¦bersetzungen der Anleitungen. Die IEA PVPS Datenbank CD kann von der Taskleitung oder von der Task 2 Webseite bezogen werden [9].



Figur 1, Bertriebsdaten in der IEA Datenbank, 414 Anlagen aus 21 Lªndern

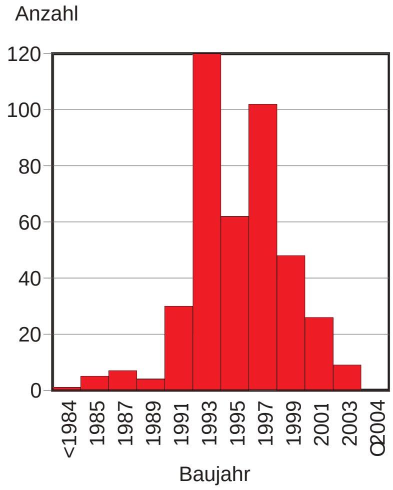


Tabelle 1, ¦bersicht der Baujahre der 414 Anlagen in der IEA

Schweizer Daten in der Datenbank

Die internationale PV Datenbank enthªlt Daten von 64 Schweizer PV-Anlagen mit einer totalen Nennleistung von 1ó986 kWp. Die Nennleistung dieser Anlagen ist zwischen 1.3 kWp und 560 kWp. Die Betriebsdaten von 1990 bis 2003 dieser Anlagen (1 bis 14 Jahre pro Anlage) reprªsentieren 313 Betriebsjahre mit einer ĂMonitoring Fractionñ von 0.95.

Abgeschlossene Aktivitª ten

Folgend Aktivitª ten wurden Jahre 2004 abgeschlossen.

2.1 Availability of irradiation data, (Frankreich),

2.2 Tools for checking the performance of PV systems, (Frankreich),

2.5 Long-term performance and reliability analysis of PV systems, (Deutschland), [1],

2.6 Country reports on PV system performance, (Schweiz), [2].

Neue Aktivitª ten

Subtask 5 : Technical Assessments and Technology Trends of PV Systems,

Subtask 6 : PV System Cost over Time,

Subtask 7 : Dissemination Activities.

TNC hat die Subtask 6 Leitung ¿bernommen. Die Arbeiten 2004 betreffen die Ausarbeitung des Arbeitsprogramms und die Vorplanung f¿r die internationale Befragung ĂCost over timeñ Das entwickelte Konzept geht ¿ber die Inhalte der vorhandenen Task 2 Datenbank hinaus. Die Informationen werden ¿ber eine mehrsprachig im Internet vorgehaltene Datenbank gesammelt. Es werden belastbare Informationen bez¿glich der Investitionskosten und den Betriebs- und Unterhaltskosten gesucht. Die weltweit ¿ber 2060 lizenzierten Datenbankanwender erhalten die Mº glichkeit, aus ihrem Tª tigkeitsumfeld entsprechende Informationen individuell einzugeben. Die Grundstruktur der Datenbank/Internetapplikation wurde 2004 entwickelt und beýndet sich Ende des Jahres in der Vernehmlassung unter den Task-Teilnehmern. Der Start des internationalen Surveys ist auf Mª rz 2005 geplant. F¿r die Subtask-Arbeitsgruppe haben sich die Vertreter der Lª nder ¥ sterreich, Kanada, Frankreich, Deutschland, Italien, Japan, USA und der Europª ischen Union mit engagiert.

Damit ist die Voraussetzung gegeben, die Erfahrungs- und Datenbasis auf drei Kontinenten zu etablieren.

Schweizer Beitrag

Im vergangenen Jahr wurde der Task 2 interne Report: Temperature Effects on PV System Performance [4], und der Task 2 Report: Country Reports on PV System Performance [2], durch die Schweizer Vertreter des Task 2 erstellt. Leider erweist es sich als schwierig Messdaten von neuen Schweizer Projekten zu erhalten und so konnten im Jahre 2004 nur Monatswerte von bestehenden Projekten in die IEA PVPS Performance Datenbank ¿bertragen werden.

Nationale / internationale Zusammenarbeit

Die internationale Zusammenarbeit innerhalb des Task 2, sowie die Intertask-Kooperation sind ein wesentlicher Bestandteil des IEA PVPS Implementing Agreements. Mit der Task 2 WWW-Homepage sind Informationen ¿ber die Aktivitª ten, sowie die komplette Datenbank f¿r die Zielgruppen zugª nglich. Die Europª ische PV Konferenz in Paris bot Gelegenheit die Resultate der Aktivitª ten des Task 2 vorzustellen.

Bewertung 2004 und Ausblick 2005

Mit der ĂPerformance Databaseñ [9] wurde ein n¿tzliches Werzeug zur Administration und Analyse von Betriebsdaten von PV Netzverbund- und Inselanlagen geschaffen. Die Nachfrage und der Download von der Task 2 Homepage zeigen ein Interesse an den Arbeiten und Publikationen des inzwischen aus neun Mitgliedern und zwei Beobachtern bestehenden Task.

Der Workplan f¿r die Phase III von 2004 bis 2007 wurde vom IEA PVPS ExCo gutgeheissen und im kommenden Jahr werden die neuen Aktivtª ten anlaufen.

Publikationen und Referenzen

[1] IEA PVPS Task 2,
Analysis of Long-term Performance and Reliability of Photovoltaic Systems,
Task 2 activity 2.5, to be published in 2005.

[2] IEA PVPS Task 2,
Country Reports on PV System Performance,
Report IEA-PVPS T2-05:2004, December 2004.

[3] Ulrike Jahn, Wolfgang Nasse,
Achievements of Task 2 of IEA PV Power Systems Programme: Final results on PV system performance,
19th European Photovoltaic Solar Energy Conference and Exhibition, Paris, France, 7-11 June 2004.

[4] IEA PVPS Task 2,
Understanding Temperature Effects on PV System Performance,
Task 2 Activity 2.4, Internal Report, May 2004.

[5] IEA PVPS Task 2,
Operational Performance, Reliability and Promotion of Photovoltaic Systems,
Proceedings of October 2001 Workshop,
Report IEAï PVPS T2-03: 2002.

[6] IEA PVPS Task 2,
Analysis of Photovoltaic Systems,
Report IEA-PVPS T2-01: 2000.

[7] International Electrotechnical Commission (IEC),
Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data Exchange and Analysis,
Standard IEC 61724.

[8] 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

[9] Performance Database, Version 1.19, Edition: May 2004, auf CD-ROM f¿r EUR 20.- erhª ltlich bei:

Taskleitung: Ulrike Jahn, Institut f¿r 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/.

IEA PVPS

Info auf Webseite: http://www.iea-pvps.org/.

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IEA PVPS Task 3
Use of photovoltaic systems in stand-alone and island applications

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Project- / Contract Number	35550 / 151123
Duration of the Project (from – to)	9/01 – 10/04

ABSTRACT

From Solar Home Systems (SHS) until large hybrid photovoltaic systems for rural electrification, IEA PVPS Task 3 main objective is to improve the reliability and cost effectiveness of PV systems in stand-alone application.

