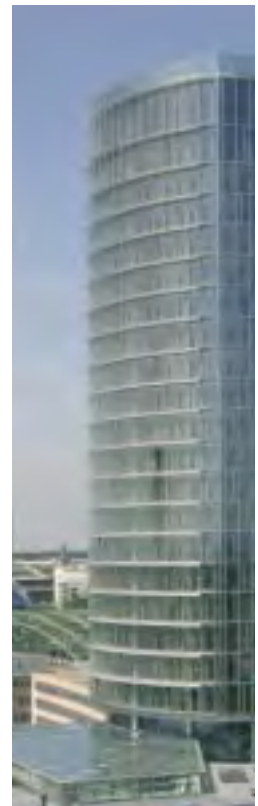
Fraunhofer Institut
Solare Energiesysteme

Annual Report 2006

Achievements and Results



left
Organic solar cell on a flexible, perforated substrate. Because the internal contacts for the solar cell are made through the perforations, inexpensive, transparent electrodes with low conductivity can be used. This solar cell concept combines the demands for inexpensive materials and efficient producibility in a roll-to-roll process (see article on p. 62).

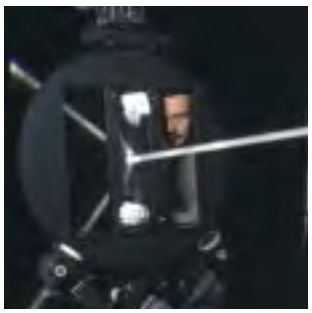
centre
Diffusion furnace in the Photovoltaic Technology Evaluation Center PV-TEC. The service centre for the solar cell industry, the only one of its kind in the world, was officially opened in March 2006 in the presence of the German Federal Minister for the Environment, Sigmar Gabriel. Occupying an area of 1200 m^2, PV-TEC offers research, development and service facilities on a production scale, helping to accelerate technology transfer to industry. Manufacturers of solar cells, wafers, modules and production equipment can analyse and further develop processes, materials and systems here (see article on p. 56).

right
"Köln Triangle" skyscraper: To improve planning reliability, Fraunhofer ISE tested the total solar energy transmittance (g value) of the complex façade on commission to the Züblin company. The tests were carried out in the Thermal Optical Measurement Laboratory, which has been accredited since 2006 according to DIN EN ISO IEC 17025. The internationally recognised accreditation of the laboratory's testing expertise encompasses not only standardised test procedures but also testing approaches which have been developed by Fraunhofer ISE and go beyond the current state of the art. In the example illustrated here, the g value was tested calorimetrically and effective g values were determined. The extension to effective g values allows different user profiles and the effect of direct and diffuse radiation to be taken into account. Architects: Gatermann und Schossig. Photo source: Ed. Züblin AG, Cologne (see article on p. 24).

The Fraunhofer Institute for Solar Energy Systems ISE conducts research on the technology needed to supply energy efficiently and on an environmentally sound basis in industrialised, threshold and developing countries. To this purpose, the Institute develops materials, components, systems and processes for the following business areas: buildings and technical building components, optical components and systems, solar cells, off-grid power supplies, grid-connected renewable power generation and hydrogen technology.

The Institute's work ranges from fundamental scientific research relating to solar energy applications, through the development of production technology and prototypes, to the construction of demonstration systems. The Institute plans, advises and provides know-how and technical facilities as services.

Table of Contents



Facts and Figures

Foreword

One highlight of 2006 for ISE was certainly the official opening of the Photovoltaic Technology Evaluation Center PV-TEC in the presence of the German Federal Minister for the Environment, Sigmar Gabriel. His "pressing the red button" was witnessed by an impressive number of high-ranking guests from industry, science and politics. The perfect completion of the project in record time was praised unanimously by all involved. Once again, I would like to express my thanks: to BMU for the financing, to the photovoltaic industry for their expert advice and to our SWT department and the technical infrastructure group at Fraunhofer ISE for the implementation. As planned, PV-TEC is already fully booked at present and for the next few years with commissions from industry (2/3) and ISE research (1/3). The innovative R&D services provided by PV-TEC are divided almost evenly between cell technology and PV production processes.

The PV-TEC services are complemented by new efforts at ISE concerning wafer and module technology. A new group addressing the market sector of wafer technology was already established at the end of 2005. At the beginning of 2006, finance was provided to set up a prototype production laboratory for modules. This facility is now fully operational under the committed leadership of Dr Harry Wirth.

I would also like to draw attention to the successful concerted action resulting in the accreditation of four measurement laboratories: the Test Centre for Photovoltaics, the Thermal-Optical Measurement Laboratory, the Calibration Laboratory for Photovoltaic Modules and the Calibration Laboratory for Solar Cells. This places ISE in an excellent position with regard to calibration and quality assurance.

We were able to appoint Dr Günther Ebert as the Head of the EES Department, starting on 1st March, 2006. At this point, I would like to sincerely thank Dr Wittwer, also on behalf of the department, for accepting the additional responsibility of provisionally leading the department during the interim period.

It was a particular personal pleasure for me to celebrate the Institute's 25th anniversary with all of ISE as part of the 4th Freiburg Solar Night, just a few days before my time as Director came to an end. Both my predecessor, Prof. Goetzberger, and my successor, Prof. Weber, were present. It was a great party! Again, I would like to record my heartfelt gratitude here to our Press and Public Relations group for the organisation of these celebrations.

My best wishes for a sunny future go to all of ISE, my successor and all friends of our Institute.

Im Joachim Luther

On 1st July, 2006, the Directorship of Fraunhofer ISE passed from Prof. Luther's hands to mine, and I am pleased to state that I found the Institute in very good condition. In view of the looming climate change and limited reserves of fossil fuels, ISE's work on conversion of solar energy and improvement in energy efficiency will be of great national and international significance in the coming years. I am sure that ISE will make an important contribution to these subjects not only in research and development, but also particularly in transferring innovative technology to practical application.

The task of leading a Fraunhofer Institute interested me specifically because the low level of unconditional external financing for these Institutes – less than 20 % of the total budget for ISE in 2006 – means that the required funding must be acquired as projects in competition with other institutes and research groups. My experience in the USA has taught me that it is exactly this competition which stimulates creativity. Under my leadership, ISE will certainly continue its efforts to offer innovative technology as a reliable partner to industry.

During the past year, the Institute grew again by the very satisfying amount of around 10 %, and now has a staff of almost 500 people with a budget of app. 29 million euros. In his contribution, Prof. Luther has already described several of the outstanding achievements of the Institute last year, which are essentially the result of his leadership until the middle of the year. Further significant successes of the Institute are summarised on p. 14. However, I would like to take this opportunity to congratulate Prof. Willeke on his appointment to a professorship at the University of Constance, where he has already supervised numerous doctoral theses from ISE.

For the future of ISE, I see an important task in supporting the rapidly developing German industry in the renewable energy sector with groups and departments located near the companies concerned. These laboratories serve not only to provide research on the topics which are particularly important to the region in question, but will also be involved in the education of students who can then obtain interesting positions in regional companies in this sector. Examples for such regional branches include the Laboratory and Service Centre LSC in Gelsenkirchen, Northern Rhineland/Westphalia, and the Technology Centre for Semiconductor Materials THM in Freiberg, Saxony (together with Fraunhofer IISB, Erlangen).

Topics which are particularly important to me personally in our future work on photovoltaics should be both the further improvement in the efficiency of solar cells of crystalline silicon and III-V hetero-structures, and the development of good solar cells from purified metallurgical silicon ("dirty Si"), a project which is based partly on my work in Berkeley. With this development, we aim not only to overcome the current shortage of high-purity silicon for the PV industry, but also to contribute to a significant, long-term reduction in both the cost of solar energy and the energy required to manufacture solar cells.

All of these goals will only be reached by the continuing, excellent work of the Institute personnel, whom I would like to thank explicitly. My gratitude also includes our Board of Trustees, who met for the first time under my direction in November and specifically congratulated me at the end of the meeting on the quality and enthusiasm of the ISE staff . Finally, I would also like to thank the representatives from industry, ministries and the European Union for their continuing support of our work. I anticipate that the coming years will be very exciting specifically in the fields which ISE addresses, so that I am delighted to be leading the Institute at this time.

Board of Trustees

The board of trustees assesses the research projects and advises the Institute Directorate and the Executive of the Fraunhofer-Gesellschaft with regard to the working programme of Fraunhofer ISE.
Status: 24th November, 2006

Chairman
Prof. Peter Woditsch
Deutsche Solar AG, Freiberg

Deputy Chairman
Helmut Jäger
Solvis Energiesysteme GmbH & Co. KG, Braunschweig

Trustees
Dr Hubert Aulich
PV Silicon Forschungs- und Produktions AG, Erfurt

Jürgen Berger
VDI/VDE-IT Innovation+Technik GmbH, Berlin

Dr Robert Brunner
Carl Zeiss AG, Jena

Dr Gerd Eisenbeiß
Forschungszentrum Jülich GmbH, Jülich

Dr Frank Güntert
Wirtschaftsministerium Baden-Württemberg, Stuttgart

Peter Hertel
W.L. Gore & Associates GmbH, Putzbrunn/Munich

Prof. Thomas Herzog
Technical University of Munich, Munich

Dr Winfried Hoffmann
SCHOTT Solar GmbH, Alzenau

Dr Holger Jürgensen
Aixtron AG, Aachen

Dr Franz Karg
Avancis GmbH, Munich

Prof. Werner Kleinkauf
Gesamthochschule Kassel, Kassel

Dr Knut Kübler
German Federal Ministry for Economics and Technology (BMWi), Berlin

Joachim Nick-Leptin
German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU), Berlin

Klaus-Peter Pischke
Kreditanstalt für Wiederaufbau, Frankfurt

Dr Dietmar Roth
Roth & Rau Oberflächentechnik GmbH, Hohenstein-Ernstthal

Rainer Schild
Vaillant GmbH, Remscheid

Hanno Schnarrenberger
Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg, Stuttgart

Dr Thomas Schott
Zentrum für Sonnenenergie- und Wasserstoff-Forschung ZSW, Stuttgart

Prof. Paul Siffert
Laboratoire de Physique et Applications des Semiconducteurs CNRS, Strasbourg, France

Prof. Joachim Luther

"Off to new shores" – this was the motto of the farewell ceremony for Prof. Joachim Luther on 15th September, 2006 in the Freiburg Konzerthaus. 350 international guests from science, industry and politics attended the laudation ceremony, a scientific symposium and an evening banquet. Joachim Luther had passed on the Directorship of the Fraunhofer Institute for Solar Energy Systems ISE to his successor, Prof. Eicke R. Weber on 1st July. The President of the Fraunhofer-Gesellschaft, Prof. Hans-Jörg Bullinger, described Luther as a "bonanza" for the Fraunhofer-Gesellschaft during the farewell ceremony. Thanks to his achievements, the currently booming demand for solar technology can be satisfied in many fields with Fraunhofer know-how. As an example of Joachim Luther's extensive activities to promote renewable energy, he cited his four-year membership of the "German Advisory Council on Global Change (WBGU)", an advisory body to the Federal Government. The German Federal Environmental Foundation DBU awarded the Environmental Prize in 2005 to Joachim Luther for his achievements in the research and market introduction of solar energy systems. At the University of Freiburg, Prof. Luther held well-attended lectures and seminars on the fundamentals of solar energy conversion and initiated a research group to investigate dye solar cells and organic solar cells. As a member of the Senate and the European Advisory Board, and as the Chairman of the Executive Committee of the Scientific-Technical Council, Luther also occupied central positions within the Fraunhofer-Gesellschaft.

The motto of the farewell ceremony quoted above expresses the fact that being 65 years old does not automatically mean retirement for Joachim Luther. He will continue to be active for solar energy as a consultant both to the industry, the Federal Government and Fraunhofer ISE, and as a member of several international bodies. The staff of Fraunhofer ISE would like to express their sincere gratitude again here for twelve and a half successful and eventful years and wish Joachim Luther all the best for his new phase in life.

A greeting and a welcome is extended to the new Director of the Institute, Prof. Eicke R. Weber. After 23 years of research in the USA, he returned to Germany to accept the Directorship of Fraunhofer ISE on 1st July, 2006. As a physicist, Eicke R. Weber had lectured in materials science since 1983 at the University of California and had established an international reputation for his work on defects in silicon and III-V semiconductors. One result of this work is the idea to use purified, metallurgical silicon ("dirty silicon") for the production of solar cells.

Simultaneously with the Directorship of Fraunhofer ISE, Eicke Weber was also appointed to a Chair for Applied Physics in Solar Energy at the University of Freiburg. Professor Weber has been awarded numerous prizes. In 1994, he received the Alexander von Humboldt Prize. He was the founding President of the Berkeley Chapter of the Alexander von Humboldt Association of America (AvHAA) and its President from 2001 to 2003. He has been intensively involved in building bridges between Germany and the USA for many years. For instance, he is the founding President of the German Scholars Organization (GSO), an association of German scientists working abroad, which was established in 2003 with the goal of strengthening contacts to potential employers in Germany from the industry, research institutes and universities. In June 2006, Prof. Weber was awarded the German Order of Merit.

Prof. Eicke R. Weber
Photo source: Photon

The organisational structure of Fraunhofer ISE has two parallel, mutually complementary main components: Departments and a grouping according to business areas. R&D marketing, external presentation of the Institute and above all, our strategic planning are structured according to the six business areas the Institute addresses.

The five scientific departments are responsible for the concrete organisation of work and laboratory operation. Most members of the scientific and technical staff are based in the individual departments.

Institute Director	Prof. Eicke R. Weber Prof. Joachim Luther (until 30.6.2006)	
Deputy Director	Dr Volker Wittwer	
Departments	Electrical Energy Systems Dr Günther Ebert	+49 (0) 7 61/45 88-52 29
	Energy Technology Dr Christopher Hebling	+49 (0) 7 61/45 88-51 95
	Materials Research and Applied Optics Dr Andreas Gombert	+49 (0) 7 61/45 88-59 83
	Solar Cells – Materials and Technology Prof. Gerhard Willeke	+49 (0) 7 61/45 88-52 66
	Thermal Systems and Buildings Dr Hans-Martin Henning	+49 (0) 7 61/45 88-51 34
Business and Technical Services	Wolfgang Wissler	+49 (0) 7 61/45 88-53 50
Press and Public Relations	Karin Schneider	+49 (0) 7 61/45 88-51 47
Strategic Planning	Dr Thomas Schlegl	+49 (0) 7 61/45 88-54 73

The photos show the new Institute Director, the former Institute Director (until 30.6.2006), the Deputy Director of Fraunhofer ISE, the Heads of the scientific departments, and the Business Manager of Fraunhofer ISE.

Eicke R. Weber, Joachim Luther, Volker Wittwer
Christopher Hebling, Hans-Martin Henning, Andreas Gombert
Gerhard Willeke, Günther Ebert, Wolfgang Wissler

Institute Profile

The Fraunhofer Institute for Solar Energy Systems ISE conducts research on the technology needed to supply energy efficiently and on an environmentally sound basis in industrialised, threshold and developing countries. To this purpose, the Institute develops materials, components, systems and processes for the following business areas: buildings and technical building components, optical components and systems, solar cells, off-grid power supplies, grid-connected renewable power generation and hydrogen technology. Further expertise - in non-solar technology - includes display technology, lighting technology and water purification.

The Institute's work ranges from fundamental scientific and technical research relating to solar energy applications, through the development of production technology and prototypes, to the construction of demonstration systems. The Institute plans, advises and provides know-how and technical facilities as services.

Fraunhofer ISE has been certified according to DIN EN ISO 9001:2000 since March, 2001.

The Institute is integrated into a network of national and international co-operation. Among others, it is a member of the ForschungsVerbund Sonnenenergie (German Solar Energy Research Association) and the European Renewable Energy Centres (EUREC) Agency. There is particularly close co-operation with the Albert Ludwig University in Freiburg.

Research and Services Spectrum

The Fraunhofer Institute for Solar Energy Systems ISE is a member of the Fraunhofer-Gesellschaft, a non-profit organisation, which occupies a mediating position between the fundamental research of universities and industrial practice. The Institute finances itself to more than 80 % with contracts for applied research, development and high-technology services. Whether it concerns a major project lasting several years or brief consultancy work, the working method is characterised by its clear relevance to practice and orientation toward the wishes of the client.

Networking within the Fraunhofer-Gesellschaft

Fraunhofer Institutes or Institute Departments working on related topics co-operate within Associations or Alliances and appear jointly on the R & D market.

Fraunhofer ISE is a member of the following organisations:

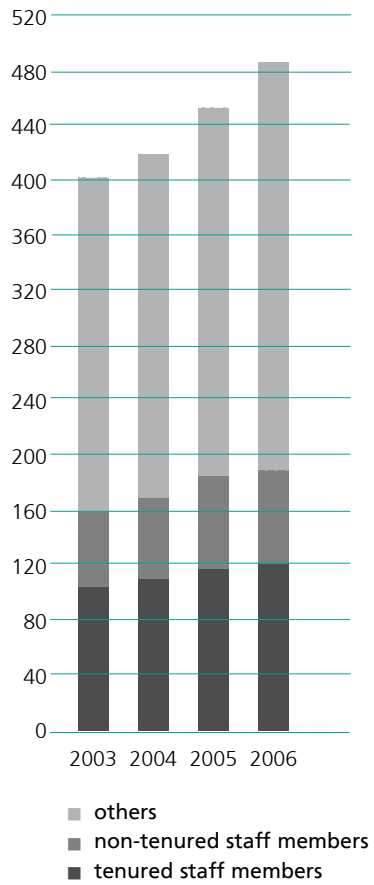
- member of the Institute Association on "Materials, Components" (materials research)
- guest member of the Institute Association on "Surface Technology and Photonics"
- member of the Thematic Association on "Energy"
- member of the Thematic Association on "Nanotechnology"
- member of the Alliance on "Optically Functional Surfaces"

Fraunhofer ISE is co-ordinating the Fraunhofer Innovation Topic of "Microenergy Technology", in the context of "Signposts to Tomorrow's Markets" (see article on p. 15).