To reach these objectives, the task has been divided into the two main following categories:

- Subtask 1 : Quality insurance, schemes for improving the reliability, lower the cost and increase the lifetime of SAPV systems.
- Subtask 2: Technical issues, technical recommendations for cost reduction of systems.

The task has finished its program in mid 2004 and published two reports at the beginning of the year: **“Guidelines for Selecting Lead-Acid batteries used in Stand-Alone Photovoltaic Power systems ”** describes all the available technologies and compare their merits for storing PV electricity. A last part presents the grey energy of each technology and calculates the amount of grey energy that can be stored and drawn back from the batteries.
“Alternatives to lead-acid batteries in stand-alone PV power systems” presents twelve ways of storing electricity and compares their efficacy with lead-acid technology. This reports is useful for getting information on what is available today and what might become a real alternative to the LA batteries which is not at all a friendly environmental way of storing a renewable resource.

The last meeting in March 2004 was held in Ginostra on Stromboli island where a hybrid 110 kW photovoltaic / diesel stand-alone system started operation at the end of 2003. That visit demonstrated well that the future of stand-alone systems will more and more be in large projects to supply electricity to small communities and so creating what we call micro-grids. The main interest in studying SAPV system will be the design and optimization of such systems which for developing countries are often the only available alternative the extension of the grid.

Introduction / Buts du projet

Considérant tous les types d'installations photovoltaïques autonomes depuis les SHS (Solar Home Systems) jusqu'aux micro-réseaux d'électrification rurale, l'objectif principal de la tâche 3 est d'améliorer la qualité et le rapport qualité/ prix des systèmes indépendants.

Pour atteindre ces objectifs, les travaux sont séparé en deux sous-tâches spécialisés :

1. **Sous-tâche 1, Assurance qualité (QA): procédures de QA pour améliorer la fiabilité et augmenter la durée de vie des systèmes.**
2. **Sous-tâche 2, Travaux techniques: recommandations techniques pour abaisser le coût des systèmes.**

Brève description du projet.

Les experts des 14 pays participants (Au, Can, CH, D, F, I, J, K, N, NL, P, Sp, Su, UK) se sont répartis les travaux en fonction de leurs compétences personnelles. Durant l'année chacun apporte ses informations et expériences et lors de chaque réunion, l'avancement d'un projet est examiné pour décider de sa publication ou des améliorations à y apporter.

Toutes les publications de la tâche sont disponibles sur le site web : www.task3.pvps.iea.org

Travaux effectués et résultats acquis en 2004

Comme le projet se termine courant 2004, il reste seulement 2 rapports à publier.

Sous-tâche 2:

"Guidelines for Selecting Lead-Acid batteries used in Stand-Alone Photovoltaic Power systems - " est terminé

Ce papier présente les technologies principales de fabrication des batteries au plomb disponibles sur le marché pour chaque type d'application :

- démarrage automobile
- traction utilisé par exemple dans les petits élévateurs, chaises roulantes,…
- stationnaire telles celles des alimentations de secours
- solaire

Ensuite, toute une série de cas mesurés sont présentés avec des détails sur le système, la durée de vie des batteries, un examen approfondi de celles-ci (microscopie des dégradations) et conclusion. Les 4 causes de pannes les plus courantes sont :

- dimensionnement incorrect
- mauvaise régulation
- sous-estimation de la consommation
- défectuosité de batterie

Ce rapport confirme une information connue des spécialiste du photovoltaïque, à savoir qu'une régulation adapté est primordiale pour garantir une duré de vie élevé des batteries. Un mauvais dimensionnement ou une sous estimation de la consommation mettent en cause la qualité de l'engineering des systèmes. Par contre la dernière cause de panne est, elle, vraiment lié à la technologie et malheureusement avec les batteries au plomb fortement tributaire des conditions de fonctionnement (température, état de charge aléatoire lié aux variations de la génération solaire,).et force est de constater que cette technologie ne sera jamais un moyen réellement économique de stocker de l'énergie renouvelable.

La fin du rapport reprend une étude déjà présenté mais édifiante calculant l'énergie grise des batteries au plomb et comparant quelle part d'énergie grise pourra être stocké durant la vie de la batterie. Ce calcul est le pendant du fameux « payback time » des générateurs photovoltaïques, c'est-à-dire pendant combien d'années un panneau doit-il fonctionner pour produire son énergie grise. Comme une batterie n'est pas un producteur d'énergie, on calcule combien d'énergie elle pourra emmagasiner et restituer durant sa duré de vie. La conclusion est ici peu favorable et seules les batteries des meilleures technologies (chères) permettent de stocker plusieurs fois leur énergie grise durant leur duré de vie.

"Alternatives to lead-acid batteries in stand-alone PV power systems" est le dernier rapport à être publié

L'objectif principal de ce document est de faire un état de l'art des différentes possibilités de stockage d'énergie qui pourraient être utilisés dans les systèmes photovoltaïques autonomes. Le document décrit les particularités propres à chaque technologie et souligne les avantages et inconvénients de chacune. Le point de référence de l'étude est défini par la batterie plomb-acide. Les autres technologies candidates sont ensuite passés en revue afin d'évaluer leurs caractéristiques et performances et d'étudier leur emploi possible dans les systèmes photovoltaïques en lieu et place des batteries au plomb traditionnelles :

- Batteries au lithium,
- Batteries au nickel,
- Batteries métal-air,
- Batteries sodium-soufre,
- Supercapacités,
- Volants d'inertie,
- Batteries redox,
- Piles à combustible,
- Stockage à air comprimé,
- Stockage magnétique à base de supraconducteurs,
- Stockage thermique,
- Stockage par pompage hydraulique.

Concernant les systèmes photovoltaïques autonomes, quelques technologies de stockage d'énergie pourront représenter une alternative aux batteries plomb-acide lorsqu'elles se seront affranchies de certaines limites actuelles (coût, complexité, taille des installations, impact sur l'environnement, etc.) qui empêchent aujourd'hui une large dissémination sur le marché et le remplacement des batteries au plomb dans un futur proche.

Le document est composé de cinq parties: les trois premières proposent une analyse des caractéristiques, performances et limites des différents types de batterie rechargeable, des moyens de stockage de courte duré (filtres) et des autres technologies de stockage de l'énergie, la quatrième fait une comparaison globale et la dernière traite de leur utilisation spécifique dans les systèmes photovoltaïques autonomes.

Fin du programme de 5 ans et publications

Une douzaine de publications sont disponibles sur le site de lIEA-PVPS (http://www.iea-pvps.org/) et un CD-ROM regroupant tous les papiers ainsi que les informations du programme europén INVESTIRE sur les technologies de stockage sont disponibles auprè de lauteur.

La liste des publications classé en 4 domaines dIntéê est donné ci-dessous :

Assurance qualité	
IEA-PVPS T3-07	Survey of National and International Standards guidelines and Quality Assurance procedures for Stand-Alone Photovoltaic systems
IEA-PVPS T3-15	Managing the quality of Stand-Alone Photovoltaic systems - Recommended practices
IEA-PVPS T3-15b	Managing the quality of Stand-Alone Photovoltaic systems – Case studies
Systèmes	
IEA-PVPS T3-08	Recommended practices for charge controllers
IEA-PVPS T3-14	Protection against the effects of lightning on Stand-Alone Photovoltaic systems - Common practices
IEA-PVPS T3-13	Monitoring Stand-Alone Photovoltaic systems : methodology and equipment – Recommended practices
Stockage	
IEA-PVPS T3-10	Management of batteries used in Stand-Alone Photovoltaic systems
IEA-PVPS T3-11	Testing of batteries to be used in Stand-Alone Photovoltaic systems – Guidelines
IEA-PVPS T3-18	Selecting batteries to be used in Stand-Alone Photovoltaic systems – Guidelines
IEA-PVPS T3-19	Alternative technologies to lead-acid batteries in Stand-Alone Photovoltaic systems
Récepteurs et utilisateurs	
IEA-PVPS T3-09	Use of appliances in Stand-Alone Photovoltaic systems: problems and solutions
IEA-PVPS T3-16	Demand side management for Stand-Alone Photovoltaic systems

Les résultats de ce projet sont résumé dans le rapport final détaillé disponible sur www.photovoltaic.ch. Le CD Rom avec toutes les publications peut être commandé auprè de lauteur ou la direction du programme photovoltaïque.

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Swiss Interdepartmental Platform for Renewable Energy Promotion in International Co-operation (REPIC)

including Swiss contribution to IEA PVPS Task 9

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Project- / Contract -Number	seco UR-00123.01.01
Duration of the Project (from – to)	March 2004 – February 2007

ABSTRACT

The Swiss State Secretariat for Economic Affairs (seco), the Swiss Agency for Development and Cooperation (SDC), the Swiss Agency for the Environment Forest and Landscape (SAEFL) 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

Seit 2004 erfolgt der Schweizer Beitrag im IEA PVPS Projekt Task 9 – „Photovoltaic Services for Developing Countries“ als Bestandteil der neu geschaffenen interdepartementalen Plattform zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit, kurz REPIC (Renewable Energy Promotion in International Co-operation), welche im Folgenden beschrieben wird. Einzelheiten zum eingangs erwähnten IEA PVPS Projekt Task 9 sind im Verlauf dieses Berichtes aufgeführt.

Das Staatssekretariat für Wirtschaft (seco), die Direktion für Entwicklung und Zusammenarbeit (DEZA), das Bundesamt für Umwelt, Wald, und Landschaft (BUWAL) sowie das Bundesamt für Energie (BFE) haben eine neue interdepartementale Plattform zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit gegründet. Ein gemeinsames Engagement der vier Bundesämter auf dem Gebiet der internationalen Zusammenarbeit ist in der vorgeschlagenen Form (zugehörige Instrumente, gemeinsames Budget) innovativ und stellt eine neue Form der interdepartementalen Zusammenarbeit dar. Aufgrund eines im Jahr 2003 erarbeiteten Konzeptes erteilten die 4 beteiligten Bundesämter der REPIC-Plattform ein entsprechendes gemeinsames Mandat zur Ausführung dieser interdepartementalen Plattform.

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.

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 2004

Die übergeordneten Ziele der REPIC-Plattform sind einerseits die Stärkung und Koordination der Bundesaktivitäten als Grundlage einer gemeinsamen Strategie zur Förderung der erneuerbaren Energien in der internationalen Zusammenarbeit. Andererseits soll die Bildung neuer strategischer Partnerschaften mit privatwirtschaftlichen Unternehmen und der schweizerischen Zivilgesellschaft zur konkreten Verbreitung erneuerbarer Energiesysteme in Entwicklungs- und Transitionsländern ermöglicht werden.

Unter diesen übergeordneten Zielen verfolgt die REPIC-Plattform die folgenden 5 konkreten Ziele:

1. Information und Sensibilisierung der Akteure;
2. Kenntnis von lokalen Rahmenbedingungen und Verbesserung von Kapazitäten;
3. Projektförderung und –realisierung;
4. Mitwirkung in internationalen Netzwerken;
5. Koordination und Qualitätssicherung.

Nachdem das Konzept und das Mandat der REPIC Plattform anfangs 2004 bereinigt werden konnten, stand die operative Umsetzung im Vordergrund. Dazu verfolgte REPIC im Jahr 2004 die folgenden Ziele:

1. Identifikation der für REPIC strategischen Elemente
2. Erstellen eines Kommunikationskonzeptes
3. Information und Mobilisierung des Nutzerkreises
4. Formalisierung von Projekteingaben, Stellungnahmen und Entscheidfindungen; Unterstützung und Begleitung von Projekten
5. Koordination

Durchgeführte Arbeiten und erreichte Ergebnisse

Aufgrund des Mandates von seco, DEZA, BUWAL und BFE wurde die REPIC-Plattform am 1. Januar 2004 operationell. Die Arbeiten zur Umsetzung der REPIC-Plattform wurden plangemäss aufgenommen und durchgeführt (strategische Elemente der Plattform, administrative Prozeduren und Hilfsmittel, Kommunikation und Koordination zwischen den beteiligten Ämtern).

Im ersten Halbjahr hat das Sekretariat zusammen mit der REPIC-Steuergruppe die Detailausführung der Plattform erarbeitet und umgesetzt. Dies betrifft insbesondere die Prozeduren, die Kriterien, die Hilfsmittel zur Projektförderung sowie das Kommunikationskonzept. Die REPIC-Steuergruppe traf sich dazu zu insgesamt fünf Arbeitssitzungen. Ausserdem fand eine Sitzung der strategischen Leitung der REPIC-Plattform statt.

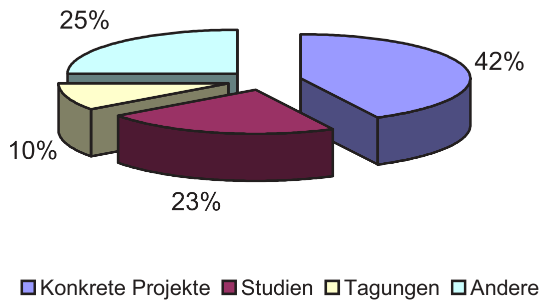
Für die operativen Belange der REPIC-Plattform wurde ein Projektleitfaden [1] mit den relevanten Arbeitshilfen und Kriterien entwickelt. Der REPIC-Leitfaden liegt in drei Sprachen vor (d/f/e). Entsprechend dem erarbeiteten Kommunikationskonzept wurde zudem ein REPIC-Flyer [2] erstellt, welcher ebenfalls in drei Sprachen vorliegt. Die REPIC-website http://www.repic.ch wird 2005 aufgeschaltet; diese enthält als Grundlage die oben aufgeführten Dokumente.

Im Verlauf von 2004 wurden 34 Vorschläge bearbeitet ; 6 weitere Vorschläge fielen unter die Übergangszeit zwischen der Drehscheibe PV EZA und der neuen Plattform REPIC. Von den insgesamt 40 Vorschlägen (Tabelle 1) wurden 19 durch die REPIC-Steuergruppe behandelt und entschieden. Von den 19 entschiedenen Vorschlägen mündeten 5 in eine direkte finanzielle Unterstützung durch die REPIC-Plattform, 2 betrafen Beiträge von REPIC an Veranstaltungen (Suisse Eole und SESEC III), 6 Vorschläge wurden nach eingehender Evaluation abgelehnt und auf 6 weitere Vorschläge wurde nicht näher eingetreten. Von den restlichen 21 Vorschlägen wurden nach den erfolgten Erstkontakten 11 von den Gesuchstellern vorderhand nicht weiterverfolgt bzw. 10 Vorschläge befanden sich Ende 2004 noch in Klärung.