International Clients and Co-operation Partners

The Fraunhofer Institute for Solar Energy Systems has co-operated successfully for years with international co-operation partners and clients from a wide range of business sectors and company sizes. A list of our partners can be found under www.ise.fraunhofer.de/german/profile/index.html

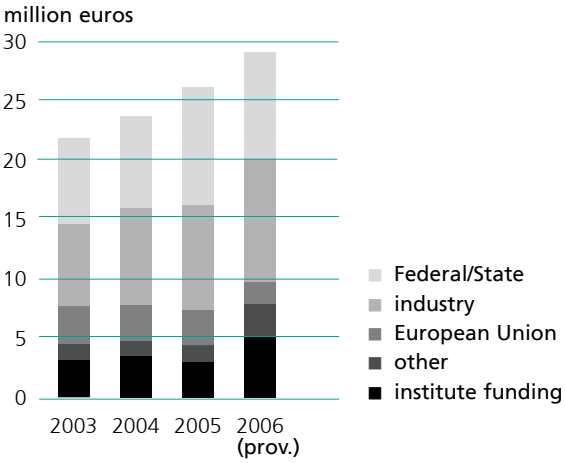
Personnel development



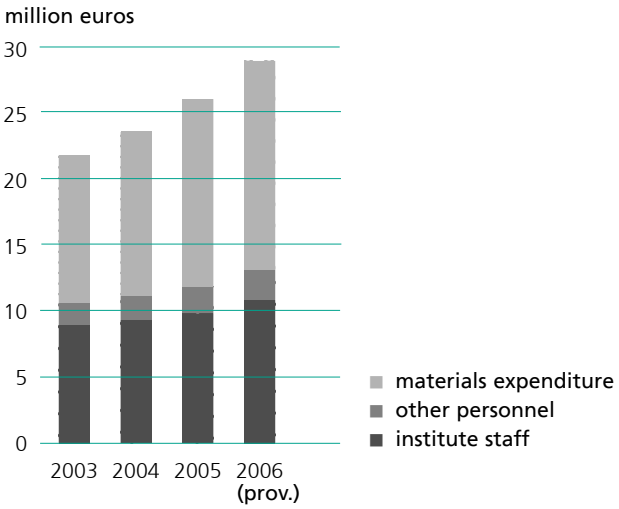
The "other" staff members are an important pillar of the institute, who support the work in the research projects and thus contribute significantly to the scientific results obtained. In December 2006, 62 doctoral candidates, 94 undergraduate students, 4 apprentices and 137 scientific assistants were employed at the Institute. In this way, Fraunhofer ISE makes an important contribution to the education system.

Finances

Income



Expenditure



In addition to the expenditure documented in the graph, the Institute made investments of 3.7 million euros in 2006 (not including the BMU investment project, PV-TEC, amounting to 12.8 million euros over 2005 and 2006).

The financial structure of the Fraunhofer-Gesellschaft distinguishes between the operational and investment budgets. The operational budget includes all expenses for personnel and materials, as well as their financing with external income and institutional funding. The integrated financial plan of the Fraunhofer-Gesellschaft allows funds to be transferred between the two budgets.

Research and Development

- test facility constructed for measuring collector efficiency curves at temperatures up to 200 °C
- three novel compact systems for solar-thermal desalination of seawater with a production rate of 100 l per day and two larger two-loop systems with 1000 l per day successfully installed and commissioned (locations: Jordan, Morocco, Egypt and Spain)
- solar collectors developed for façade integration, which offer new perspectives for architectural design with their different colours and high energy efficiency
- commissioning and accreditation of the Test Centre for Photovoltaics
- accreditation of the Thermal-Optical Measurement Laboratory
- thermal insulation system with vacuum insulation panels developed together with the Maxit company and successfully tested for compliance with safety regulations in a test wall
- demonstration Fresnel collector built in co-operation with MAN/SPG in Almeria
- organic solar cells contacted through perforations and monolithically connected modules produced for the first time
- dye solar cell modules prepared with attractive optical designs
- in situ epitaxy applied to produce an emitter for crystalline silicon thin-film solar cells with comparable performance but requiring less than 1/10 of the processing time
- first prototype of a HyCon® concentrator demonstrated for direct conversion of sunlight into hydrogen with an efficiency value of 18 %
- FLATCON® concentrator modules reach an efficiency value exceeding 27 % in operation
- radiation-resistant triple-junction and quintuple-junction space solar cells developed on the basis of III-V semiconductors
- first close-packed concentrator photovoltaic receiver in the world, with an area of 10 x 10 cm^2 and dimensioned for 1000 x solar concentration, successfully tested in the field
- new two-stage contacting procedure with the potential for high efficiency developed for silicon solar cells
- thin (70 µm) multicrystalline silicon wafers with an area of 125 x 125 mm^2 successfully produced by optimised wire-sawing
- Photovoltaic Technology Evaluation Center PV-TEC successfully commissioned. Standard processes implemented for wafer formats of 125 x 125 mm^2, 156 x 156 mm^2 and 210 x 210 mm^2. Efficiency values of up to 16 % were achieved for multicrystalline silicon and up to 17 % for monocrystalline silicon.
- prototype production laboratory for modules taken into operation, complementing the services of PV-TEC
- high-efficiency solar cells produced with an efficiency value of 21.7 % achieved using amorphous silicon for passivation and locally laser-alloyed back-surface contacts
- bypass circuit without diodes for solar modules makes complicated cooling measures unnecessary, even for high module currents
- indoor module measurements in the ISE calibration laboratory allow an accuracy of ±2%
- ISE Module Calibration Laboratory accredited
- photovoltaic hybrid power supplies developed within the EVEREST project reliably provide electricity for geophysical/environmental measurement stations on Schauinsland mountain
- new, patented procedure for catalytic partial oxidation (CPO) reforms diesel without creating soot
- planar, self-breathing and methanol-fuelled miniature fuel cell successfully demonstrated within a complete system (2 W_{el})
- portable, fully automated electrolyser to produce hydrogen (100 Nl/h at 10 bar) passed field test
- fully automated, reversible fuel cell system developed for an autonomous power supply and successfully tested

Power to Go

Fraunhofer "Signpost to Tomorrow": Microenergy Technology

With the aim of promoting the national economy and strengthening Germany's market position, the Fraunhofer-Gesellschaft has investigated national and international research trends, analysed the roadmaps of international corporations and compiled the specific expertise and strengths of Fraunhofer Institutes within a portfolio process. As the result of this process, twelve technological fields were identified which have a particularly high potential for market-relevant innovation.

One of these twelve topics, which have a special strategic significance for the Fraunhofer-Gesellschaft as "Signposts to Tomorrow's Markets", is the research focus on "Microenergy Technology". Technology for efficient energy conversion in the low power range, electronic energy storage, energy transfer and energy management are the main subjects addressed. The development goal is optimised energy systems to lengthen the operating times of electronic devices that are operated off-grid.

The motivation for these developments is the trend for portable electronic devices to become more powerful with each new product generation, but with an increased energy demand for the additional functions, which shortens the operating time noticeably.

Photovoltaic, thermoelectric and piezoelectric technologies all convert energy in the form of light, heat or movement in the immediate surroundings to electricity. These are subsumed under the heading of "Energy Harvesting". In addition, conversion technologies such as miniature fuel cells or micro-turbines are driven actively with a chemical fuel.

Fraunhofer ISE is co-ordinating the R&D activities of ten Fraunhofer Institutes in this highly attractive thematic focus, aiming to address its economic potential on the one hand, and on the other hand, to join industrial clients in transferring the innovative results to the market.

The President of the Fraunhofer-Gesellschaft, Prof. Hans-Jörg Bullinger, opened the "Fraunhofer Symposium on Microenergy Technology" in Berlin.

In addition to numerous joint presentations at industrial trade fairs and conferences, Fraunhofer ISE organised the "Fraunhofer Symposium on Microenergy Technology" under the title of "Power to Go" in Berlin in October 2006. After the workshop had been opened by the President of the Fraunhofer-Gesellschaft, Prof. Bullinger, 120 international speakers and participants presented and discussed the state of the art and compared this to the demands of various industrial branches.

This event was so successful that the second symposium on "Microenergy Technology" will be held in Freiburg from 27th to 29th November 2007, together with the "PowerMEMS" workshop, which will be held in Europe for the first time.

Further information on these events can be found under:
www.microenergy-technology.com
www.powermems.org

Dr Christopher Hebling

Awards and Prizes

Above: Dr Oliver Schultz during his speech at the Einstein Award Ceremony for Young Scientists, 2006. (Photo: SolarWorld AG)

Left: Dr Benedikt Bläsi, one of the "100 Heads of Tomorrow". (Photo: Niels Starnick/Bild am Sonntag)

Prof. Joachim Luther received the **Fraunhofer Medal** in recognition of his distinguished service to the Fraunhofer-Gesellschaft. The President of the Fraunhofer-Gesellschaft, Prof. Hans-Jörg Bullinger, presented the former Director of Fraunhofer ISE with this rare honour during his farewell ceremony.

Prof. Eicke R. Weber, who has been the new Director of Fraunhofer ISE since 1st July, 2006, was awarded the **German Order of Merit** by the German General Consul in San Francisco on 16th June, 2006.

Dr Benedikt Bläsi was selected as one of the **"100 Heads of Tomorrow"** within the initiative, **"Germany – Nation of Ideas"**, that started in 2006.

Dr Oliver Schultz received the **Einstein Award for Young Scientists** in Dresden in September 2006. In addition, he was selected as a member of the **"Science Team"**, which was presented by the "Bild der Wissenschaft" journal and the foundation, "Stifterverband für die Deutsche Wissenschaft", shortly after the beginning of the World Cup.

Dr Andreas Schmitz was awarded the **Innovation Prize of the German Hydrogen and Fuel Cell Association** for his doctoral thesis, "System development of miniaturised planar fuel cells", which he submitted to the Technical University in Berlin in 2005.

Denis Erath received the Prize of the **"Verband Druck und Medien in Baden-Württemberg e.V."** for the best student completing a degree course in Print and Media Technology. In addition, he was awarded the **"Adolf I. Döpfert-Stiftungspreis"** for his excellent undergraduate thesis on "Optimising front-surface contacts of crystalline silicon solar cells with a screen-printing procedure" at the Stuttgart Media University (HdM).

Buildings and Technical Building Components

Optical Components and Systems

Solar Cells

Off-Grid Power Supplies

Grid-Connected Renewable Power Generation

Hydrogen Technology

Service Units

Buildings and Technical Building Components

Sustainable buildings not only protect the atmosphere, but are also easier to market. In particular, the marketing aspect will become more important when the impending "building energy passport" is introduced, as in future, the user will be able to evaluate the energy efficiency of a building. Buyers and tenants can be found more readily for buildings which use regenerative energy and feature high energy efficiency. This applies equally for new buildings and for the existing building stock, for commercial buildings and family homes. At the same time, sustainable buildings offer more user comfort: an abundance of natural lighting without glare, pleasant temperatures throughout the entire year and fresh air without draughts.

The most recent surveys confirm that around 40 % of the end energy consumption in Germany is used to keep building occupants comfortable. The energy is used for heating, cooling, ventilation and illumination. The rational use of energy reduces the amount of energy consumed for these services and often improves the user comfort at the same time. One principle applies in general: The lower the remaining energy demand, the larger is the share which renewable energy can usefully supply. At Fraunhofer ISE, buildings and their technical services represent a central area of activity. We are always the right partner to contact when completely new solutions are sought or if particularly high specifications are to be met. We develop concepts, turn them into practicable products or processes and test them in demonstration buildings. We design sophisticated buildings with simulation tools which we can develop further if required. The topics are treated at all levels, ranging from underlying development to market introduction of materials, components and systems.

These tasks rely on co-operation between many disciplines - from materials research and coating design up to development of components and systems, including the necessary testing. For their application in building projects, we offer advice, planning and concept development on questions of energy and user comfort, as well as the implementation of new approaches to energy-efficient operation management and controls. Furthermore, we accompany completed projects with scientific monitoring.

Important aspects of our work on the building envelope include daylighting and solar control. In lightweight constructions, the heat capacity of the building is playing an increasingly important role, particularly when energy-saving cooling concepts are to be realised. We are developing new processes and systems for this application based on phase-change materials.

In heating, ventilation and air-conditioning (HVAC) technology, increasing attention is being paid to heat pumps for buildings with a low energy consumption, combined heat and power systems or their extension as combined heat, power and cooling systems. In addition to solar-heated domestic hot water and solar-assisted space heating, promising solar energy applications for the future are offered by building integration of photovoltaics and solar-driven air-conditioning in summer.

Operation management is essential for optimal functioning of the complete system - building envelope, HVAC technology and users. New, model-based concepts for operation management are used to constantly monitor and evaluate, and if necessary correct, the performance of individual building components.

We characterise materials and systems with comprehensive measurement technology. In monitoring projects, we evaluate operating experience from selected buildings and thus improve our own concepts and those of our clients. We support national demonstration programmes with extensive analyses.

Working in a team together with architects, professional planners and industrial representatives, we plan the buildings of today and develop the buildings of tomorrow. In doing so, we follow an integrated planning approach, optimising concepts with respect to economic viability, energy efficiency and user comfort. We help to define the international boundary conditions for this work by participating in programmes of the International Energy Agency IEA.

The long-term durability of new materials and components is becoming increasingly significant. Thus, we have further intensified our efforts on this topic and offer services which include not only characterisation by measurements but also model-based prediction of the ageing process.

Contacts

Building concepts and simulation	Sebastian Herkel	Tel.: +49 (0) 7 61/45 88-51 17 E-mail: Sebastian.Herkel@ise.fraunhofer.de
Solar façades	Tilmann Kuhn	Tel.: +49 (0) 7 61/45 88-52 97 E-mail: Tilmann.Kuhn@ise.fraunhofer.de
Durability analysis	Michael Köhl	Tel.: +49 (0) 7 61/45 88-51 24 E-mail: Michael.Koehl@ise.fraunhofer.de
Lighting technology	Jan Wienold Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 33 E-mail: Jan.Wienold@ise.fraunhofer.de Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fraunhofer.de
Heating, ventilation and air-conditioning technology	Dr Benoît Sicre Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-52 91 E-mail: Benoit.Sicre@ise.fraunhofer.de Tel.: +49 (0) 7 61/45 88-51 34 E-mail: Hans-Martin.Henning@ise.fraunhofer.de
Sorptive and phase change materials	Peter Schossig	Tel.: +49 (0) 7 61/45 88-51 30 E-mail: Peter.Schossig@ise.fraunhofer.de
Thermal solar systems	Matthias Rommel	Tel.: +49 (0) 7 61/45 88-51 41 E-mail: Matthias.Rommel@ise.fraunhofer.de
Monitoring and demonstration projects	Sebastian Herkel Klaus Kiefer	Tel.: +49 (0) 7 61/45 88-51 17 E-mail: Sebastian.Herkel@ise.fraunhofer.de Tel.: +49 (0) 7 61/45 88-52 18 E-mail: Klaus.Kiefer@ise.fraunhofer.de

Interdisciplinary co-ordination

Buildings and technical building components	Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-51 34 E-mail: Hans-Martin.Henning@ise.fraunhofer.de
Optical components and systems	Dr Andreas Gombert	Tel.: +49 (0) 7 61/45 88-59 83 E-mail: Andreas.Gombert@ise.fraunhofer.de
Hydrogen technology	Dr Christopher Hebling	Tel.: +49 (0) 7 61/45 88-51 95 E-mail: Christopher.Hebling@ise.fraunhofer.de

Model-Based Analysis of Building Operation

At present, technical systems for buildings are not usually monitored to check the energy efficiency of their operation. One of the reasons for this is the lack of practicable tools to optimise the use of energy in building operation and monitor it with minimal delay. Our work focuses on the development of corresponding methods and tools.

Christian Neumann, Sebastian Herkel, Christof Wittwer, Rainer Becker, Hans-Martin Henning

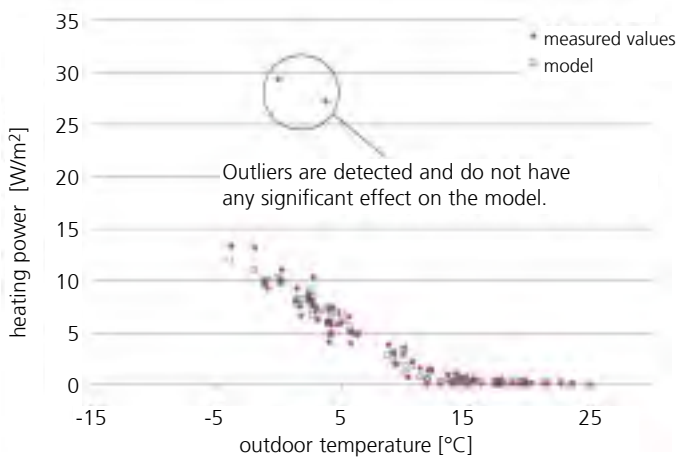


Fig. 1: Operation monitoring applying simple characteristic curve models and robust regression. This "energy signature" for an office building shows the relationship between the outdoor temperature and the heating power. The increase in heating power needed with decreasing outdoor temperature can be clearly recognised. The red symbols indicate the measured values, while the blue symbols represent the calibrated model. The model parameters are identified by multiple linear regression. As it is a robust regression algorithm, outliers have only a slight effect on the quality of the model (the manually introduced measurement points in the diagram above do not show any effect on the quality of the model. The probability value is greater than 85 %.) At the same time, outliers can be automatically detected with this algorithm and the building operator is notified.