Tabelle 1

Status	angenommen	abgelehnt	zur Klärung	stand by	Total
Anzahl	5 + 2	12	10	11	40

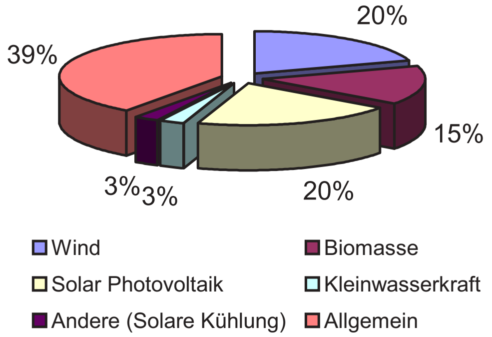
In Bezug auf die Art der Vorschläge betrafen 17 konkrete Projekte, 9 Studien, 4 Tagungen; die restlichen 11 betreffen andere Anfragen.



Figur 1 : Art der Anfragen und Vorschläge

Bei den durch REPIC unterstützten Projektvorschlägen betreffen 2 die Förderung von Windkraftanlagen durch entsprechende Windmessungen und 1 Projekt betrifft die gebäudeintegrierte Photovoltaik. Ein Projekt stellt den Schweizer Beitrag im Netzwerkprojekt IEA PVPS Task 9 sicher und ist damit eine Fortsetzung eines Projektes innerhalb der früheren Drehscheibe PV EZA. Zudem wurde eine Tagung des Ökozentrums Langenbruck zur internationalen Zusammenarbeit auf dem Gebiet der erneuerbaren Energien unterstützt.

Technologisch betrachtet zeigten die Anfragen bei der REPIC-Plattform im ersten Jahr eine Präferenz für Wind und Photovoltaik (je 8 Vorschläge), 6 für Biomasse, 1 für Kleinwasserkraft, 1 für Kühlung sowie 16 mehr allgemeine Vorschläge, welche technologisch nicht zugeordnet werden können.



Figur 2: Verteilung der Projektvorschläge auf die verschiedenen Technologien

In Bezug auf die geografische Verteilung der Projektvorschläge betrafen 7 die Zielregion Afrika, 5 Zentralamerika, 4 Asien, 3 Osteuropa, 1 Südamerika und 1 Naher Osten. 19 Vorschläge hatten keinen spezifischen geografischen Fokus.

Unterstützte Projekte

Im Einzelnen wurden durch REPIC bisher die folgenden Projekte direkt unterstützt :

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	http://www.entec.ch http://www.oja-services.nl/iea-pvps/tasks/i_task09.htm
Projektstatus	laufend bis 2006
Dokumentation	Jahresbericht Schweizer Beitrag IEA PVPS Task 9, 1999 – 2003 [3] Publikationen IEA PVPS Task 9 [4]

IEA PVSDC hat sich bei Beginn der zweiten 5-Jahresphase Mitte 2004 den neuen Namen "Photovoltaic Services for Developing Countries" gegeben, um von der aussagelosen Bezeichnung Task 9 wegzukommen. Der neue Name signalisiert auch die stärkere Ausrichtung der Arbeitsgruppe auf die Erörterung von PV gestützten Dienstleistungen im ländlichen Raum in Entwicklungsländern, anstelle einer engen Beschränkung auf ländliche Elektrifizierung.

Der Schweizer Beitrag zu IEA PVPS SDC wurde wie vorgesehen durch die Expertentätigkeit von entec erbracht. Auch für die zweite 5-Jahresphase hat die Schweiz signalisiert, die Führung des Aufgabenbereichs Unterstützung und internationale Zusammenarbeit (Subtask 20) weiterzuführen. Im Rahmen dieser Aufgabe wurde neben einer regulären Arbeitssitzung in Stockholm (8. - 10.3.2004) ein Erfahrungsaustausch Seminar am Hauptsitz der SIDA durchgeführt.

Zusammen mit der GTZ und KfW organisierte PVSDC eine zweitägige Arbeitskonferenz (22. - 23.3.04) zum Thema "From projects to markets - perspectives for private sector participation". Es wurden sehr intensiv bekannte Entwicklungsstrategien, Dienstleistungsmodelle und angewandte Finanzierungsinstrumente diskutiert. Es ist bemerkenswert zu sehen, wie ernst es die Entscheidungsträger der deutschen Entwicklungszusammenarbeit mit der Förderung erneuerbarer Energien und der Umsetzung der "millenium development goals" nehmen und den internationalen Erfahrungsaustausch suchen und nutzen.

Zusammen mit der KfW hat PVSDC ein Programm Seminar "Erneuerbare Energien und Klimaschutz" in Frankfurt (2.11.2004) durchgeführt. Die von A. Arter, entec, gehaltenen Vorträge in Eschborn und Frankfurt hatten die Themen:

- Critical comparison of selected financing mechanisms in relation to transaction costs and impact
- Erfolgsversprechende und weniger geeignete Ansätze der PV-Förderung

Beitrag zum GEF Projekt „Malaysian Building Integrated Photovoltaics“

Projektart	Ko-Finanzierung der GEF PDF-B Projektphase (GEF Project Preparation and Development Facility)
Schweizer Partner	Enecolo AG, Mönchaltorf
Technologie	Photovoltaik
Beschreibung	Nach einer Präsentation von Enecolo anlässlich eines im Jahr 2001 vom seco unterstützten Workshops zur Förderung der erneuerbaren Energien in den ASEAN Staaten hat sich ein Kontakt mit dem lokalen GEF-UNDP Büro und den malaysischen Behörden entwickelt. Auf dieser Grundlage wurde ein GEF PDF-B Projekt zum Thema der Photovoltaik Gebäudeintegration erarbeitet und durchgeführt. In der PDF-B Projektphase wurde unter Beteiligung von Enecolo ein „full GEF project“ erarbeitet.
Land	Malaysia / später ASEAN
Schweizer Beitrag	Die Schweizer Erfahrungen auf dem Gebiet der Photovoltaik Gebäudeintegration sind ein Schlüsselfaktor für dieses insgesamt erste GEF-Projekt für netzgekoppelte Photovoltaik Systeme. Das Projekt baut auf einer ausgezeichneten lokalen Partnerschaft auf.
Website	**http://www.solarstrom.ch** **http://www.gefonline.org/projectDetails.cfm?projID=1897**
Projektstatus	Die PDF-B Phase ist abgeschlossen; das „full project“ wurde durch den *GEF Council* im Mai 2004 bewilligt; Projektvolumen 25 Mio. USD, GEF-Beitrag 4.8 Mio. USD. Die Implementierung des Projektes ist für 2005 vorgesehen. Nach Möglichkeit werden sich Schweizer Akteure an diesem Projekt beteiligen.
Dokumentation	Schlussbericht GEF PDF-B Malaysian Building Integrated PV (MBIPV) [5]

Beitrag zur 2. Tagung „Erneuerbare Energien in der Entwicklungszusammenarbeit“

Projektart	Veranstaltung
Schweizer Partner	Ökozentrum, Langenbruck
Technologie	verschiedene
Beschreibung	Die 2. internationale Fachtagung diente dem Erfahrungsaustausch und der Vernetzung aller Akteure auf dem Gebiet der Erneuerbaren Energien und der Entwicklungszusammenarbeit. Sie hatte zum Ziel, die qualitative und nachhaltige Umsetzung von Projekten in Entwicklungsländern zu fördern.
Land	Schweiz
Site web	**http://www.oekozentrum.ch**
Projektstatus	abgeschlossen
Dokumentation	Workshopunterlagen [6]

Beitrag an eine Machbarkeitsstudie für einen Windpark in Constantza, Rumänien

Projektart Machbarkeitsstudie

Schweizer Partner NEK Umwelttechnik AG, Zürich

Technologie Wind

Beschreibung Das Projekt betrifft eine Machbarkeitsstudie für einen Windpark im Hafen von Constantza in Rumänien. Ausgehend von den als günstig erachteten Windverhältnissen werden während einem Jahr die Windgeschwindigkeiten detailliert evaluiert. Die Studie soll darüber Aufschluss geben, ob sich der Standort für einen Windpark eignet; es wäre dies der erste Windpark dieser Art in Rumänien.

Land Rumänien

Schweizer Beitrag Die Schweizer Erfahrung in der Planung von Windparks bildet die Grundlage dieses Vorhabens, welches die Zusammenarbeit mit interessierten lokalen Partnern umfasst.

Website **http://www.nek.ch/d/news/index.htm**

Projektstatus laufend

Beitrag an die Erstellung einer Windkarte für Nicaragua

Projektart Machbarkeitsstudie

Schweizer Partner ENCO AG, Bubendorf, zusammen mit METEOTEST, Bern

Technologie Wind

Beschreibung Die zwei Schweizer Unternehmen kombinieren in diesem Projekt ihr Know-how in Hinsicht auf eine digitale Windkarte für Nicaragua. Diese Karte wird dem interessierten Publikum zugänglich sein und soll dazu dienen, geeignete prioritäre Standorte für die Erstellung von Windkraftanlagen in Nicaragua zu identifizieren. Anschliessend sollen durch die beteiligten Partner auf dieser Grundlage konkrete Projekte entwickelt werden.

Land Nicaragua

Schweizer Beitrag Schweizer Erfahrungen in der digitalen Kartografie und Windmessungen bilden die Grundlage dieses Projektes. Eine ähnliche Karte wurde bereits für die Schweiz erstellt. Im Projekt besteht eine gute Partnerschaft mit geeigneten lokalen Partnerinstitutionen.

Website **http://www.enco-ag.ch** und **http://www.meteotest.ch**

Projektstatus laufend

Bewertung 2004 und Ausblick 2005

Nach den Vorbereitungsarbeiten im Jahr 2003 war das Jahr 2004 durch die operative Umsetzung der REPIC-Plattform gekennzeichnet. Dazu mussten die notwendigen Prozeduren, Kriterien und Unterlagen in Zusammenarbeit mit den 4 Bundesämtern erstellt und festgelegt werden. Trotz dem hierzu notwendigen Aufwand und entsprechendem Koordinationsbedarf konnten diese Arbeiten im ersten Halbjahr 2004 erfolgreich abgeschlossen werden. Die vorgesehenen Prozeduren und die Koordination innerhalb der REPIC-Steuergruppe waren damit weitgehend eingespielt und die Aktivitäten verlagerten sich demnach zusehend auf die Projektebene.

Von den zahlreichen Anfragen wurden im ersten operativen Jahr der REPIC-Plattform noch viele Projektvorschläge entweder als nicht im Zielbereich der Plattform liegend oder als unzureichend beurteilt. Es zeigte sich, dass viele Vorschläge den Anforderungen und Kriterien der REPIC-Plattform noch nicht entsprachen, was auch mit der Erfahrung aus der früheren PV EZA Phase übereinstimmt. Dies hat andererseits naturgemäss auch damit zu tun, dass sich die entsprechenden genauen Zielvorstellungen, Abläufe und Informationen erst im Verlauf des Jahres etablieren konnten. Ausserdem war die Bekanntheit der REPIC-Plattform durch diese Umstände noch begrenzt. Dies mag auch dazu beigetragen haben, dass die Auswahl der Technologien noch etwas einseitig war.

Die ausgewählten Projekte, welche eine Unterstützung durch die REPIC-Plattform erfahren, wurden demgegenüber als erfolgversprechend beurteilt. Der weitere Verlauf dieser Projekte wird eng begleitet. So konnte z.B. mit dem GEF PDF-B Projekt in Malaysia ein grösseres GEF-Projekt ausgelöst werden. Dieses Beispiel zeigt die mögliche Funktion der REPIC-Plattform in erfolgreicher und beispielhafter Weise: Mit einem begrenzten Aufwand war es möglich, gefragtes Schweizer Know-how in einem neuen Gebiet einzusetzen und damit ein grösseres Projekt zu generieren. Dieser Umstand wird in sich als Erfolg gewertet, unabhängig davon, ob für die Ausführung des anstehenden GEF-Projektes letztlich Schweizer Akteure zum Einsatz kommen.

Diese ersten Erfahrungen mit der REPIC-Plattform weisen den Weg für die nächsten Schritte und Schwerpunkte der Tätigkeiten. Es wird im Jahr 2005 besonders darum gehen, die Information und Kommunikation der REPIC-Plattform zu verstärken und auf der Projektseite die Aktivitäten technologisch zu diversifizieren. Ein nationales Seminar zum Thema der erneuerbaren Energien in der internationalen Zusammenarbeit wird am 21. September 2005 in Bern stattfinden und Gelegenheit zu einem breiteren Informations- und Erfahrungsaustausch bieten.

Besonderes Gewicht erhalten angesichts dieser Betrachtungen im Jahr 2005:

- die systematische Kommunikation und Berichterstattung
- die Sammlung von ersten Erfahrungen mit geförderten Projekten
- eine effiziente Gesuchsbearbeitung
- die plangemässe Projektabwicklung

Referenzen / Publikationen

[1] ***REPIC-Leitfaden***, zu beziehen bei NET Nowak Energie & Technologie AG oder http://www.repic.ch

[2] ***REPIC-Flyer***, zu beziehen bei NET Nowak Energie & Technologie AG oder http://www.repic.ch

[3] ***Jahresbericht Schweizer Beitrag IEA PVPS Task 9***, 1999 – 2003, http://www.photovoltaic.ch

[4] ***Publikationen IEA PVPS Task 9***, http://www.iea-pvps.org

[5] ***Schlussbericht GEF PDF-B Malaysian Building Integrated PV (MBIPV)***, zu beziehen bei NET Nowak Energie & Technologie AG oder Enecolo AG

[6] ***Workshopunterlagen*** zu beziehen bei http://www.oekozentrum.ch/

Annual Report 2004

PV-NAS-NET

Coordination of Newly Associated States and EU RTD Programmes on Photovoltaic Solar Energy

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Project- / Contract Number	NNE5-2002-00046, BBW Nr. 02.0321
Duration of the Project (from – to)	01.01.2003 - 31.12.2004

ABSTRACT

The overall objective of the project is better coordination of science and technology activities in the sector of photovoltaics in the Newly Associated States* (NAS), thus integrating them into the European Research Area. The purpose of the project is to bring up a realistic picture of the achievements and failures in the PV field in 10 NAS: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

The project PV-NAS-NET - the network of the representatives of ten Newly Associated States, four EU Member States (the Netherlands, Greece, Austria and Finland) and Switzerland is complementary to PV-EC-NET. It was created to increase the coherence of the PV RTD activities of the NAS and the EU and therefore to promote the development of Photovoltaic Solar Energy (PV) in NAS countries.