The building sector is responsible for more than 40 % of the European energy consumption. At the same time, the potential to save energy by appropriate building operation management, i.e. by taking measures involving very low or no investment costs, ranges from 5 - 30 %. This applies particularly to the non-residential building stock. Extensive experience, such as that which we have gained within monitoring projects such as EnBau:MONITOR (www.enbau-monitor.de), emphatically supports this statement.

The focus of our work on analysing building operation is the development of model-based procedures which take account of the boundary conditions encountered in practice, such as scanty data bases and cost restrictions. At the same time, the procedures should be able to recognise errors in building operation, identify possible energy-saving potential and monitor the optimised operation.

We tested simple procedures for operation analysis and monitoring within the EnBau:MONITOR project (fig. 1). Beyond that, we have begun to establish an exergy-based analytical procedure for the energy supply of complex buildings. Several other research projects provide opportunities to investigate the suitability of further model-based approaches.

Such procedures and tools are targeted towards the providers of facility and energy management systems and companies involved in "Performance Contracting".

Both EnBau:MONITOR and our current project in co-operation with the company, Ennovatis GmbH, are supported by the German Federal Ministry for Economics and Technology BMWi.

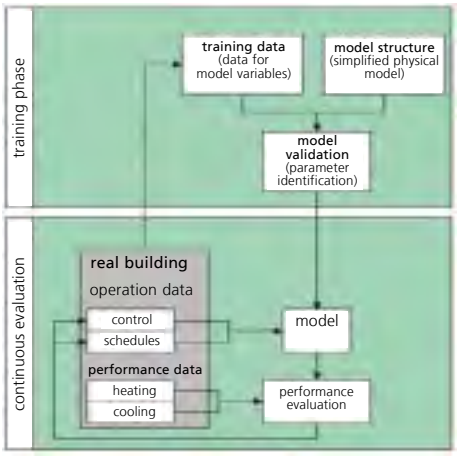


Fig. 2: As a basic principle, models for operation analysis and optimisation must be initially calibrated. Drawing on measured data for the building to be investigated, the model parameters are varied until the model is able to reproduce the energy-related behaviour of the building (training phase). After this, the calibrated model can be used to monitor the building operation by comparing the measured data from real operation (e.g. heating or cooling energy) with the values calculated by the model (continuous evaluation). If deviations occur between the real building and the model, then a recommendation for action can be derived. In the ideal case, there is automatic feedback to the building management control. If the model is designed appropriately, it can also be used to identify potential to save energy.

Active Solar Façades

The largest share of energy consumed in private households is used for space heating and to heat domestic hot water. It is thus an obvious option to extend the potential for gaining solar heat. The goal of a major project, which Fraunhofer ISE is co-ordinating, is to use the building façades as a source of solar heat.

Michael Köhl, Markus Heck, Franz Brucker, Daniel Philipp, Hans-Martin Henning

In contrast to solar generation of electricity, where the electricity grid functions as an energy storage unit in industrialised countries, the problem of long-term storage of heat has still not been solved. Against this background, and also considering the fact that more and more roof areas are occupied by photovoltaic systems, we are concentrating increasingly on the development of architecturally attractive and technically mature façade collectors. Solar façades supply heating energy with a seasonal profile which matches the demand better than conventional collectors, and they serve simultaneously as thermal insulation.

Together with nine partners from industry and research, we are examining the complete chain from the choice of materials to architectural integration:

- selection of materials
- development of anti-corrosion barriers based on pyrolitically deposited zirconium oxide
- coloured sputtered solar absorber coatings
- coloured solar absorber paints (fig. 1)
- development and application of durability analysis procedures
- corrosion tests
- development of non-glazed absorber panels
- systems studies
- architectural building integration

The first prototype of a coloured façade collector – Solabs™ - was exhibited at the trade fair, Intersolar 2006. An initial demonstration façade with Solabs™ has been constructed at EPFL (Ecole Polytechnique Fédérale de Lausanne) in Lausanne (fig. 2).

The project is funded by the European Union.

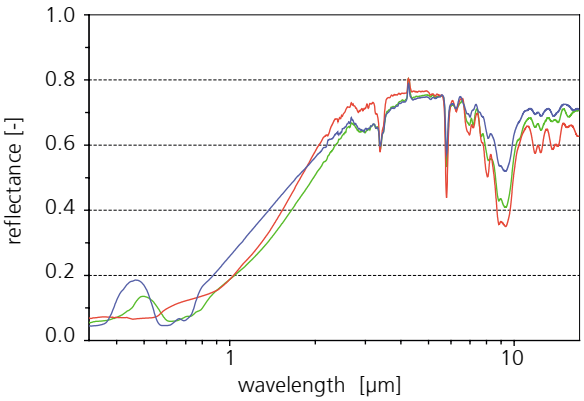


Fig. 1: Reflectance spectra for coloured, selective solar paints, which are independent of the paint thickness. The following integrated values for solar absorptance α and thermal emittance ε at 100 °C are derived from the reflectance spectra: $\alpha = 0.844$ and $\varepsilon = 0.361$ for the green paint, $\alpha = 0.832$ and $\varepsilon = 0.395$ for the red paint and $\alpha = 0.805$ and $\varepsilon = 0.322$ for the blue paint. By reducing the emittance with respect to conventional paint ($\varepsilon > 0.9$), the lower absorptance and thus the lower solar fraction resulting from the colour is more than compensated. With the absorptance and emittance values for the differently coloured paints being very similar, the architect can choose the paint colour according to purely aesthetic criteria.

Fig. 2: The demonstration façade at EPFL (Ecole Polytechnique Fédérale de Lausanne) gives an impression of the architectural and technical possibilities for the Solabs™ façade.

User-Friendly and Reliable Solar Control

Optimal use of daylighting and efficient solar control are central aspects of energy-optimised buildings. Our work thus concentrates both on the development of sun-shading systems and on research and optimisation of methods to evaluate them.

Tilmann Kuhn, Jan Wienold, Hans-Martin Henning

Fig. 1: Our method for evaluating sun-shading systems is often used in building projects or for product characterisation. The figure shows the planned "Prime Tower" in Zurich (architects: Annette Gigon / Mike Guyer). We were involved in the façade planning with consultancy and testing.

In order to evaluate the solar-control effect of façades, we have developed a method which is distinguished by taking both varying user behaviour and also the correct angular dependence for the g value and the transmittance into account. During 2006, the method was successfully audited according to DIN EN ISO IEC 17025. It has been officially accredited according to this standard since the end of 2006.

To characterise glare in the working environment, we have developed a new criterion, the "Daylight Glare Probability" (DGP). In contrast to procedures prescribed by current standards and guidelines, there is a very high correlation with this procedure between the subjective responses of users and the DGP value. The predictive power was proven by comprehensive studies with many test persons and different façade constructions under real daylighting conditions. This work was carried out within the ECCO-Build project, which was supported by the European Union.

In the past, terrorist attacks on office buildings with large glazed surfaces caused injuries due to flying glass to many people. The currently available, protective screens reduce visible comfort appreciably, particularly by causing glare. Together with the Fraunhofer Institute for High-Speed Dynamics EMI, we have lodged a patent application for a new sun-shading system which could also act as protection against flying glass. The new blinds aim to combine high thermal and visual comfort with reliable mechanical protection.

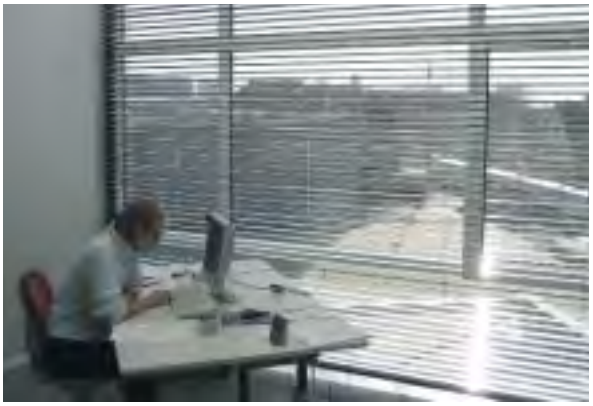


Fig. 2: Our new method predicts the probability of persons being disturbed by glare at their desks. The previous binary yes/no criteria for glare protection are replaced by a continuous criterion scale. This enables a more useful comparison to be made between different systems.

Heat-Transfer Fluids based on Paraffin-Water Emulsions

Phase Change Slurries (PCS) are heat-transfer fluids which contain Phase Change Materials (PCM). The PCM is finely distributed in a liquid as micrometre-sized particles and increases the heat capacity during the melting process by up to a factor of four. In order to prevent the individual PCM particles from sticking to each other, they can be surrounded by a solid shell (micro-encapsulated PCM) or stabilised as an emulsion.

Peter Schossig, Stefan Gschwander, Thomas Haussmann*, Hans-Martin Henning

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

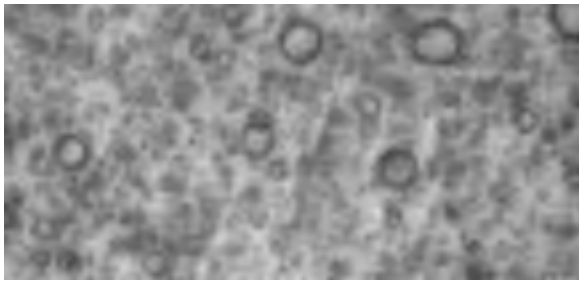


Fig. 1: Micrograph of an emulsion. In the micrograph, the paraffin droplets can be recognised, which remain separate even without a shell when subjected to shearing stress. The figure also indicates the size distribution: Whereas the emulsion contains individual large droplets with a diameter of about 20 µm, most of the particles have a diameter of about 5 µm,

For a number of years, we have co-operated with the BASF company in developing Phase Change Slurries based on micro-encapsulated slurries. In micro-encapsulated PCS, the finely distributed paraffin droplets are enveloped in a solid polymer shell. These capsules make the PCS very stable with respect to shearing stress acting on the slurry. However, if the stress continues over a long period, there will always be some damage to the capsules. In addition, the capsule shells occupy part of the available solid volume and thus reduce the proportion of thermally active PCM.

A solid capsule shell is not used within emulsions. Here, the individual droplets remain isolated due to the added emulsifier. The emulsifier is preferentially located at the interface between the hydrophobic paraffin and the hydrophilic carrier liquid. The polarity of the hydrophilic part of the emulsifier molecule prevents the existing PCM droplets from agglomerating; a stable emulsion of PCM and carrier liquid results.

The proportion of paraffin can be higher in an emulsion than in a suspension, because the proportion of emulsifier can be smaller than that of polymer needed for the capsule shells for a constant proportion of carrier liquid. This leads to higher heat capacity values. Further, it can be assumed that the emulsions are capable of regeneration, as the effect of the emulsifier is retained. Even if individual paraffin droplets should agglomerate, they could be separated again by the shearing stresses that act on the fluid.

Initial tests have already demonstrated great stability of these heat-transfer fluids to shearing strain and during phase changes. In further work, we aim to use these PCS as storage fluids in cooling systems and test them in real cooling systems.

The developments are made in co-operation with industrial partners. The project is supported by the German Federal Ministry for Economics and Technology BMWi.

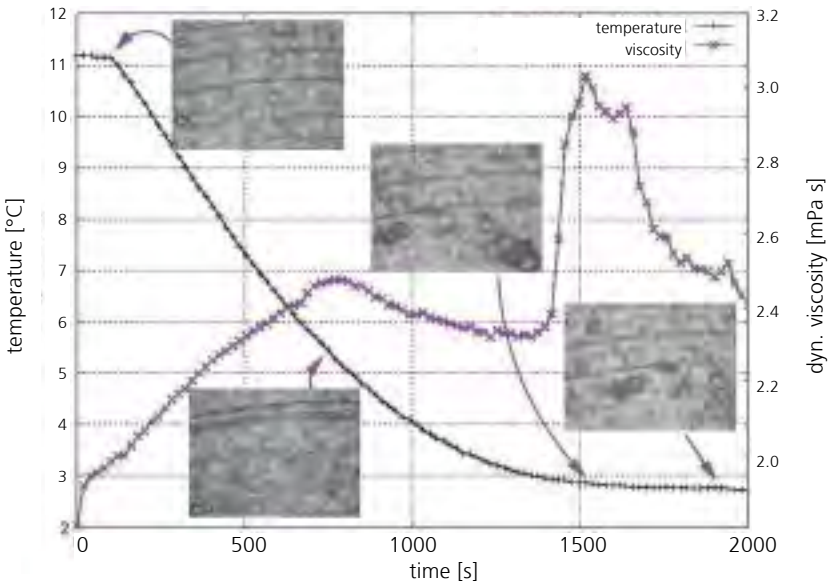


Fig. 2: Effect of temperature on the viscosity and the appearance of a PCS emulsion during the phase change from the liquid to solid state. The blue and black curves show the sample viscosity and the thermostat temperature respectively as a function of time. The appearance of the emulsion changes as a function of temperature (particles become smaller, agglomerate and separate again). These changes are reflected in the viscosity of the emulsion.

Cooling by Active Circulation through Building Components and Integrated Latent Heat Storage

To avoid overheating of office buildings in summer and reduce the energy demand for cooling, we are developing building components with integrated phase change materials (PCM) and actively circulated heat-transfer media. Based on the building materials with micro-encapsulated PCM, which Fraunhofer ISE helped to develop, we are now investigating activated cooling ceilings incorporating PCM, which require significantly less cooling energy than conventional cooling ceilings, can be controlled and can use alternative heat sinks.

Peter Schossig, Thomas Haussmann, Doreen Kalz, Hans-Martin Henning

Many low-energy office buildings rely on passive cooling concepts. In the passive cooling approach, installation of air-conditioning for the entire office area is avoided. The pre-condition is that internal and solar heat gains are minimised or avoided. By using the heat storage capacity of the building, the remaining thermal loads can be transferred to natural heat sinks (outdoor air, groundwater, ground).

If the available thermal storage mass is insufficient, the combination of actively cooled building components with PCM offers an alternative for cooling the building. It presents several advantages compared to conventional, large-area heating and cooling systems. The temporary storage of large quantities of heat during the day by the phase transition from solid to liquid leads to a significant reduction in the excess heat which must be actively removed by a cooling system. Cooling energy is saved and the cooling system can be smaller. At the same time, shorter operating periods reduce the pumping energy demand.

In addition to saving energy, the additional installation of a distributed storage medium for heating or cooling energy in conventional cooling ceilings allows alternative heat sinks to be used which provide relatively expensive but temporally unrestricted power (e.g. ground

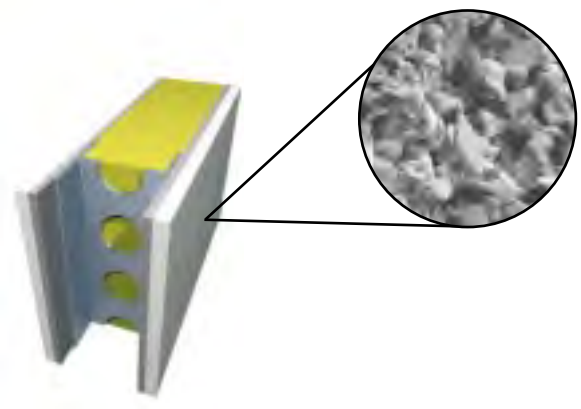


Fig. 1: Phase change materials (PCM) can be used to prevent overheating in summer and thus to reduce the demand for cooling energy in buildings. Excess heat during the day is stored as latent heat during the solid/liquid phase transition and is then released again during the night. The first building materials with micro-encapsulated PCM (see detail), which Fraunhofer ISE helped to develop, are commercially available.

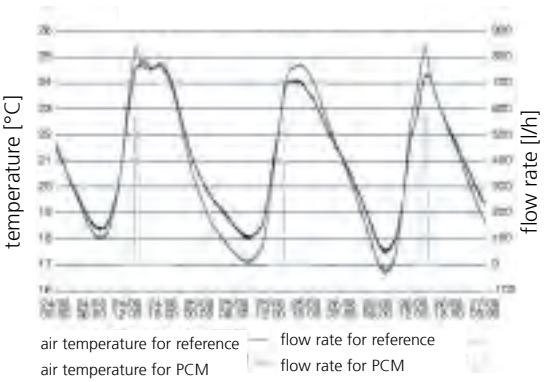


Fig. 2: The PCM in an activated cooling ceiling can reduce the cooling energy demand particularly effectively during the transitional seasons of spring and autumn. The plotted measurement results from test cooling ceilings at Fraunhofer ISE for three consecutive days show that only the reference cooling ceiling without PCM (purple and blue curves) had to be cooled actively, whereas the PCM cooling ceiling (black and green curves) could be operated on a purely passive basis.

probes). The available cooling power can be accumulated over longer periods in the PCM in the cooling ceiling. If the cooling power of the heat sink ("cold source") is not sufficient during the course of the day, the remainder can be met by the excess that had previously been accumulated in the PCM cooling ceiling.

In co-operation with our project partners, we investigate cooling ceilings that are based on the PCM building materials which Fraunhofer ISE helped to develop and are now commercially available on the German market. The measurements range from material characterisation with the differential scanning calorimeter (DSC), through the measurement of ceiling samples, to the measurement of complete cooling ceilings in test rooms at Fraunhofer ISE. In 2005, a new test room for large-area cooling and heating systems was constructed, which allows measurements to be made under controlled conditions analogous to DIN 4715-1 and EN 14240:2004.

The development of a design tool based on simulation, which can aid planners and users in the application of PCM in buildings, is another focus of our work.