There are significant differences in the extent of PV RTD among the Newly Associated States and even more in comparison with those in the EU Member States. There is a need for identifying and overcoming existing barriers to the development of PV in these countries. The characteristics of the new enlarged European PV industry and the energy market require emphasis on technology transfer and dissemination, if new and improved energy technologies are to have the maximum impact. It is of strategic importance to have up-to-date information, to use the available results, to avoid mistakes made earlier by others, etc., and, if possible, to orient ongoing research activities towards the problems which are typical and important for both, the NAS and EU countries. PV-NAS-NET project aims at creating enhanced networking and coherence among PV RTD activities in NAS and EU countries in order to advance the above mentioned objectives in a coherent manner focussed on market, social and environmental needs.

The main goals of PV-NAS-NET are therefore:
- to improve the coherence of the NAS activities and European RTD programmes on PV energy;
- to formulate recommendations for PV RTD programming in NAS and the EC.

** Most Newly Associated States have become meanwhile Member States of the European Union. Reference of NAS remains for consistency in the project.*

Introduction and Objectives

There are significant differences in the extent of PV RTD among the Newly Associated States and even more in comparison with those in the EU Member States. There is a need for identifying and overcoming existing barriers to development of PV in these countries. The characteristics of the new enlarged European PV industry and the energy market require emphasis on technology transfer and dissemination, if new and improved energy technologies are to have the maximum impact. It is of strategic importance to have up-to-date information, to use the available results, to avoid mistakes made earlier by others, etc., and, if possible, to orient ongoing research activities towards the problems which are typical and important for both, the NAS and EU countries. PV-NAS-NET project aims at creating enhanced networking and coherence among PV RTD activities in NAS and EU countries in order to advance the above mentioned objectives in a coherent manner focussed on market, social and environmental needs.

The overall objective of the project is better coordination of science and technology activities in the sector of photovoltaics in the Newly Associated States (NAS), thus integrating them into the European Research Area. The purpose of the report is to bring up a realistic picture of the achievements and failures in the PV field in 10 NAS: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

Figure 1: Logo of the Project

The main goals of PV-NAS-NET are therefore:

- to improve the coherence of the NAS activities and European RTD programmes on PV energy;
- to formulate recommendations for PV RTD programming in NAS and the EC.

The underlying goals, supporting these main goals are:

- to establish and disseminate a common information base on PV RTD programmes, activities and achievements in the field of PV RTD within the NAS;
- to benchmark the NAS PV RTD programmes and activities;
- to coordinate activities with other organisations and networks;
- to set up an inventory of the NAS PV position in relation to EU;
- to formulate new EU funded RTD coordination activities in the field of PV.

Brief Technical Description of the Project

PV-NAS-NET is an Accompanying Measure Network of the representatives of ten Newly Associated States, four EU Member States and Switzerland. The main target of PV-NAS-NET is the increase of the coherence of the PV RTD activities of the NAS and the EU and therefore to promote the development of Photovoltaic Solar Energy (PV) in NAS countries. To achieve this, PV-NAS-NET implements an information network and perform a benchmark of PV programmes and activities in the NAS. This information is used for the analysis of the position of NAS in the field of PV in comparison to EU countries. Based on this, PV-NAS-NET formulates PV RTD recommendations for NAS countries and prepares recommendations for future European Thematic Networks and Target and Key actions.

PV-NAS-NET is a complementary network to the PV-EC-NET - Network for Coordination of European and national RTD Programmes for Photovoltaic Solar Energy (NNE5-2001-00201). PV-EC-NET brought together the coordinating institutions of the national PV RTD programmes of the members of the European Union, Switzerland and Poland. The main goal of PV-EC-NET was to increase the efficiency and coherence of the PV RTD Programmes of the EU. The activities of the PV-NAS-NET have been strongly correlated with the activities of PV-EC-NET. Therefore five participants of the PV-EC-NET take part in PV-NAS-NET.

The approach of PV-NAS-NET coincides well with the approach described in the Commission communication "Towards a European Research Area", including the creation of a database, the formation of a structure for the exchange of information and a benchmark of the PV RTD activities within the Newly Associated States.

With the goal to compare and, where possible, improve, the efficiency of the NAS PV RTD programmes and activities, the benchmark of these programmes is part of the activities of PV-NAS-NET. This benchmark aims to identify successful strategies and their key features. Based on this, the network aims to provide recommendations for NAS and EC PV RTD programming, thereby benefiting the NAS, and EU PV RTD programmes by strengthening the European PV RTD base and its impact on the European PV industry.

In order to increase the coherence of activities at as many levels as possible, the information gathered for the coordination and the benchmark is made openly available to all interested parties of the member- and associated states through several different means of communication, like Internet, newsletters, etc.

The activities of PV-NAS-NET are arranged in 5 Work Packages (WP):

WP 1: Network Management
WP 2: Collection of information on PV RTD programs and activities in the NAS
WP 3: Benchmark of the PV RTD programmes and activities in NAS
WP 4: Dissemination of information
WP 5: Recommendations for NAS National Governments and the European Commission

The most important deliverables of PV-NAS-NET is a NAS PV Information Office and a commonly accepted set of recommendations for NAS and EC PV RTD programmes. Further deliverables consist of a common information base, be a commonly accessible web site, containing all available information on NAS PV RTD programmes and activities.

Work Done and Results Achieved

Collection of information on PV RTD programmes and activities in the NAS: In order to provide a consistent and transparent information set, standard information collection formats have been formulated based on the formats developed in PV-EC-NET. Information has been collected on national programmes and activities in NAS, the visions and strategies behind them, the budgets and methods available for them and the results achieved with them.

Table 1: Topics of PV RTD Covered by Research Articles Published by Scientists in NAS.