We apply detailed simulation studies to investigate the power, the potential and the occupants' thermal comfort resulting from systems based on capillary tube mats with integrated PCM. One objective is to determine the optimal melting range of the PCM for the investigated application in the case of heating or cooling. In a simulation study on passive cooling of an office building, we showed that:

- an acceptable indoor climate was achieved with capillary tube mats – comparable to conditioning with concrete core temperature control
- the inclusion of PCM reduces the operative room temperature
- the active circulation of water through the PCM storage element completely discharges it
- the chosen control strategy and operation mode for the capillary tube mats is decisive for the thermal comfort and cooling power
- a lower melting range is more effective for active discharging of the PCM storage unit by water circulation.

The research project is supported by the German Federal Ministry for Economics and Technology BMWi as part of the LowEx consortium.

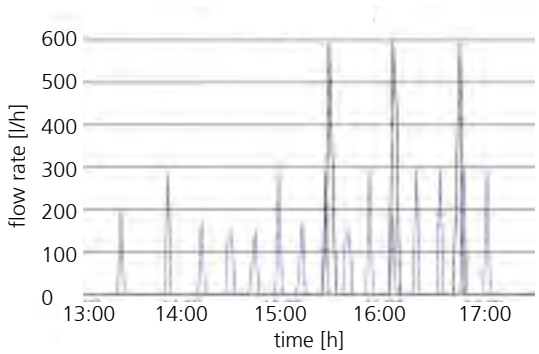


Fig. 3: The possibility to reduce pumping energy is an advantage of the combination of cooling ceilings with PCM. The parallel measurements shown here for cooling ceilings with PCM (black line) and without (reference – blue line) in test rooms at Fraunhofer ISE demonstrate that the reference ceiling not only required active cooling two hours earlier, but also switched on and off much more frequently.

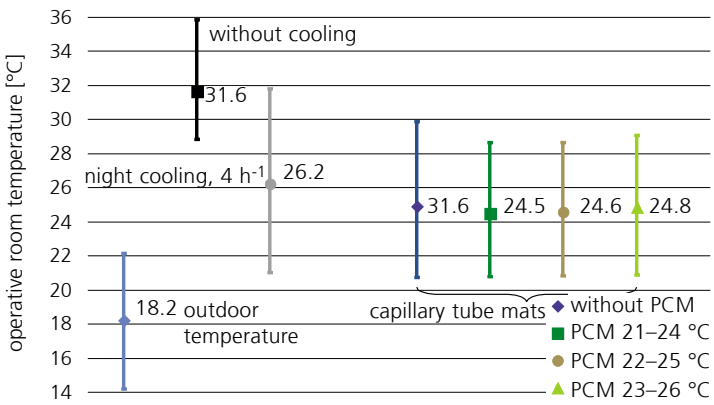


Fig. 4: Measurements in an office in lightweight construction: The daily average of the operative room temperature is shown, as well as its average maximum and minimum (from 22.8 to 27.8.2004) for selected cooling strategies. The outdoor temperature is also shown. The thermal indoor climate is significantly improved by using the capillary tube mats rather than a night cooling approach. Application of PCM reduces primarily the maximum operative room temperatures, but also the average values.

Sorption-Assisted Air-Conditioning with Liquid Sorbents

Building air-conditioning represents a rapidly growing market. Thermally driven systems present an interesting alternative to the currently dominating compression technology when viewed from both ecological and economic perspectives. Fraunhofer ISE is working with industrial partners on the development and market introduction of this type of system.

Christian Neumann, Daniel Gessner, Till Mansfeld*, Carsten Hindenburg**, Hans-Martin Henning

* Solares Bauen GmbH, Freiburg
** Independent consultant

Fig. 1: Liquisorp project: Completely installed system in the Freiburg University Clinic. The photo shows the compact, orange-red housing of the air-conditioning equipment. In the foreground, the heating circuits for heating the brine in the regenerator (summer operation) and for heating the supply air (winter operation) can be seen.

Thermally driven systems for sorption-assisted room air-conditioning already operate efficiently with heating temperatures of 50 – 80 °C. This situation results in interesting possibilities for combination with solar heat or waste heat. Applications are also possible within combined heat, power and cooling systems.

We are investigating the performance of such systems under real application conditions within monitoring projects. Our approach is to prepare energy and cost balances and identify optimisation potential, both with regard to the construction and also the measurement and controls technology.

Our work at present is concentrating on systems with fluid sorbents which operate with an aqueous lithium chloride solution.

In co-operation with the company, Menerga Apparatebau, we have constructed two demonstration systems. The larger of the two systems has a capacity of 12000 m^3/h and is installed in the Medical Clinic building of the Freiburg University Clinic. The system is supplied by district heating from the Clinic's internal heating plant. As a result of the intensive monitoring, numerous improvements have already been made to the system.

The project was funded by the utility, badenova AG, from its Innovation Fund for Atmospheric and Water Conservation.

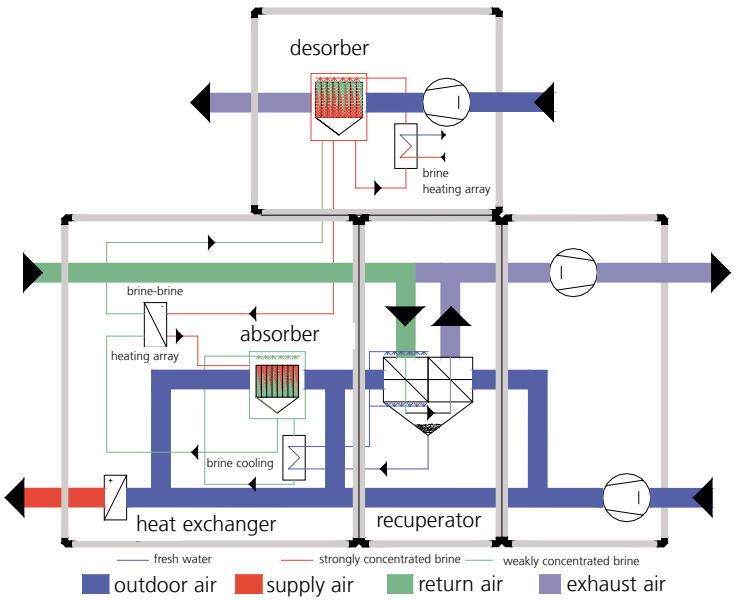


Fig. 2: Schematic diagram of a sorption-assisted air-conditioning system with fluid sorbents. The system serves to provide cooled and dehumidified supply air. First the warm and humid outdoor air is cooled in a heat exchanger by adiabatic humidification of the return air. Then it is dehumidified in the absorber with a hygroscopic lithium chloride solution. The concentration of the solution is lowered by the humidity absorbed from the air. In order to regenerate the dehumidifying potential of the lithium chloride solution, it is reconcentrated in the regenerator. There, the reverse process to the absorber takes place: Water is driven out of the brine and released to a separate outdoor air current. The brine must be heated for this to happen. This supply of heat is the thermal driving force for the process.

Heat Pumps for High Energy Efficiency in Residential Buildings

We develop highly efficient heat pumps for applications in energy-optimised residential buildings. Our focus is on exploitation of additional heat sources such as solar energy and novel combinations of different heat sources. In addition, we apply natural refrigerants. In our laboratory, we measure newly developed heat pumps in ventilation equipment and support our project partners in further developments. We also investigate the application of the equipment in low-energy residential buildings and the existing building stock.

Andreas Bühring, Christel Russ, Marek Miara, Christian Bichler, Martina Jäschke*, Thore Oltersdorf, Rainer Becker, Jeannette Wapler*, Matthias Schubert, Daniel Kühn, Andreas Bruckbauer, Eva Müller, Christine Freudenberg, Robert Salignat, Hans-Martin Henning

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Fig. 1: With this newly developed combined evaporator[1], two heat sources, such as exhaust air and solar energy, can be used simultaneously by the heat pump, without the cooler loop design becoming more complex. The refrigerant in the gap between the coaxial pipes can extract heat simultaneously from the liquid in the inner pipe and from the air current in the outer pipe.
[1]Patent application by Fraunhofer ISE

Heat pumps enable the use of energy from the surroundings or low-temperature solar heat in large quantities to heat residential buildings or domestic water. As electricity is used to operate them, highly efficient operation is imperative, in addition to low production costs and robust operation.

Fraunhofer ISE assists industrial partners in implementing innovative ideas and also develops its own equipment and patents. By combining different heat sources (exhaust air, outdoor air, ground, solar heat), we raise the efficiency and widen the current limits on applying heat pumps. Similarly, we support the transition from fluoridated hydrocarbons to natural refrigerants such as propane or CO_2, as this can further improve the environmental balance of heat pumps.

In order to measure our own prototypes or new heat pumps from our clients, we have set up an automated test rig with two parallel test stands. We use it to characterise compact heating and ventilation units with exhaust-air heat pumps from different manufacturers.

In the strategic NEGEV project (New Integrated Energy Concepts for Buildings), which is funded by the German Federal Ministry for Economics and Technology BMWi, we have developed a propane heat pump. It features a series connection of the condensers and a particularly high coefficient of performance. The heat pump was tested in our test rig and then measured in field tests.

In two extensive field measurement projects, we are currently investigating the efficiency of 240 heat pumps from different manufacturers, both in the existing building stock and in newly constructed low-energy residential buildings. We record data for all important system parameters every minute and transmit them to the Institute by radio. We analyse the system performance under differing boundary conditions and then derive recommendations for further development of the equipment. This leads to starting points for joint development projects with our partners.

The work is carried out with financial support from the German Federal Ministry for Economics and Technology BMWi and in co-operation with industrial partners.

Fluid Dynamic Simulations for Better Building Services Technology

We develop different procedures to optimise the design of components for building services technology. Using different programs for computational fluid dynamics, we are investigating the air flows in heat exchangers and evaporation processes in heat pumps. In simulations, we model the flow of flue gas onto the heat exchangers in the combustion chamber of a wood-pellet boiler, and investigate the effect of varying the chamber design on the heat exchange, pressure loss and combustion management.

Andreas Bühring, Jörg Dengler,
Rehan Yousaf*, Christian Bichler, Benoît Sicre, Thore Oltersdorf, Anant Narare, Tunc Askan, Hans-Martin Henning

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

With the help of computational fluid dynamic (CFD) simulations, we support our clients in optimising components for building services technology. This mainly concerns systems in which heat is transported by air currents or flowing liquids, or where the fluids exchange heat with the equipment components.

An investigation in virtual reality can reduce the cost and effort for constructing test samples considerably. The effect of smaller optimisation steps can be investigated adequately without the need for new test objects. We check the simulation results by making measurements on selected variants in our test rigs.

Depending on the task at hand, we use different programs for the simulations, for example Fluent and Ansys-CFX. We draw on the various mathematical-physical models which are already available, and define our own special functions to extend these when necessary.

The figures illustrate our current areas of interest and results of our work.

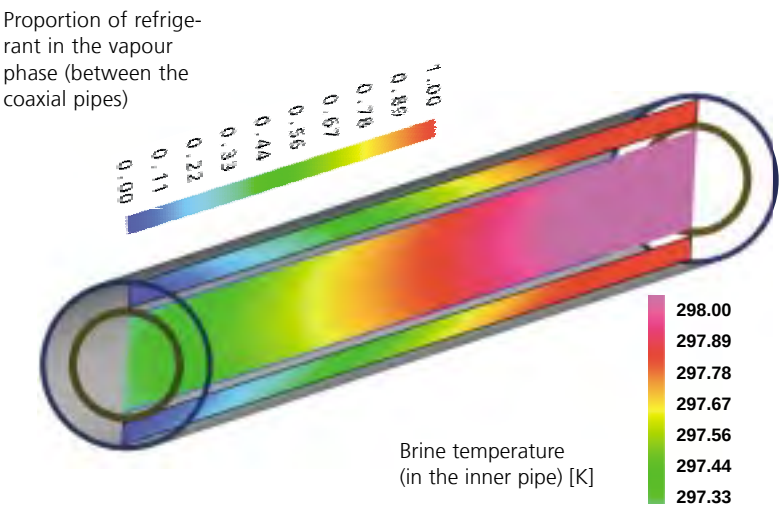


Fig. 1: As the refrigerant flows from left to right in the gap between the coaxial pipes of the combined evaporator, it is heated by absorbing energy from the air current outside and the brine in the inner pipe, which simultaneously cools down. We apply the CFX program to calculate the phase transition of the refrigerant from the liquid phase (blue), via the evaporation steps of nucleate boiling and droplet boiling, to the superheated gaseous phase (red).

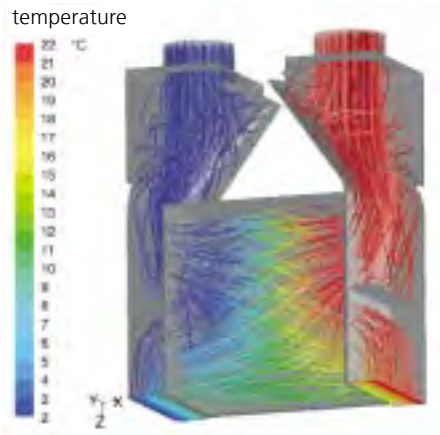


Fig. 2: Simulated air flow through an air-to-air heat exchanger for heat recovery from the room extract air to a ventilation unit. Colour-coded flow lines represent the movement and temperature of the entering air currents (left: cold outdoor air, right: warm air extracted from the room) throughout the simulated zone. By varying the geometrical configuration of the entrance zone and the heat-exchanging surfaces, we can optimise and check the design with simulations using the Fluent program.

Fig. 3: Optimisation of the hot heat exchanger of a Stirling engine, which is fuelled with wood pellets and generates heat and electricity. We apply simulation to investigate possible optimisation variants, in order to transfer the greatest amount of energy from the exhaust gas to the Stirling process and thus increase the proportion of electricity generated. The figure shows the geometrical grid used to represent the hot heat exchanger in the CFD simulation.

New Testing Unit for the Development of Process Heat Collectors

Until now, the collector efficiency curves obtained in German and other European testing laboratories have been determined for collector inlet temperatures of maximally 100 – 120 °C. This is not adequate for the development and evaluation of process heat collectors, as these are used with operating temperatures ranging from 80 °C to 250 °C. At Fraunhofer ISE, we have set up a new test rig, with which we can measure efficiency curves for temperatures up to 200 °C.

Korbinian Kramer*, Stefan Mehnert, **Matthias Rommel**, Arim Schäfer, Thorsten Siems, Christoph Thoma, **Hans-Martin Henning**

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

For our collector measurements at Fraunhofer ISE, we use both an outdoor test stand with a tracker and an indoor test rig with a solar simulator, which can operate independently of the weather. Both test facilities are used both for certification measurements and for development work. We have developed the new testing unit for process heat collectors as an additional module, which can be used in both test facilities. This extends our experimental basis for developing process heat collectors: For concentrating collectors, the outdoor test stand must be used because of the need for direct radiation, whereas non-concentrating collectors can also be investigated with the indoor test rig. This offers the advantages of saving time and costs due to independence from the weather, which is particularly important for developmental work, better reproducibility and greater flexibility for specific experimental investigations.

We use water under pressure as the heat transfer fluid. The saturated vapour temperature of water at 200 °C is 15.3 bar. This defined the essential specifications for the components of the new testing unit. Up to now, we have measured efficiency characteristic curves for flat-plate collectors, a double-glazed flat-plate collector with compound parabolic concentrators (CPC) and evacuated tubular collectors with CPC reflectors at collector temperatures up to 185 °C (Fig. 2).

Fig. 1: Efficiency characteristic curve measurement for an evacuated tubular collector with a CPC reflector exposed to the solar simulator at Fraunhofer ISE. The new testing unit, with which we can make accurate measurements up to 200 °C, is at the bottom left of the photo. The testing unit is designed to be transportable, so that we can also use it in the outdoor test stand with a tracker and natural solar radiation.

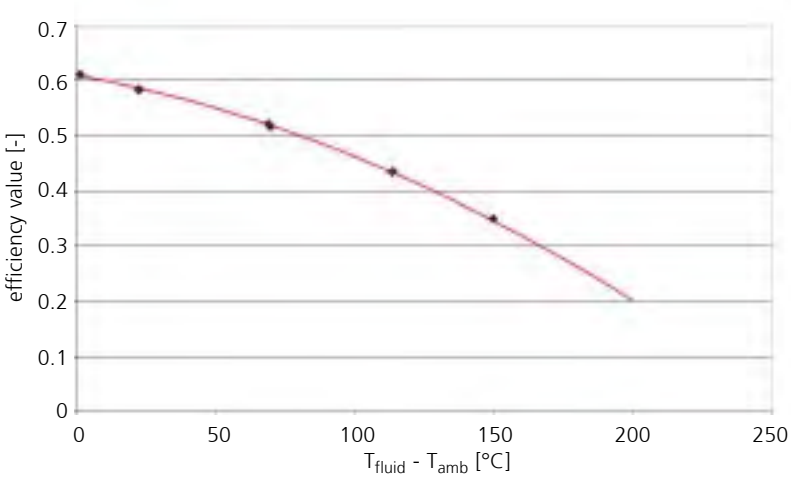


Fig. 2: The graph shows the measured efficiency points and the resulting characteristic curve. During the measurement, the radiation intensity from the solar simulator in the collector plane was 934 Wm^{-2} and the ambient air temperature was 33 °C. The average fluid temperature during the measurement of the last measurement point was 184 °C.

The project is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU within IEA Task 33/4 of the "Solar Heating and Cooling Programme".

Adsorption Technology for Heating and Cooling: Materials, Components, Systems

Together with partners from universities, we are conducting research on new adsorbents for applications in thermally driven heat pumps and chillers, as well as in thermal storage units. Significantly improved adsorbents, compared to classic zeolites and silica gels, were found. In order to achieve higher power density values in adsorption heat pumps, we are developing an adsorbent-metal compound with hierarchical porosity. A further emphasis is on the development of improved evaporator structures.

Ferdinand Schmidt, Tomas Núñez,
Stefan Henninger*, Lena Schnabel**,
Ursula Wittstadt, Gerrit Füldner,
Gunther Munz, Daniel Sonnekalb,
Anna Jahnke, Benoit Reynier,
Hans-Martin Henning

* Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität Freiburg
** Promotionsstipendiatin der Deutschen Bundesstiftung Umwelt DBU

The adsorbents which are currently used in commercially available adsorption heat pumps and chillers were originally designed and synthesised with other goals in mind (e.g. gas separation or catalysis).

Thus, there is still a major optimisation potential for applications in chillers and heat pumps, using new materials. Within a research network project, we have characterised and evaluated newly developed adsorption materials at Fraunhofer ISE.

For thermal storage applications, only inexpensive adsorption materials can be considered due to the large amounts of material required. Both chemically hydrophilised activated charcoal and layered silicates have proved to be promising. Basic research is needed on both classes of materials, before it is appropriate to start product development.

Aluminophosphates (AlPO) and silico-aluminophosphates (SAPO) have been identified to be particularly promising for heat pumps and chillers.

Fig. 1: Framework structure of copper BTC (benzene tricarboxylate), a metal-organic framework material, as represented in molecular simulation. The copper atom is represented in magenta, carbon green, oxygen red and water molecules as white-red. The Cu BTC structure shows a greater water adsorption capacity in the usable vapour pressure range than all previously investigated adsorbents.

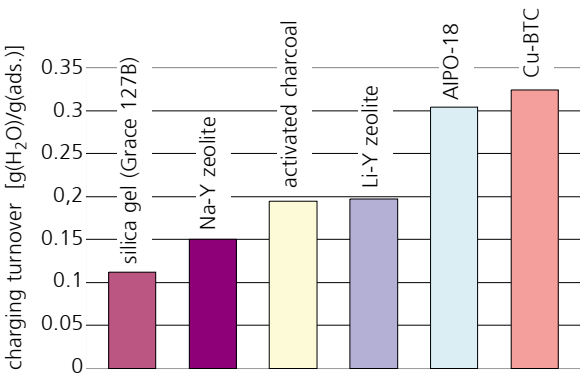


Fig. 2: Comparison for the charging turnover in adsorbed water for various investigated adsorbents in a chiller cycle (temperature levels: 140 °C desorption for 35 °C condensation, 30 °C adsorption for 10 °C evaporation).

Metal-organic framework (MOF) materials have been investigated here for the first time with respect to their application in adsorption heat pumps. Among them, copper BTC (benzene tricarboxylate) has proved to be a type with excellent water adsorption properties.

All of the new materials mentioned are cost-intensive, and thus only have a chance of economic amortisation if used in applications with many thousands of adsorption cycles. Therefore, an important goal for us is to shorten the cycle period of adsorption heat pumps by increasing the heat and material transport. A further motivation for raising the power density is to save valuable component volume. In some applications, such as vehicle air-conditioning, the use of adsorption chillers only becomes feasible if the power density is increased significantly.

The work in the research network project, which is co-ordinated by Fraunhofer ISE, is supported by the German Federal Ministry for Education and Research BMBF.

In an internal research project of the Fraunhofer-Gesellschaft (WISA Programme), which Fraunhofer ISE is also co-ordinating, we are co-operating with the Fraunhofer Institutes IFAM, ITWM and IVV to develop compound structures of adsorption materials and open-celled metal foams and fibre structures. We anticipate that the application of these compound materials with hierarchical pore structure should enable a leap in the power density of adsorbers.

There is also considerable potential for optimising the other components of an adsorption heat pump. At present, we are concentrating on developing improved evaporators. As a prerequisite, we constructed an evaporator test rig at Fraunhofer ISE. It allows the evaporation of water from small heat transfer structures to be measured at low temperatures and pressures (3 °C to 20 °C, corresponding to 6 to 23 mbar). Characterisation of different heat transfer structures and operating modes provides information on the potential for optimising the evaporator units. This work is supported by the European Union within the SoCold project.

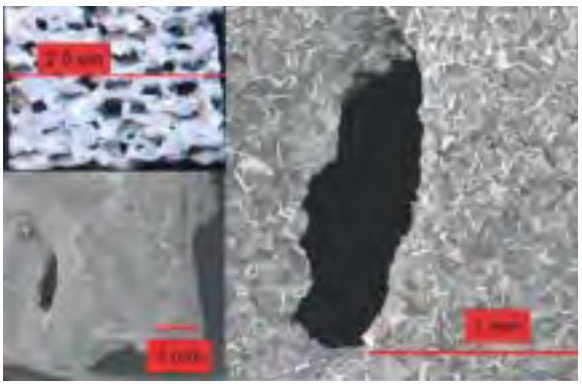


Fig. 3: Compound of an aluminium foam and zeolite (upper left) for adsorbers with high power density. Scanning electron micrographs of the foam with different magnification factors (lower left and right) demonstrate the dense occupation of the foam surface with zeolite crystals. Foam production: Fraunhofer IFAM, Bremen; Coating and scanning electron micrographs: University of Erlangen, AK Schwieger.

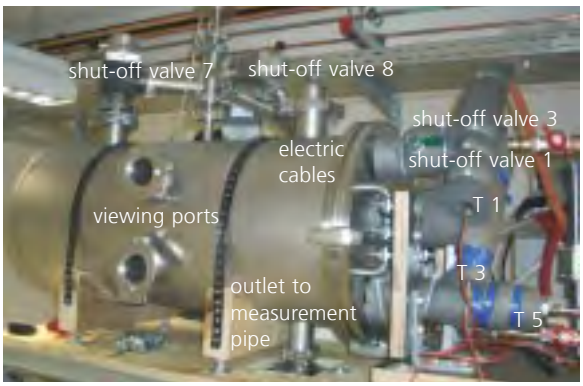


Fig. 4: Photo of the evaporating chamber of the measurement stand. The different types of evaporator structures (flooded, sprayed) are positioned inside this vacuum-tight chamber. Structures with up to 2 kW cooling power can be measured here. The cooling power balance is determined from the fluid side. The necessary cables and temperature sensors for this can be seen on the cover at the right-hand end of the chamber.

Optical Components and Systems

Solar energy systems convert solar energy, which is incident on the earth as electromagnetic radiation, into thermal, electric or chemical energy. We develop optical components and systems to transmit, reflect, absorb, filter, redirect or concentrate solar radiation better, depending on the requirements.

The broad bandwidth of the solar spectrum, covering wavelengths from 0.3 to 2.5 µm, and the need to produce optical components and systems inexpensively over large areas, present major challenges. To meet these, we follow novel approaches, which combine materials research, optical design and production technology. In addition to optical know-how and close co-operation with our clients, comprehensive knowledge of solar energy systems is necessary to transfer the approaches successfully to new products for solar technology. Fraunhofer ISE provides excellent opportunities for the synergetic interaction needed for this.

The interdisciplinary topic, "Optical Components and Systems", is the basis for several market sectors of solar technology: windows and façades, solar thermal collectors, photovoltaics and solar power stations. Our expertise is also appreciated by clients who do not come from the solar sector. For example, we provide support for lighting and display technology.

Switchable coatings on window panes allow the window transmittance to be reduced when the building is in danger of overheating. Gasochromic glazing, in which the absorption can be varied over a wide range, has already been tested successfully in demonstration façades. Laboratory samples of photochromic and photoelectrochromic systems have shown very good optical results and are extremely promising for glazing units. Now that the fundamental mechanisms for switchable reflectors have been clarified, they can be developed specifically for certain applications. Microstructured surfaces form the basis for sun-shading systems which reflect undesired direct solar radiation but still transmit diffuse daylight.

The combination of micro-optical know-how and interference lithography over large areas has allowed Fraunhofer ISE to expand its activities in an area outside solar technology, namely display technology. Here, we are working on micro-structured polymer films which improve the brightness and contrast of displays. Light redirection is a central topic in lighting technology. Drawing on our work for daylighting technology, we also offer our expertise in optical materials and surface properties for optical design in artificial lighting technology.

We have developed selective absorber coatings for solar thermal collectors (temperatures of up to 230 °C) and transferred them to industrial production for many years now. However, coatings for absorber pipes in solar-thermal power plants must permanently withstand much higher temperatures of around 400°C. This is achieved by integrating additional layers into the coating stack to act as diffusion barriers, selected according to the type of absorber pipe. In photovoltaic concentrator modules, solar radiation is concentrated onto tiny, high-performance solar cells. We optimise the required concentrator optics with respect to efficiency and costs.

Over the past years, we have continually extended our modelling capacity. It encompasses fundamental physical models such as effective-medium theory, rigorous and scalar diffraction theory, scattering theory, thin-film methods, geometric and non-imaging optics, as well as planning tools, e.g. for lamp design. This means that we can respond quickly and efficiently to clients' enquiries in determining the feasibility of a desired optical component. Vacuum coating and micro-structuring processes are available to us as production methods. Our characterisation methods not only include standard procedures but also use special equipment, e.g. to determine bi-directional optical properties. Whenever needed, we extend the palette of services by close co-operation with recognised research institutions within and outside the Fraunhofer-Gesellschaft.

Special facilities:
- vacuum deposition system for quasi-industrial production of complex coating systems over large areas (140 cm x 180 cm)
- interference-lithography equipment for homogeneous production of microstructures and nanostructures over areas of up to 120 cm x 120 cm
- optical measurement technology: spectrometry with integrating spheres, goniometry, light-scattering measurements

Optical Components and Systems

Photogoniometer measurement of the spatial distribution of light transmitted and reflected by a glazing unit with micro-structured, light-redirecting elements. The sample consists of a prismatic structure on a polymer film, which was laminated onto glass and integrated into a glazing unit. Structures for light-redirecting elements or seasonal solar control are developed, produced and optimised at Fraunhofer ISE. Near-normally incident light is refracted by both flanks of the prismatic structure and the incident ray is divided into two transmitted rays. The three rays have been made visible for the photo. Whereas light from the low winter sun and bright sky radiation is transmitted, light from the high-standing sun in summer is reflected by the structure. The seasonal variation between transmission and reflection is controlled by the changing altitude angle of the sun (see article on p. 42).

Contacts

Coating – technology and systems	Wolfgang Graf	Tel.: +49 (0) 7 61/45 88-59 46 E-mail: Wolfgang.Graf@ise.fraunhofer.de
Microstructured surfaces	Dr Benedikt Bläsi	Tel.: +49 (0) 7 61/45 88-59 95 E-mail: Benedikt.Blaesi@ise.fraunhofer.de
Component development, light guiding and solar concentration	Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fraunhofer.de
Solar power plants, light guiding and solar concentration	Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fraunhofer.de
Lighting technology	Jan Wienold Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 33 E-mail: Jan.Wienold@ise.fraunhofer.de Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fraunhofer.de
Display technology	Dr Benedikt Bläsi	Tel.: +49 (0) 7 61/45 88-59 95 E-mail: Benedikt.Blaesi@ise.fraunhofer.de

Interdisciplinary co-ordination

Optical components and systems	Dr Andreas Gombert	Tel.: +49 (0) 7 61/45 88-59 83 E-mail: Andreas.Gombert@ise.fraunhofer.de
Buildings and technical building components	Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-51 34 E-mail: Hans-Martin.Henning@ise.fraunhofer.de
Solar cells	Prof. Gerhard Willeke	Tel.: +49 (0) 7 61/45 88-52 66 E-mail: Gerhard.Willeke@ise.fraunhofer.de

Selective Absorber Coatings and Secondary Reflectors for Solar Thermal Power Stations

As part of our work on solar thermal power stations, we have developed selective absorber coatings and reflector coatings. In addition to the optical properties, durability at high temperatures was a major objective. The developments are intended for evacuated absorber pipes for parabolic trough power stations, absorber pipes exposed to the atmosphere for Fresnel collectors, and secondary reflectors for power tower plants and Fresnel collectors (see also the article on p. 87).

Andreas Georg, **Wolfgang Graf**, Christina Hildebrandt, Andreas Gombert

In solar thermal power stations, sunlight is focussed by reflectors onto a selective absorber. Among linearly concentrating systems, the distinction is made between parabolic trough systems and Fresnel reflector systems with secondary reflectors. Depending on the system and application, the operating temperatures range between 300 and 500 °C. For thermodynamic reasons, the aim is to reach the highest temperatures possible. The existing multi-layer coatings are stable over long periods only for temperatures up to 400 °C. If additional, temperature-stable layers are included, the coatings can be protected against the dominating degradation processes, diffusion and oxidation (Fig. 2). Diffusion includes not only the migration of elements from the substrate into the coating, but also the movement of elements within the multi-layer stack. Oxidation occurs primarily in films in contact with air, but can also play a role for coatings in vacuum, as metals are located adjacent to each other in oxidised and non-oxidised states. The preferred deposition method is sputtering (Fig. 3).

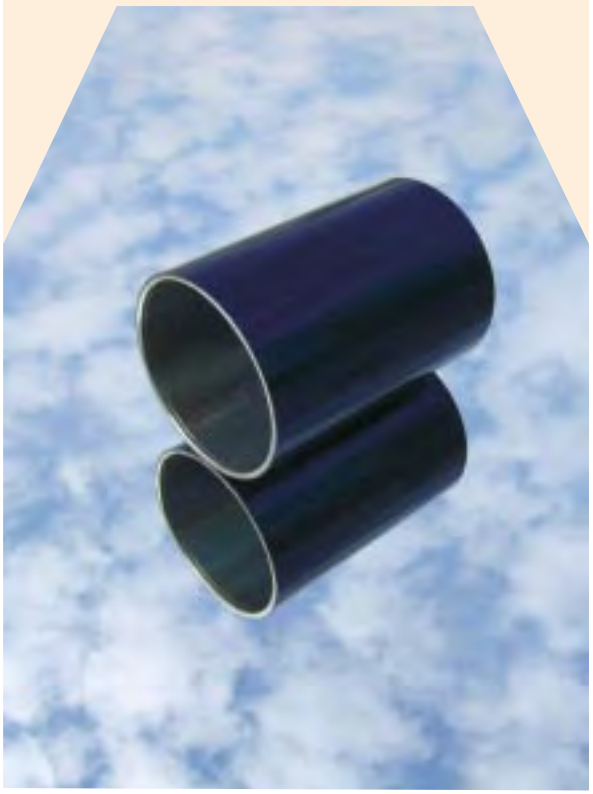


Fig. 1: Segment of an absorber pipe on a reflector element.

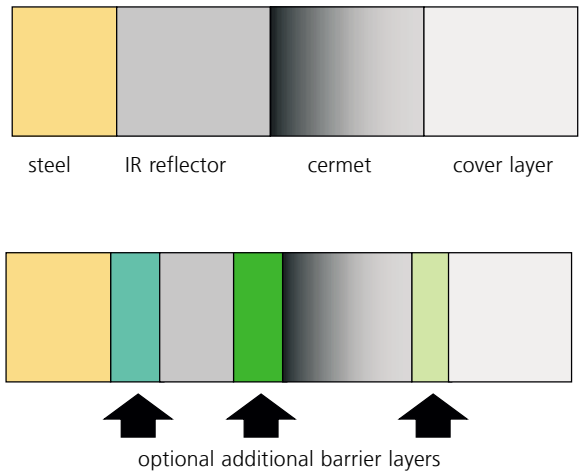


Fig. 2: Schematic multi-layer configuration of a conventional solar absorber coating with a metal infra-red reflector, an absorbing ceramic-metal composite material (cermet) and an anti-reflective cover layer. Below it, the configuration of a novel solar absorber coating with additional barrier layers to achieve stability at higher temperatures.

Different materials and thin-film combinations were investigated and optimised for the selective absorber coatings. As a further parameter affecting long-term stability, we studied the composition and pre-treatment of the steel pipe, particularly its surface. In addition to optical characterisation, we focussed on investigating the chemical stack structure as a function of temperature loads. A limited change in the coating layer structure always occurs during the initial hours of a temperature load. However, this is reproducible and can be taken into account in the manufacturing process. The solar absorptance of the best coating system up to now changes by 5 % during the first hour of exposure to 500 °C in air, but then only by 1 % during the following 1800 hours. The emittance changes by 3 % during the first hour, but thereafter by only 1 % (with reference to a Planck blackbody radiator at 450 °C, the intended operating temperature).

The reflectors were constructed with first-surface mirrors to attain a high reflectance value. The surface temperatures in the secondary reflectors reach up to 300 °C. We initially deposit an adhesion and barrier film onto the glass substrate, followed by a reflecting silver film and finally a cover layer. Apart from improving the coating adhesion, the adhesion and barrier layer primarily serves to suppress positive ions from diffusing out of the glass into the silver film and from the silver into the glass. The cover layer protects the silver against corrosion, above all against reaction with sulphides. Additional adhesion coatings can be introduced between the silver and the cover layers. They are mainly important to improve stability against cleaning processes. Essential factors determining the stability of the multi-layer coating include the choice of glass type and the cleaning of the glass substrate. Up to now, we have achieved a solar reflectance of 95 %. If the reflectance is calculated with respect to the radiation which is reflected by the primary reflectors, the value is just on 1 % higher.

The work is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU.

Fig. 3: Sputtering equipment to coat steel pipes with absorber coatings and glass panes with reflective coatings.

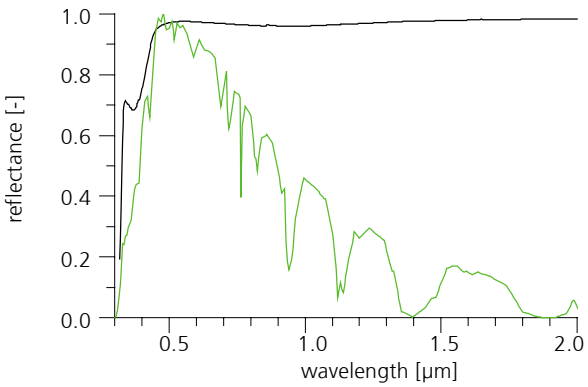
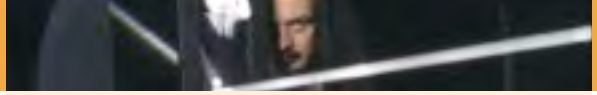


Fig. 4: Reflectance spectrum of a first-surface mirror (R_{sol} = 0.95, black). The solar spectrum (AM1.5, green) is also shown.