	Different types of solar cells											
	Crystalline Si	Amorphous Si	Poly-Si	A_3B_5	CIS	CdTe	Organic cells	Theory	Applications	Contacts, AR coat., etc.	Concentrators	Testing
Bulgaria		■	■		■	■				■		
Czech Rep.	■	■	■	■		■	■	■	■			■
Estonia					■	■	■					
Hungary	■	■		■					■	■		
Latvia												
Lithuania	■	■	■									
Poland	■	■	■	■	■	■	■	■		■		■
Romania	■		■			■		■	■		■	■
Slovak Rep.	■	■		■		■			■			■
Slovenia	■	■	■		■			■				

Table 2: Funds and Ressources in kEUR from 1996 to 2003 (whole period)

Country	RTD			Demonstration/dissemination			Total
	national	EC	foreign	national	EC	foreign	
Bulgaria	20	67	57	9	142	56	**351**
Czech Republic	100	900	300	62	398		**1 760**
Estonia	730	640	470				**1 840**
Hungary	1 884	1080		10	15		**2 989**
Latvia	25				28	15	**68**
Lithuania	40	280					**320**
Poland	2 870	337	95	140	120	100	**3 662**
Romania	220	80	10	400	600	200	**1 510**
Slovakia	63	270	3.3	5.3		2.5	**344**
Slovenia	250	250		70	100		**670**
Total	**6 202**	**3 904**	**935**	**696**	**1 403**	**373**	**13 514**

Benchmark of the PV RTD activities and organisational structure in the NAS: A benchmark has been carried out focussing the NAS programmes and activities as well as the involvement of universities, industry and the European Commission in PV RTD, demonstration and dissemination programmes / activities and interactions between them. Results are available. An example is given on the “SMARTness” of PV RTD programmes and activities in NAS.

Table 3: Assessment of PV RTD Programme Objectives in NAS Countries in Terms of SMART - Assessment of Objectives in Specific, Measurable, Ambitious, Realistic and Time-bound Terms.

‘SMART’ assessment of PV RTD programme objectives	
Criteria	Assessment
Specific here means two things: first of all, objectives should be specifically related to the programme; preferably unique to the programme. In this way results can be seen as attributable to the programme and to the programme only. Secondly, “specific” means that results are defined in terms of targets, a certain goal to be reached (i.e. a certain kWp price level or so many kWh generated) and are not defined in actions only (i.e. stimulate the use of PV.)	The majority of NAS do not have national programmes dedicated to PV. However, the goals of the PV RTD projects are usually set very clearly and specifically, e.g., developing solar cell technology for national industry (Poland), improving silicon solar cell efficiency and reducing their price (Lithuania), supporting rural electrification in isolated areas (Romania), increasing professional interest among the young people (Czech Rep.), etc.
Measurable here means that objectives are defined in measurable units. This is done to facilitate the monitoring that is envisaged.	Specific objectives for the projects are generally defined in terms that can be easily measured and controlled (cell efficiencies, installed power, etc.)
Ambitious and *Realistic* can be seen as the two extremes on the scale of challenge. Programmes should be ambitious so as to pose enough of a challenge. On the other hand they should be realistic and their targets should not be too far fetched	The goals of the projects that are scientific in their nature are, as a rule, very ambitious, especially when we take into account rather limited financial and other resources and lack of a legislative support for PV RTD. Their implementation depends too much on enthusiasm, professional skills, and devotion of the individuals. Demonstration projects are less ambitious and more realistic; nevertheless the end users appreciate their implementation
Finally programme objectives should be *Time-bound.* They should be made clear as to when an objective should be realised. On the road to the objective intermediate milestones may be defined.	As the national projects are financed on a rather small scale and occasional, time-bound criteria for these projects are set quite loosely. Even in the cases where time frames were defined very precisely, not every team kept the schedule (Poland). The situation is different for dissemination programmes (Czech Rep., Hungary) or for the projects supported by international sources (Estonia).

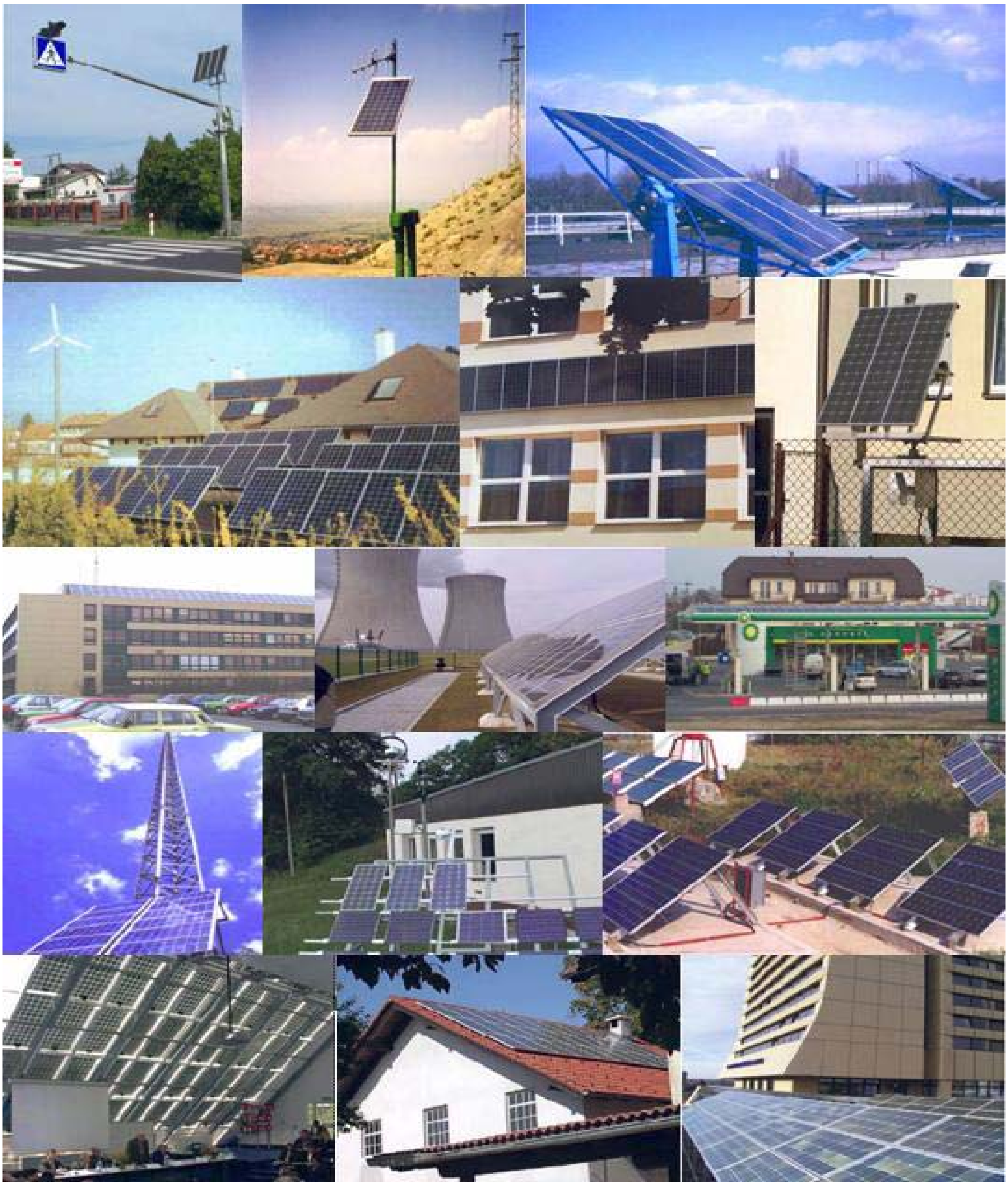

Figure 2: PV-NAS-NET Made PV in NAS more Tangible. Installations from different NAS countries. Source: PV-NAS-NET 2004

National and International Cooperation

The project is an international network comprising PV RTD (programme / project) management bodies. As such it has a strong focus on international cooperation and identifying cooperation opportunities and synergies.