Switchable Mirrors with Magnesium-Nickel Coatings

Visibly switchable mirrors can be prepared with thin magnesium-nickel (Mg_xNi) coatings. The reflective metal is transformed reversibly into a transparent hydride by incorporation of hydrogen. Applications in windows for solar control and overheating protection are conceivable, particularly in combination with light-redirecting structures. For rapid and complete switching, it is essential to ensure a certain ratio of magnesium to nickel, among other factors.

Jürgen Ell*, **Andreas Georg**, Wolfgang Graf, Andreas Gombert

* Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität Freiburg

Switchable mirrors have major economic potential, as they can be used to switch the transmittance of glazing over a very large dynamic range. In a preliminary stage before product development, we have investigated a model for the switching mechanism.

When diluted hydrogen gas flows over thin films of metallic Mg_xNi with a palladium (Pd) coating, they react and form a transparent hydride (fig. 1). The reaction can be reversed with diluted O_2 gas. Typical switching times are about one minute for hydration and about 10 minutes for dehydration. An essential feature of the process is that the hydride grows as a layer, starting from the interface with the substrate. The mobility of hydrogen in the hydride is very low compared to that in the metal. If the hydride should grow from the Pd surface, this would block further hydrogen transport into the coating.

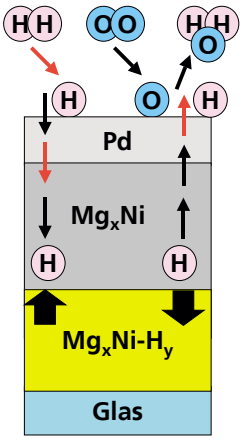


Fig. 1: Mechanism for the reactions with H_2 (left) and O_2 (right) for Mg_xNi coatings with a medium Ni content ($4 \leq x \leq 8$). The gas molecules are dissociated on palladium and the hydrogen atoms pass through the various interfaces. In the reaction with H_2, hydride formation begins at the substrate and grows towards the surface as a continuous layer. The kinetically dominating reaction steps are identified with red arrows.

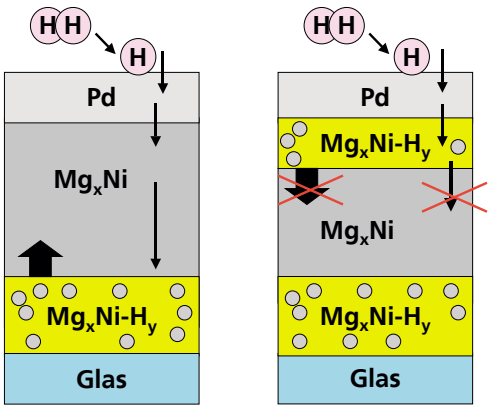


Fig. 2: Mechanism for the reaction of an Mg_xNi coating with H_2 for coatings rich in Ni or Mg. For coatings rich in Mg ($x > 8$, left), the hydride grows as a layer from the substrate, but metal islands remain enclosed in the hydride layer. In coatings rich in Ni ($x < 4$), an additional hydride layer with metal enclosures grows from the Pd surface, which brings the reaction to a halt.

Nucleation of the hydride at the substrate surface can be encouraged by a favourable ratio of magnesium to nickel. Certain chemical and structural properties of the Pd-Mg_xNi and Mg_xNi-substrate interfaces also play a major role. The hydride formation in coatings rich in magnesium (fig. 2, left) also begins from the substrate side, but metal islands remain enclosed in the hydride layer, which cannot be further hydridised due to the blocking effect of the hydride. In coatings rich in nickel (fig. 2, right), an additional hydride layer grows from the palladium surface. After it has reached a certain thickness, it blocks any further hydrogen transport and the reaction stops.

Although the stability has been significantly improved by applying suitable measures, slight oxidation of the Mg_xNi can still be determined after about 250 switching cycles. It is fundamentally possible to avoid this with effective barrier layers or by a so-called electrochromic configuration, in which the hydrogen is transported to and fro between the Mg_xNi layer and an additional hydrogen storage layer by application of a voltage.

The work on metal hydrides was supported by the German Federal Ministry for Economics and Technology BMWi.

High-Frequency Gratings for Optical Applications

High-frequency grating structures with periods which are shorter than the wavelength of light can be used to achieve special optical effects. At Fraunhofer ISE, we have developed technology to generate customised structures over large areas. Micro-replication processes can be used to incorporate such functionalised surfaces into products.

Benedikt Bläsi, Andreas Gronbach, Jörg Mick, Andreas Gombert

If surface gratings feature structure periods which are shorter than light wavelengths, these structures can no longer be resolved and thus act as an effective medium. This can be used for various optical effects: Continuous profiles result in a gradient in the effective refractive index and reduce reflection. Lamellar structures have polarisation-dependent optical properties and can be used e.g. as phase-retarding components or polarisers. We simulate such structures with approximation procedures (effective-medium theory) as well as with wave-optical tools (rigorous diffraction theory). This enables us to describe the optical properties of given structures and to design new structures corresponding to clients' specifications.

Using interference lithography, surface structures with periods from 200 nm upwards can be generated at Fraunhofer ISE. The most recent developments allow the stability of the exposure unit to be controlled so well that high-contrast exposure over several hours is possible. In addition, we have investigated novel, high-resolution photoresist systems and adapted the exposure processes such that we can generate structures with particularly high aspect ratios. In this way, we can now produce sophisticated structures also over large areas.

Micro-replication procedures allow such functionalised surfaces to be applied to mass products at low cost. Anti-reflective surfaces and films with polarisation-dependent optical properties, which are produced with these procedures, are then particularly interesting for display technology.

In order to transfer new developments rapidly to the market, we have founded the company, holotools GmbH. It produces embossing tools for production.

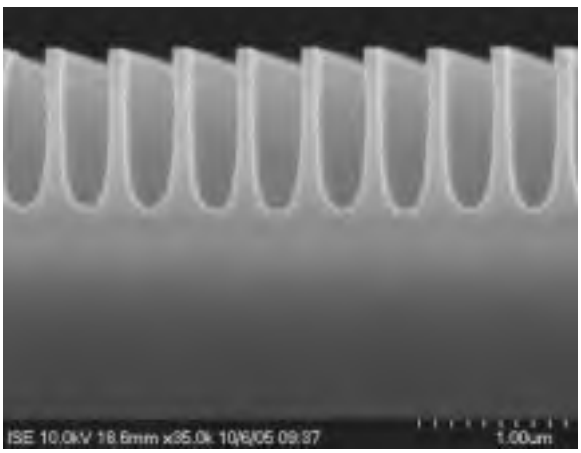


Fig. 1: Linear structure with a large aspect ratio for an application as a phase-retarding component.

Fig. 2: The interference lithography laboratory at Fraunhofer ISE. Homogeneous grating structures can be generated here over areas of up to 1.2 x 1.2 m^2.

Solar-Control Glazing based on Micro-Structured Surfaces

In summer, unshaded windows lead to high room temperatures or a high cooling energy demand, whereas in winter, sunlight can make an important contribution toward space heating. For this reason, we are developing windows with seasonal solar control, which are based on the redirection of light by micro-prisms. A micro-structured film, which is integrated into the glazing unit, ensures that rays from the high summer sun are reflected, whereas light from the lower winter sun can enter the building.

Benedikt Bläsi, Jörg Mick, **Peter Nitz**, Werner Platzer, Günther Walze, Andreas Gombert

The role of windows in the building envelope is to allow visual contact with the surroundings and to control the input of radiation in the form of light and heat into the building. Daylight reduces the need for artificial lighting, and in winter the solar radiation contributes to space heating. By contrast, too much radiation in summer results in uncomfortably high room temperatures or an increased cooling demand.

We develop seasonally effective solar-control glazing, which reflects light from the high summer sun but allows light from the lower winter sun to enter the building. This is achieved by redirection (refraction and total internal reflection) of radiation in prisms which are integrated into the glazing units in the form of a micro-structured film. Glazing units with integrated light redirection are suitable for applications in positions where an undistorted view is not absolutely necessary, e.g. in skylights or as part of translucent façade elements. Partial view and schematic representation of the surroundings are possible, however, if required.

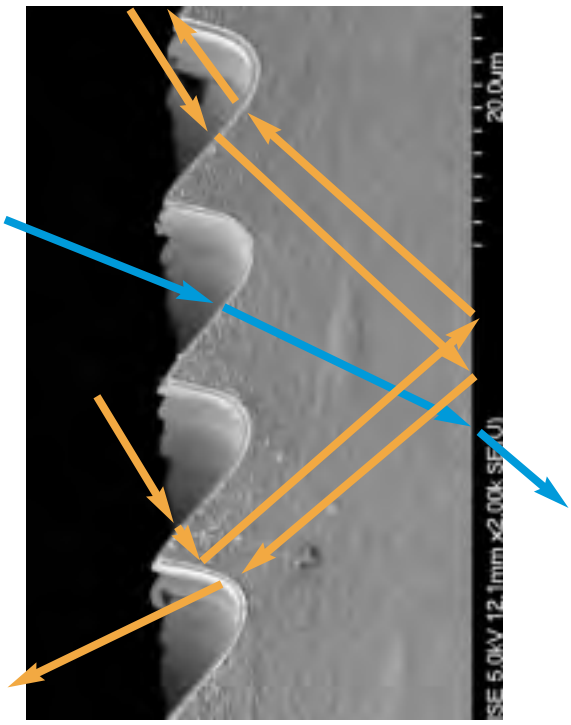


Fig. 1: Scanning electron micrograph of a prismatic structure which was produced by interference lithography. It is designed to provide seasonally dependent solar control and to scatter light, which is achieved with the visible amplitude modulation of the prisms. The ray paths for summer (red) and winter (blue) are indicated schematically.

Refraction of white light by the prismatic structures separates it into different colours. In order to reduce or avoid the effect of coloured fringes in the room, we have superimposed light scattering over the prismatic effect, so that the separated colours remix to give white light. We scatter the light by weakly modulating the period or the amplitude of the microstructures. A corresponding amplitude modulation is visible in the structure illustrated in fig. 1. The structure looks like frosted glass due to the light scattering.

The master forms for microstructures which can be manufactured by mass-replication procedures in polymers can be produced in various ways. We have compared structures generated at Fraunhofer ISE by interference lithography with those from ultra-precision tooling (e.g. diamond milling). The latter structures can be cut directly into an embossing roller, which has advantages for the replication and allows an endless film roll to be embossed without seamlines.

On the other hand, production by interference lithography allows simple modulation by superposition of a second exposure step (fig. 1). In the course of the project, a method was developed to modulate micro-mechanically produced micro-structures (fig. 2) which also cause the desired light scattering.

Thus, two different types of technology are now available, which can each be applied as appropriate to the particular specifications.

Our partners from the glazing industry succeeded in laminating structured films onto glass and then processing these into insulating glazing units. The seasonal solar-control function of the glazing prototypes is evident in the pronounced dependence of their transmittance on the angle of incidence (fig. 3). In order to transfer the results to products, we are currently co-operating with our industrial partners in investigating long-term stability and optimising production processes.

The work presented here was funded by the German Federal Ministry for Economics and Technology BMWi in a joint project with industry.

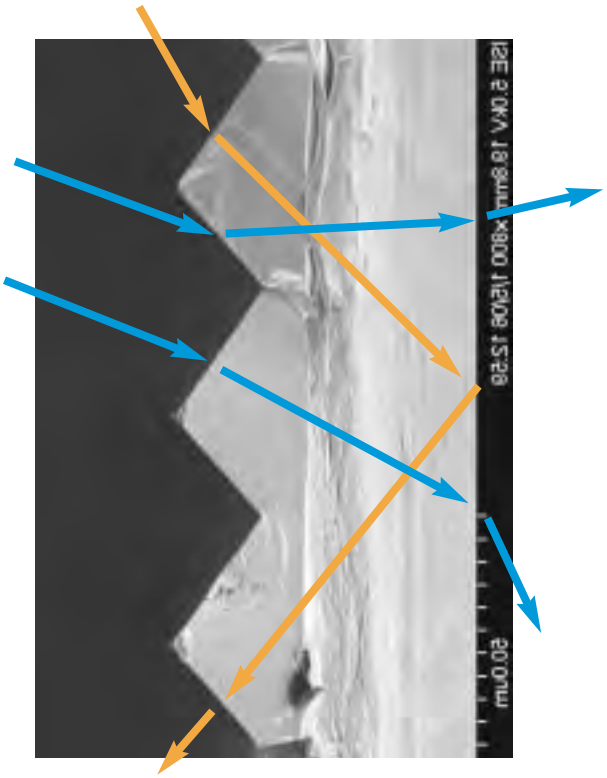


Fig. 2: Scanning electron micrograph of a micro-mechanically produced structure with a seasonal solar-control function. This structure is modulated on a length scale which is significantly longer than the structure period. For this reason, the modulation is not visible in this image. The schematic ray paths are analogous to those in Fig. 1.

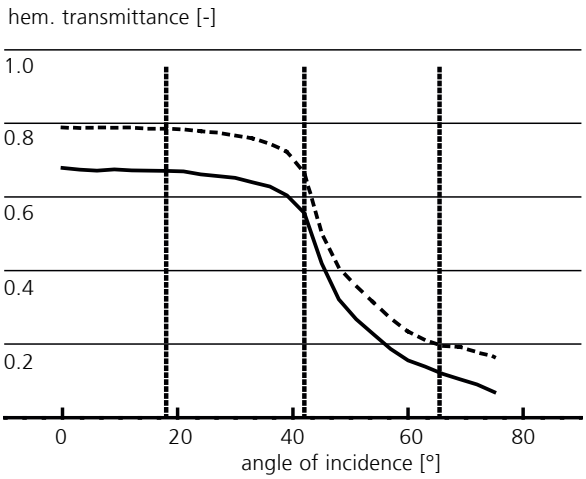


Fig. 3: Transmittance of a glazing unit offering seasonal solar control as a function of the angle of incidence in the profile plane. Measured values are shown for direct light (dashed line) and solar radiation (solid line), for a double glazed unit including the microstructure of fig. 2 (without a low-e coating). In addition, typical solar altitude values for Freiburg are indicated (18°, 42° and 66°, dotted lines).

Solar Cells

Photovoltaics has experienced a boom for more than ten years, which was encouraged particularly by the targeted market introduction programmes in Japan and Germany: The globally installed peak power capacity increased during this period from a few hundred MW to around 5 GW.

More than 90 % of the solar cells manufactured today are of crystalline silicon. The price-to-performance ratio, long-term stability and reliable predictions for further cost reduction indicate that this peak performer in terrestrial photovoltaics will continue to dominate the market for at least the next ten years.

Since the beginning of 2006, we have been operating a new service facility for the photovoltaic industry, the Photovoltaic Technology Evaluation Center PV-TEC. It was set up with funding from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU (app. 12 million euros) and the Fraunhofer-Gesellschaft (2 million euros). Research, development and service are offered to the photovoltaic industry on a new dimension, namely production scale, taking advantage of the laboratory area of 1200 m^2. Flexible automation of processing stations makes statistically relevant experiments feasible, with a throughput of up to 1000 wafers per hour, wafer edge dimensions up to 210 mm and wafer thicknesses well under 200 µm.

Since November 2006, the cell production line of PV-TEC has been complemented by the ISE prototype module production laboratory. The production laboratory allows new cells and materials to be processed in industrially relevant quantities and formats. Processing steps and systems technology for module production are developed up to the preliminary stage of mass production. The core equipment includes a flexible tabber-stringer and a laminator, accompanied by a selection of measurement and testing systems.

In order to reduce consumption of the relatively expensive starting material, which is currently in short supply (further production capacity is only now being installed), the silicon wafers are becoming thinner and thinner. Despite this, we are achieving equally high, or even higher, efficiency values by appropriately adapting the cell structure. We are leading the way in producing high-performance solar cells of extremely thin, flexible 40 µm wafers, which can already be processed completely in our pilot line. We are also working on processes to produce thin wafers directly.

Concerning the crystalline thin-film solar cell, we have intensified our research on the concept of a wafer equivalent. A high-quality thin film is deposited from gas containing silicon onto inexpensive substrates. The result looks like a wafer and can be processed into a solar cell in exactly the same way in conventional production lines. The silicon-containing gas is available in practically unlimited quantities. The experimental results are extremely promising.

The second type of material we investigate is the III-V class of semiconductors such as gallium arsenide. At present, it is still associated with a special market that can be summarised by the keywords, space, optical concentrators and special applications. We are working on radiation-resistant tandem and triple-junction cells for extra-terrestrial applications. For terrestrial use, we are developing concentrator cells for the highest optical concentration factors. With our most recent spin-off company, Concentrix Solar GmbH, we will be introducing our extremely efficient FLATCON® concentrator technology to the market within the next two years.

Dye and organic solar cells represent a third class of materials. In particular, the technology for dye solar cells has developed well beyond the laboratory scale over the last few years. We were able to demonstrate that modules of dye solar cells can be produced with industrially relevant technology such as screen-printing and new sealing technology. However, long-term stability and the upscaling of this technology to module areas exceeding 0.5 m^2 must still be demonstrated. Organic solar cells, which are currently at the basic research stage, will open up new application areas due to various special properties including their mechanical flexibility. As their production costs should be intrinsically low, they are suitable voltage sources for products with short lifetimes. Combined with printed organic electronic circuits, they offer an interesting possibility for integration into packaging materials and textiles. Now that we have extended our theoretical understanding and installed an automated characterisation line, we can optimise the efficiency and cost-effective production of these novel cells.

Solar cells must be protected against the environment by encapsulation with durable materials, an area which still exhibits considerable potential for improving the quality and reducing costs. We are working on new module concepts and materials combinations also for thinner and larger solar cells, as well as those with contacts only on the back surface. Deeper understanding of ageing mechanisms and procedures to characterise them play a key role in our contribution toward increasing the long-term quality of photovoltaic modules.

Our solar cell activities in Freiburg are complemented by the Fraunhofer ISE Laboratory and Service Centre in Gelsenkirchen and the Technology Centre for Semiconductor Materials THM in Freiberg, Saxony, which is operated jointly with Fraunhofer IISB.

Solar Cells

1 kW demonstration system of a PV concentrator system equipped with FLATCON® modules. FLATCON® concentrator systems focus sunlight with the help of lenses onto tiny high-performance solar cells based on III-V semiconductors. The modules are mounted on a two-axis system to track the sun. This year, a pilot production plant to produce the module base plates was set up at Fraunhofer ISE. The technology, which was developed at Fraunhofer ISE, is currently being transferred to production by Concentrix Solar GmbH, an ISE spin-off company. In 2007, a 500 kW power station will be constructed in the Spanish province of Castilla La Mancha.

Contacts

Wafer technology	Dr Achim Eyer	Tel.: +49 (0) 7 61/45 88-52 61 E-mail: Achim.Eyer@ise.fraunhofer.de
Crystalline silicon high-efficiency solar cells	Dr Stefan Glunz	Tel.: +49 (0) 7 61/45 88-51 91 E-mail: Stefan.Glunz@ise.fraunhofer.de
	Dr Daniel Kray	Tel.: +49 (0) 7 61/45 88-53 55 E-mail: Daniel.Kray@ise.fraunhofer.de
	Dr Oliver Schultz	Tel.: +49 (0) 7 61/45 88-52 65 E-mail: Oliver.Schultz@ise.fraunhofer.de
Crystalline silicon thin-film solar cells	Dr Stefan Reber	Tel.: +49 (0) 7 61/45 88-52 48 E-mail: Stefan.Reber@ise.fraunhofer.de
Solar cell processing technology / PV-TEC	Dr Ralf Preu	Tel.: +49 (0) 7 61/45 88-52 60 E-mail: Ralf.Preu@ise.fraunhofer.de
	Dr Daniel Biro	Tel.: +49 (0) 7 61/45 88-52 46 E-mail: Daniel.Biro@ise.fraunhofer.de
	Dr Jochen Rentsch	Tel.: +49 (0) 7 61/45 88-51 99 E-mail: Jochen.Rentsch@ise.fraunhofer.de
	Dr Stefan Rein	Tel.: +49 (0) 7 61/45 88-52 76 E-mail: Stefan.Rein@ise.fraunhofer.de
Concentrator technology	Dr Andreas Bett	Tel.: +49 (0) 7 61/45 88-52 57 E-mail: Andreas.Bett@ise.fraunhofer.de
III-V solar cells and epitaxy	Dr Frank Dimroth	Tel.: +49 (0) 7 61/45 88-52 58 E-mail: Frank.Dimroth@ise.fraunhofer.de
Dye and organic solar cells	Dr Andreas Gombert	Tel.: +49 (0) 7 61/45 88-59 83 E-mail: Andreas.Gombert@ise.fraunhofer.de
Characterisation of solar cells and materials	Dr Wilhelm Warta	Tel.: +49 (0) 7 61/45 88-51 92 E-mail: Wilhelm.Warta@ise.fraunhofer.de
Photovoltaic modules	Dr Harry Wirth	Tel.: +49 (0) 7 61/45 88-51 93 E-mail: Harry.Wirth@ise.fraunhofer.de
Laboratory and Service Centre, Gelsenkirchen	Dr Dietmar Borchert	Tel.: +49 (0) 2 09/1 55 39 -11 E-mail: Dietmar.Borchert@ise.fraunhofer.de
Technology Centre for Semiconductor Materials THM, Freiberg	Prof. Roland Schindler	Tel.: +49 (0) 7 61/45 88-52 52 E-mail: Roland.Schindler@ise.fraunhofer.de

Interdisciplinary Co-ordination

Solar cells	Prof. Gerhard Willeke	Tel.: +49 (0) 7 61/45 88-52 66 E-mail: Gerhard.Willeke@ise.fraunhofer.de
Optical components and systems	Dr Andreas Gombert	Tel.: +49 (0) 7 61/45 88-59 83 E-mail: Andreas.Gombert@ise.fraunhofer.de

Wire-Sawing of Thin Multicrystalline Silicon Wafers

The market for solar modules is currently experiencing price rises, partly due to increased demand, partly due to higher costs for the raw material, silicon. One approach to counteract this development is to enlarge the solar wafer area gained per block of crystalline silicon. We are optimising wire-sawing technology with the aim of preparing high-quality and thin silicon wafers. This is a major challenge, particularly for multicrystalline material, as the breakage rate may not be increased in the process.

Dominik Barucha, Markus Bergmann, Philipp Ettle, Achim Eyer, **Daniel Kray**, Kuno Mayer, Teresa Orellana, Akhil Ravi, Mark Schumann, Gerhard Willeke

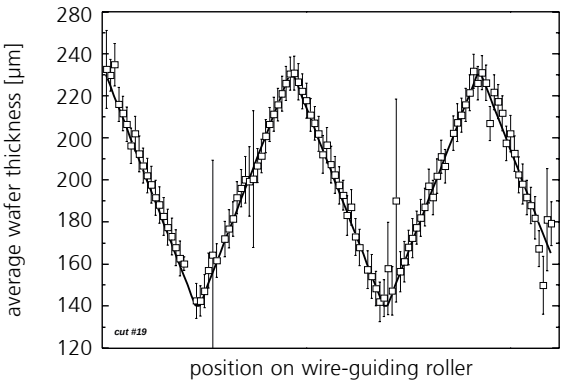


Fig. 1: Using different wire pitches on the wire-guiding rollers, we have succeeded in producing neighbouring wafers with varying thicknesses. It was then possible to cut wafers with thicknesses between 140 and 250 µm, e.g. for tests of solar cell concepts on multi-crystalline material. In the graph, the measured average wafer thicknesses are plotted as a function of the wafer position on the wire-guiding rollers. The intended wafer thicknesses, which are indicated by the solid line, were achieved nearly in all cases.

Fig. 2: If gentle processes are applied to materials which have little internal strain, extremely thin wafer thicknesses can be achieved. Thus, we succeeded in demonstrating a minimum wafer thickness of 70 µm for wafers with an area of 125 x 125 mm^2. The suitability of these processes for industrial production must now be tested.

More than half of the current solar cell production is based on multi-crystalline silicon wafers as the raw material. The standard thickness of solar cells in production is currently 240 – 270 µm. With the goal of reducing costs, the industry aims to reduce the solar cell thickness significantly. However, it is necessary to optimise the wire-sawing technology used if still thinner wafers are to be produced, allowing the implementation of modern concepts for solar cells. With this target, we at Fraunhofer ISE are wire-sawing samples with small wire diameters and pitches.

To evaluate the wafer properties as a function of thickness, we use wire-guiding rollers with different wire pitches, so that neighbouring wafers with different thicknesses can be cut (fig. 1). With the aid of this procedure, we succeeded in cutting adjacent wafers with thicknesses between 140 and 250 µm. We observed that the scatter in wafer parameters did not increase as the thickness was reduced. As the properties of multi-crystalline material depend strongly on position (e.g. the diffusion length), these sets of wafers represent an important precondition for carrying out materials investigations or tests of solar cell concepts.

With the objective of producing solar cells with the highest efficiency values on increasingly thin wafers – particularly of multi-crystalline material – we are also conducting research on the minimum feasible wafer thickness. By applying a suitably adapted process, we have already succeeded in producing wire-sawn wafers with an area of 125 x 125 mm^2 and a thickness of only 70 µm (fig. 2).

Generation of Local High Doping by LCE Processes

Novel solar cell concepts demand efficient and flexible micro-structuring processes. The process of Laser Chemical Etching (LCE), which we have developed, can stimulate new approaches for local high doping, e.g. to produce a selective emitter.

Achim Eyer, Andreas Fell, Sybille Hopman, Takuro Kato, **Daniel Kray**, Kuno Mayer, Matthias Mesec, Christoph Ziegler, Gerhard Willeke

Highest-efficiency solar cells feature so-called selective emitters, i.e. different doping profiles under the contacts and over the non-metallised areas. These reduce the contact resistance between silicon and the metal, and raise the open-circuit voltage of the solar cell. Up to now, selective emitters could only be produced with complex, multiple-step processes. By using etching liquids containing phosphorus in our LCE process, we have found a way to carry out micro-structuring and simultaneous strong doping with phosphorus in a single step. With the aid of emission SRI (sheet resistance imaging), we proved that local high doping can be achieved with LCE (fig. 1). The sheet resistance of the doped areas can be varied between 15 and 40 Ω/sq by adjusting the laser parameters. As a reference, we tested the water-jet guided laser and measured the results. Micro-structuring with little damage was possible, but no doping (fig. 2). As the LCE process offers great flexibility with regard to the doping liquid and the laser parameters, we can greatly simplify the generation of a selective emitter and prior micro-structuring of an anti-reflective layer on the front surface of a solar cell. In addition, we expect that by adapting the surface emitter of the solar cells, it will be possible to significantly raise the blue response and thus the total efficiency.

Fig. 1: Emission SRI image of groups of three identical LCE grooves, each group produced with a different laser power. Lighter colours indicate higher local doping levels. Local high doping can be achieved by using etching chemicals containing phosphorus in LCE with varying laser energy values. Depending on the choice of parameters, we have already measured sheet resistance values between 15 and 40 Ω/sq. In comparison to fig. 2, the doping can be clearly attributed to the etching fluid containing phosphorus.

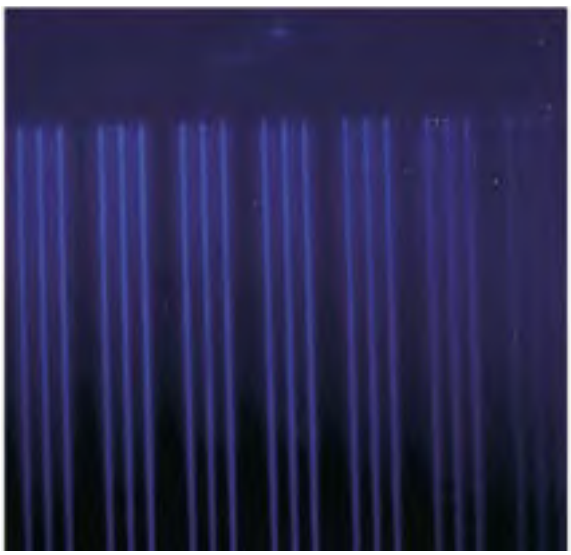


Fig. 2: Emission SRI image of a sample prepared analogously to that in fig. 1, but using water as the laser-guiding medium. It is not possible to achieve doping. The lighter colour only indicates the low-damage micro-structuring of the grooves.

In Situ Epitaxy of Emitters for Crystalline Silicon Thin-Film Solar Cells

Emitters for solar cells, typically the "n" layer of the "pn" diode structure of the solar cell, are almost always produced by diffusion at present. At Fraunhofer ISE, we have investigated a significantly more rapid and flexible process for producing emitters: chemical vapour deposition of silicon. In only a tenth of the typical processing time, we can produce emitters which are of comparable quality to the references with emitters produced by diffusion.

Evelyn Schmich, Norbert Schillinger, Mira Kwiatkowska, Fabian Trenkle, Jochen Hees, Harald Lautenschlager, **Stefan Reber**, Gerhard Willeke

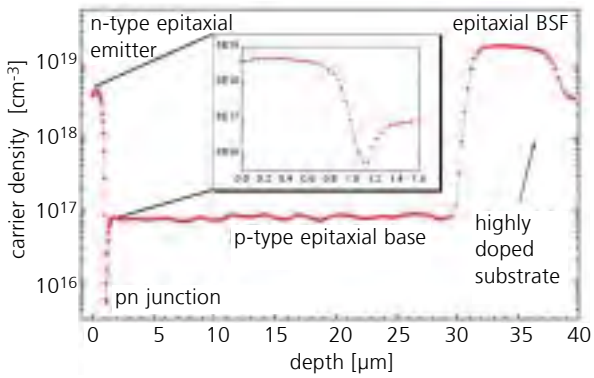


Fig. 1: Doping profile of a crystalline silicon thin-film solar cell grown epitaxially in situ. In the insert, the box-shaped profile of the emitter can be clearly seen, which ensures the best possible properties for the solar cell.

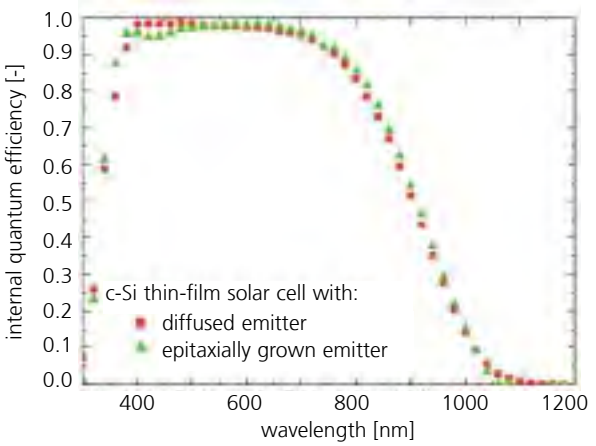


Fig. 2: Internal quantum efficiency of the solar cell characterised in fig. 1, compared to the conventionally diffused reference. There is practically no difference between the two curves, i.e. the charge collection properties of both solar cells are almost identical.

When an emitter is produced by diffusion in silicon, the laws of diffusion determine the result: the concentration profile is clearly determined by the temperature, processing time and concentration of the source. If a short processing time is used, as is desirable for production, the resulting emitter is not optimal, because the doping concentration is very high. By contrast, if an optimal, "box-shaped" emitter with a depth of 1 µm is diffused, the processing time of more than an hour is uneconomically long. In addition, a portion of the dopant source always remains on the surface and can only be removed by additional processes. In order to meet this challenge innovatively, we applied the process of epitaxial chemical vapour deposition (CVD). We have already used this process for many years to produce the base ("p layer") of crystalline silicon thin-film solar cells.

With a typical deposition rate of 5 µm per minute, only a few seconds are needed to deposit an optimal emitter with any desired doping type and concentration. Practical application initially demonstrated that it is feasible to deposit thin silicon layers with a box-shaped profile for emitters in CVD equipment for photovoltaics. The equipment could be used both for highly efficient solar cells from silicon wafers and also for crystalline silicon thin-film solar cells. For the latter application, we produced pn structures in situ with a very good doping profile, as fig. 1 illustrates. Solar cells made with these structures displayed very good performance: The best open-circuit voltage of 646 mV for the cells exactly equals that of the conventionally diffused reference, and the efficiency value of 14.8 % is similar to the value of 14.9 % for the reference. Figure 2 demonstrates that the reference and the epitaxially grown emitter are also characterised by equivalent internal quantum efficiency values. However, the latter emitter requires only a tenth of the processing time, without a further etching step.

Part of the work has been supported within the framework of the EU-funded "Crystal Clear" project.

Physical Vapour Deposition for Crystalline Silicon Solar Cells

Physical vapour deposition (PVD) processes have long been used in the laboratory for contacting highly efficient solar cells. At Fraunhofer ISE, we have now demonstrated that these processes meet the requirements for cost-effective implementation in industrial production.

René Bergander, Jan Catoir, Gernot Emanuel, Frank Fleischhauer, Stefan Glunz, Andreas Grohe, Jürgen Kamerewerd, **Ralf Preu**, Philipp Richter, Oliver Schultz, Winfried Wolke, Gerhard Willeke

Most industrially produced solar cells of crystalline silicon have contacts made from metal-containing pastes. These are applied in a screen-printing process and then briefly heated to create a conductive semiconductor-metal contact. A paste containing aluminium is alloyed into the back of the solar cell to create a layer which increases the doping concentration of the silicon wafer to the extent that the surface is significantly passivated.

By contrast, we apply physical vapour deposition processes to deposit the metal contacts onto highly efficient laboratory solar cells. On the back of the solar cell, an approximately 0.1 µm thin dielectric film is deposited, which acts as an excellent passivator and reflector for the surface, before an approximately 2 µm thick aluminium coating is deposited. The actual contact itself is created by local alloying of the aluminium with high-energy laser pulses. With the goal of implementing this contacting process, we have investigated the boundary conditions for industrial application of three PVD processes suitable for in-line production: sputtering, thermal evaporation and electron-beam evaporation. By producing high-efficiency solar cells, we were able to demonstrate that efficiency values of 21 % can be attained with all three processes. Furthermore, we proved that the use of very high deposition rates and relatively impure aluminium did not affect the solar cell performance negatively. Due to the significantly smaller amount of material in the deposited coatings, the material costs can also be clearly reduced in comparison to the aluminium-containing pastes.

The work was carried out in co-operation with our project partners, Applied Materials GmbH in Alzenau and Deutsche Cell GmbH in Freiberg, within the framework of the INKA project, which is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU.

back surface	V_{OC} [mV]	J_{SC} [mA/cm²]	FF [%]	η [%]
electron beam	675±5	39.4±0.3	78.5±2.3	20.9±0.8
thermal	677±3	39.4±0.3	78.4±1.0	20.9±0.5
sputtered	669±1	39.0±0.4	78.8±0.5	20.6±0.3

Fig. 2: Characteristic curve data from high-efficiency solar cells for the investigated PVD processes. All processes achieve approximately the same high efficiency level of about 21 %.

Fig. 1: Sputtering system for in-line deposition of aluminium and silicon nitride.