Evaluation 2004 and Outlook 2005

The second project year has brought about substantial results. Important publications and events have drawn the attention to PV (RTD) issues in the NAS. Most final results (publications) will be accessible early 2005. Special mention merit:

- Meeting Venue "Photovoltaic Research and Technological Development" held in Warsaw on 15 November 2004 – organised by PV-NAS-NET
- Publication of "Status of PV in NAS" at the 19th EUPVSEC in Paris in June 2004

Figures 3 and 4: Meeting Venue "Photovoltaic Research and Technological Development"held in Warsaw on 15 November 2004. Source: PV-NAS-NET

Figure 5: Front page of a largely disseminated report. It has drawn particularly much attention from the PV sector and audience at the 19th EUPVSEC in Paris in June 2004.

Further results are:

- Communication network mainly based on www.pv-nas.net and exchange of information in the new ERA NET scheme based project PV ERA NET.
- Set of recommendations for both the national governments and the European Commission concerning the national and EC PV RTD programmes.

These results will become accessible early 2005.

References

Publications

Status of Photovoltaics in the Newly Associated States, February 2004, 72 pages

Further publications soon available at http://www.pv-nas.net

Website of the EU project and related networks

- http://www.pv-ec.net
- http://www.pv-net.net
- http://www.asi-net.net
- http://www.pv-era.net

Acknowledgement

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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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Project- / Contract Number	CA-011814-PV ERA NET
Duration of the Project (from – to)	1 October 2004 – 30 September 2008

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.

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.

- WP1: Information Exchange and Best Practice
- WP2: Strategy Issues
- WP3: Joint (Transnational) Activities
- WP4: Project Management and Coordination

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.

Accordingly, the activities and objectives specific to the work packages are:

WP1: Information Exchange and Best Practice

The **main activity** will be, first, to improve the information and communication and, subsequently, build trust among programme managers and, second, to elaborate on best practice. Information will be about photovoltaic RTD programmes - their contents, approaches and context - in participating programmes. Useful tools are developed and used. A major achievement will be the mutual knowledge of the programmes which provides the ground for the work on Strategy Issues (WP2).
The **main goal** will be to provide structured information exchange and to elaborate on (guidelines for) best practices in photovoltaic RTD programming

WP2: Strategy Issues

The **main activity** 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.
The **main goal** will be a complete 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 modes 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 Done and Results Achieved

The project officially started in late 2004. Accordingly, the focus of the work was on preparing the project, organising the kick-off meeting and setting-up the tasks.

The kick-off meeting held in Düsseldorf / Köln (Germany) included the presentation and discussion of each RTD programme involved in PV ERA NET. An assessment of these programmes has been started by establishing a reporting structure (programme contents, approaches and contexts). This first piece will be the basis for further organised exchange of information between RTD programmes dealing with PV.

Figure 1: Kick-off Meeting in the Parliament Building in Düsseldorf (Germany). Source: M. Hübner

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: Participants in PV ERA NET

Participants full name		Country
Forschungszentrum Juelich GmbH, Projekttraeger ETN	FZJ-ETN	Germany
Ministerium für Wissenschaft und Forschung	MWF	Germany
Ministerium für Verkehr, Energie und Landesplanung	MVEL	Germany
Agence de l'environnement et de la maîtrise de l'énergie	ADEME	France
Danish Energy Authority (DEA)	ENS	Denmark
Bundesamt für Energie	BFE	Switzerland
NET Nowak Energy & Technology Ltd.	NET	Switzerland
Department of Trade and Industry	DTI	United Kingdom
Ministerio de Educación y Ciencia	MEC	Spain
Ministry of Scientific Research and Information Technology	MSRIT	Poland
Forskningsradet för miljö, areela näringar och samshällsbyggande	Formas	Sweden
Swedish Energy Agency	STEM	Sweden
Nederlandse Organisatie voor Energie en Milieu	SenterNovem	The Netherlands
Bundesministerium für Verkehr, Innovation und Technologie	BMVIT	Austria
Forschungsförderungsfond für die gewerbliche Wirtschaft	FFF	Austria
General Secretariat for Research and Technology, Ministry of Development	GSRT	Greece
Centre for Renewable Energy Sources	CRES	Greece

Evaluation 2004 and Outlook 2005

The project has had a very positive start in late 2004. The work programme for 2005 has three focal areas and can be described as follows:

Programme Contents
Programme managers exchange relevant information on the state of the art of existing programmes, their priorities and their most relevant running projects. Based on preliminary information (made) available, the most appropriate tool and format for information exchange is proposed. Subsequently, a set of key indicators for the description of PV RTD programmes is used and a common reporting structure for the future and sustained assessment of PV RTD programmes is developed in order to facilitate and structure the exchange of internal information. Some of this information shall be used for a condensed survey report and to be largely disseminated at a later stage. This information shall be updated on a regular (preferably annual) basis.

Programme Approaches

The programme approach (evaluation process, management, administrative procedures) is documented by all participants for their respective programme(s). At least two levels are considered. The first level refers to projects: the process reaches from the call decision to the start and evaluation of individual projects. The second, higher level refers to programmes. The way programmes are managed from the start until the final evaluation is focussed. Additionally, the administrative procedures are described with special focus on budgetary aspects and legal implications. With the support of an external adviser, a comparative summary can be considered in order to work out best practices. The development of (the guidelines for) best practices is done in the light of the (administrative and legal) context and is discussed with each participant before releasing a (draft) report.

Programme Context

The national (and regional) landscape of PV RTD will be described for all participant programmes. The focus is on key stakeholders in PV RTD sectors, mainly in research and industry sector, and their involvement in public and private, fundamental and applied R&D (who's who). It shall be shown how the programmes are oriented (towards targets, target groups) and how key stakeholders are involved between the different sectors and within / between countries. Some general and concise information can be considered for a survey report after consultation of the parties concerned.

Most activities will be elaborated by the programme managers themselves or closely related national structures. The first project meeting will include a workshop for programmers providing a global and structured presentation of the national / regional programmes involved, under the headline of "Starting from the individual concept to the ERA goal". A major achievement will be the mutual knowledge of the programmes as well as the structured information exchange preparing the ground for the work on Strategy Issues (WP2). The focus of information is clearly on participating programmes, some additional insight shall be however enlarge the very essential knowledge concerning survey and especially best practices from other most significant PV RTD programmes in the world (mainly USA, Japan, but also selected emerging PV countries). Some information can be used from networks participants are actively involved (e.g. IEA-PVPS).

Results of the three tasks described above will be presented and discussed at the first Joint Workshop / Stakeholders' Meeting to be attended by a wider target audience, namely key stakeholders involved in the respective national / regional programmes. The Joint Workshop / Stakeholders' Meeting on the topics a) "PV RTD in Europe – Programme Contents, Approaches and Contexts" and b) PV RTD in Europe - Future Strategic Issues in Programming shall corroborate a common understanding of the participants' programmes and how these programmes are managed and implemented. Information and documents can be released on that occasion. The workshop shall build at the same time the basis for the further work, especially for work package 2 dealing with strategic issues.

References / Publications

Website to be launched: http://www.pv-era.net

PV ERA NET „Green Power from Sunlight", February 2005, Brussels