New Processes for Producing Solar Cell Contacts

The technology most commonly used in the solar cell industry to produce the front-surface contacts is screen-printing with metal-containing pastes. Although the process is robust, it has major drawbacks with regard to the solar cell quality, with the contact fingers being too broad, the contact resistance high and the conductivity low. Thus, the goal of extensive research activity at Fraunhofer ISE is to develop new production processes which can be applied industrially and yet still offer the potential for high cell efficiency.

Monica Aleman, Aleksander Filipovic, **Stefan Glunz**, Matthias Hörteis, Anke Herbolzheimer, Ansgar Mette, Peter Regenfuß*, Philipp Richter, Christian Schetter, Oliver Schultz, André Streck*, Gerhard Willeke

* Laserinstitut Mittelsachsen, Mittweida

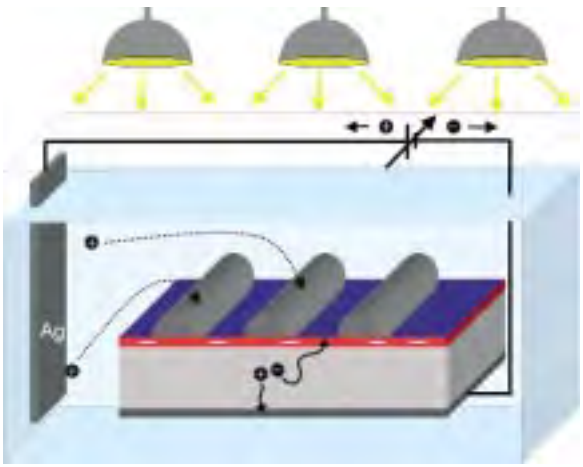


Fig. 1: Operating principle of light-induced plating. The solar cell and the silver anode (left) are located in an electrolytic bath. The back surface of the solar cell is connected to a protective potential with respect to the silver anode. By illuminating the solar cell, an additional negative voltage is generated at the front-surface contact grid, so that positive silver ions are deposited here and reinforce the contact grid. This process is considerably simpler to implement industrially than direct contacting of the fine front-surface contact grid.

After evaluating various metallisation concepts, it became evident that the potential for high efficiency is very limited if the entire contact structure on the front surface of the solar cell is applied in a single step. By contrast, the following two-step process is much more promising and forms the basis for all of the processes developed at Fraunhofer ISE.

Deposition of a contact metal with a novel process

This contact line ensures good mechanical adhesion and good electrical contact to the emitter layer of the solar cell. Further, it serves as a "nucleation line" for the following electro-plating steps.

Reinforcing the contact line with a electro-plating process

Electro-plating reinforcement of the thin contact lines greatly reduces the linear resistance of the contact fingers. So-called light-induced plating is the technology which Fraunhofer ISE applies for this step. It makes use of the photovoltaic effect of the solar cell (fig. 1) and is simple to implement industrially.

By dividing the process into two steps, we can use the optimal configuration (metal, geometry, etc.) for each specific "task" (contact formation and conductivity). This two-step process is the basis for contacting high-efficiency solar cells at Fraunhofer ISE, e.g. the world-record cell of multicrystalline silicon.

To produce the nucleation layer, we have developed four promising types of technology:

- pad-printing with screen-printing pastes
- contact-free metal aerosol printing (MAP)
- nickel deposition on surfaces with locally perforated dielectric layers
- local laser melting of metal powders (LAPO)

In the MAP process, a metal aerosol is created from a screen-printing paste. This metal aerosol is directed onto the solar cell through a specially designed printing nozzle (fig. 2). The metal aerosol is surrounded by a focussing gas sheath, which prevents the metal aerosol from coming into contact with the nozzle walls and clogging the printing jet. Furthermore, this focussing allows structures to be printed, which are about a factor four smaller than the jet diameter. In this way, we have already succeeded in preparing line widths of less than 50 µm with standard screen-printing pastes. With the classic ink-jet printing process, this would inevitably result in the printing nozzle becoming clogged. The solar cells prepared in this way had a significantly better efficiency value than that of solar cells prepared in parallel with standard screen-printing, due to the reduced shading by the contact fingers.

In the LAPO technique, a metal powder is spread over the solar cell surface, which is then melted by a laser along the required lines (fig. 3). The remaining powder is then removed and can be recycled. By optimising the laser parameters in co-operation with the Laserinstitut Mittelsachsen in Mittweida, we were able to reduce the damage to the solar cell structure, particularly the pn junction located just under the surface, to a minimum. In this way, we achieved fill factors exceeding 78 %. It is particularly noteworthy that contacts were also made successfully to solar cells with a surface structure and dielectric surface passivation.

The work presented here was supported to a large extent by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU within the KonVoi project.

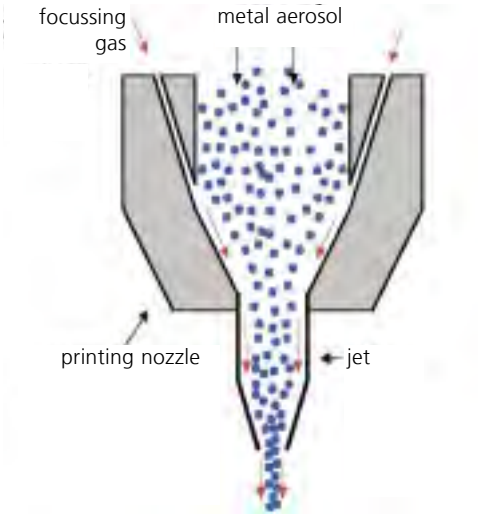


Fig. 2: Printing nozzle for metal aerosol printing (MAP). The metal aerosol is focussed by a gas sheath. It prevents the relatively large metal particles from coming into contact with the inner surfaces of the printing nozzle. The dimensions of the printed structures are a factor 4 smaller than the jet diameter.

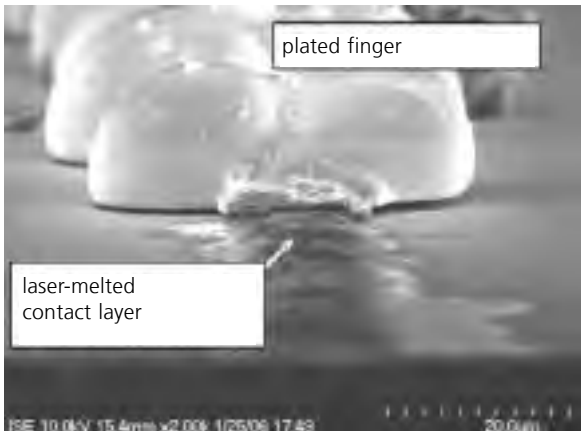


Fig. 3: Scanning electron micrograph of a metal nucleation layer, which was created by laser-melting a metal powder (LAPO). In the upper part of the image, the thicker contact is visible. It has been reinforced by light-induced plating.

Industrially Producible, Highly Efficient Silicon Solar Cells

Although silicon solar cells with efficiency values exceeding 20 % have already been produced on a laboratory scale for several decades, they play only a minor role in industrial production. However, cost calculations clearly show that increasing the efficiency – particularly in the context of the current silicon prices dictated by the market – is imperative if the electricity generating costs are to be reduced.

Stefan Glunz, Filip Granek, Daniela Grote, Andreas Grohe, Christian Harmel, Martin Hermle, Annerose Knorz, Norbert Kohn, Antonio Leimenstoll, Ralf Preu, Philipp Richter, Sonja Seitz, **Oliver Schultz**, Gerhard Willeke

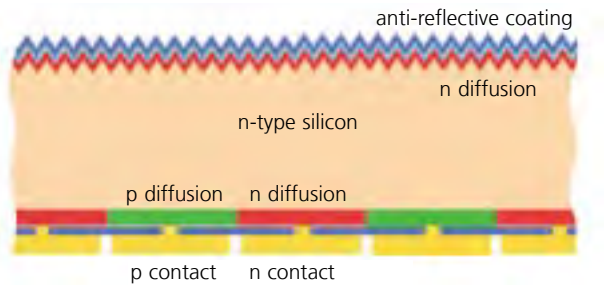


Fig. 1: Structure of a back-surface contact solar cell. Both positive and negative contacts are located on the back surface of the cell. The front of the cell is textured and covered with an anti-reflective coating to improve the coupling of light into the cell.

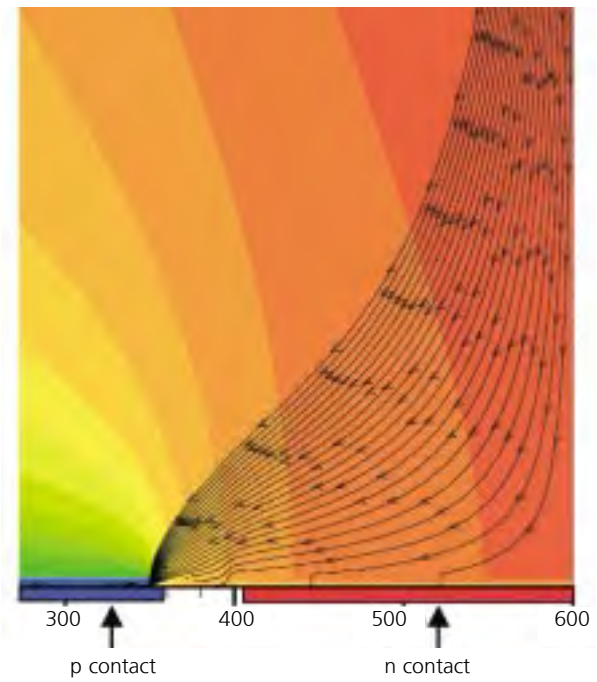


Fig. 2: Detail of a two-dimensional numerical simulation of the hole current flow (arrows) and the distribution of the quasi Fermi levels (colours) in a back-surface contact solar cell.

A particularly elegant type of high-efficiency solar cell is that with purely back-surface contacts, in which both the negative and the positive contacts are located on the back surface (fig. 1). These cells are distinguished by an aesthetically attractive appearance, a high efficiency value and simple module circuitry. However, the separation of the p-doped and n-doped zones is much more complex than for standard solar cells. The development of the associated structuring technology was one of the main challenges in a research project to develop an industrially producible, highly efficient, back-surface contact solar cell. On the one hand, the goal is to achieve a high efficiency value but on the other hand, the cell production should be sufficiently cost-effective for industrial manufacturing, a condition which excludes photolithographic processes, for example.

One decisive criterion is the minimum structure dimension which can be achieved. Stated simply: The finer the structures, the greater the potential for high efficiency, but also the greater the process complexity. In order to quantify the minimum resolution needed, we started by carrying out two-dimensional simulations (fig. 2). The results obtained indicated that it is particularly effective to use a laser for structuring the p-doped and n-doped zones on the back surface. However, an important specification for the laser process is that it should not cause any damage to the silicon. With a process that was optimised to comply with these boundary conditions, we were able to prepare a solar cell of Czochralski silicon with purely back-surface contacts and an efficiency value of 21 %, without applying photolithographic steps.

These results were obtained in co-operation between Fraunhofer ISE, the Institute for Solar Energy Research (ISFH) in Hameln and the company, Q-Cells AG. The project is supported financially by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU, as well as Q-Cells AG.

Contacts for Thin Solar Cells

With wafer thicknesses of less than 200 µm and increasing cell currents, it is becoming increasingly demanding to produce suitable contacts for solar cells. We are developing technology that is intended to minimise the mechanical load on the cells during production and operation. In November 2006, our new prototype module production unit started operation. It complements the cell production of the Photovoltaic Technology Evaluation Center PV-TEC.

Harry Wirth, Marco Tranitz,
Andreas Gombert

The contacting process for solar cells plays a decisive role for the yield and the durability of a PV module. Particularly for thin cells, weaknesses in process control or the materials design can lead to higher cell breakage rates.

We are investigating new, gentler contacting methods, which introduce less strain to the contact zones and the cell material. Laser-soldering offers one interesting option. With its localised, well-dosed application of heat, it is possible to reduce thermo-mechanical strain between the cell connectors and wafers. In addition, the high power allows short processing times per soldered point. Figure 1 shows a cell string prototype with cell connectors that were soldered to the cells with a laser.

In November 2006, the new prototype production unit for photovoltaic modules was commissioned at Fraunhofer ISE. Figure 2 shows an interior view. With the prototype production unit, we can fill the gap between laboratory development and industrial production technology. We support our clients in the testing and further development of their products, be it new cells, materials or processing steps. In the module prototype production unit, sufficiently large numbers and sizes of modules can be processed to obtain industrially relevant information. The knowledge gained can be immediately transferred to industrial series production. The central equipment in the prototype production unit includes a tabber-stringer from the Somont company with fully automated and experimental lines, a laminator and various analytical facilities for quality control (fig. 2).

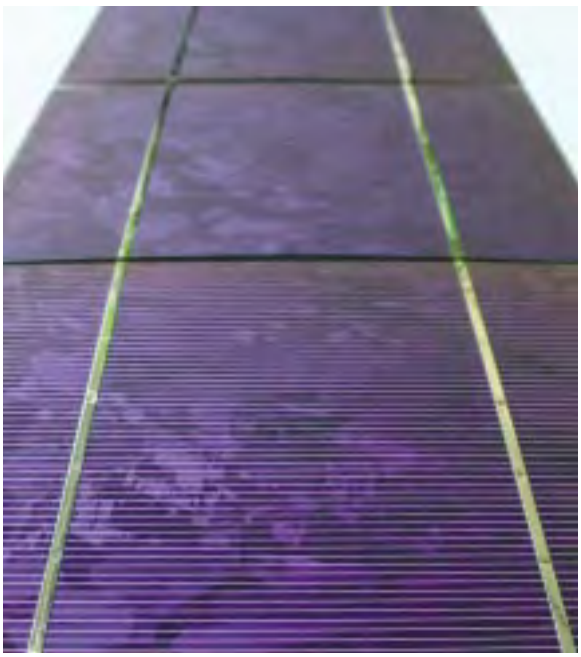


Fig. 1: Laser-soldered cell string with 156 mm cells from the PV-TEC production line.

Fig. 2: Prototype production unit for photovoltaic modules with the tabber-stringer (in the foreground) and the laminator (left).

Photovoltaic Technology Evaluation Center PV-TEC

The Photovoltaic Technology Evaluation Center PV-TEC has been operating fully since March 2006. Equipped with the most modern processing and analytical facilities over a laboratory area of 1200 m², the centre offers a wide range of services. For the first time in photovoltaic research, it is possible here for complex experiments to be combined with a high system throughput. The centre offers its research services to manufacturers of solar cells, equipment and materials, as well as to research institutions.

Daniel Biro, Ralf Preu, Gernot Emanuel, Stefan Glunz, Stefan Rein, Ingo Brucker*, Jochen Rentsch, Clemens Faller, Thomas Faasch, Norbert Kohn*, Udo Belledin*, Heike Furtwängler*, Christian Harmel, Denis Erath, Martin Zimmer, Florian Clement, Nicola Mingirulli, Albrecht Weil*, René Bergander, Andreas Grohe, **Gerhard Willeke**

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Fig. 1: Extremely modern production facilities are available in PV-TEC. The basic equipment includes: Multi-functional wet-chemical batch-processing facility, in-line texturing system, tube diffusion/oxidation, plasma-enhanced chemical vapour deposition (PECVD), sputtering equipment, screen-printing line, laser system, solar cell tester and solar cell sorter. High-speed, in-line measurement instruments are integrated into the equipment.

The demand for R&D services concerning production technology for solar cells has increased very strongly over the last few years. In particular, there is great interest in research work which can be applied directly to production.

For this reason, Fraunhofer ISE organised a workshop in October 2004, to which all larger companies involved in the photovoltaic industry were invited. The object of the workshop was to gather the requirements on a new research centre which was to be tailored to the needs of the PV industry. To allow the financial framework for the intended research services to be estimated, the participating companies were also requested to provide non-binding statements of intent as a complement to the workshop. The industry indicated the potential for annual commissions totalling more than two million euros.

With these boundary conditions, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU granted 12 million euros to Fraunhofer ISE for initial equipment of the centre. The Fraunhofer-Gesellschaft contributed a further two million euros for infrastructural measures. At the end of 2005, the new "Photovoltaic Technology Evaluation Center PV-TEC" was taken into operation. It is located in the Solar Info Center, Freiburg, close to the main building of Fraunhofer ISE. In March 2006, the centre was officially opened in the presence of Sigmar Gabriel, the German Federal Minister for the Environment. The extremely high demand for services from PV-TEC confirms our expectations that establishing such a centre would significantly accelerate technological transfer from the laboratory to the expanding solar industry.

The concept on which the new centre is based consists of several levels. The foundation is an automated basic processing chain with a capacity of 200 to 1000 wafers per hour. The processes which it includes serve as a reference for comparison with new technology, processing sequences or materials. All of the facilities were equipped with innovative components in addition to those needed for the basic processing chain, so that there are extensive opportunities to conduct R&D. The complete processing chain is designed for wafer formats with an edge length of 125, 156 or 210 mm.

In addition to the basic processing chain, PV-TEC has unoccupied areas available, where clients can arrange for equipment to be installed temporarily so that process development can occur on site.

Characterisation is an essential component of the services offered by PV-TEC. Thus, it not only offers a comprehensively equipped characterisation laboratory, but various characterisation instruments are also integrated into the automated processing chains, so that rapid, in-line characterisation is possible.

The services offered by PV-TEC include:
- process development and technology evaluation
- production and characterisation of solar cells and semi-finished products
- quality testing of silicon and other materials
- training of external personnel

Fig. 2: Various high-resolution measurements can be carried out in the PV-TEC characterisation laboratory. The most important types of measurement are: infra-red multi-functional measurement, large-area determination of the external quantum efficiency, spatially resolved lifetime measurement, sheet and contact resistance topography, reflectance spectroscopy. In-line measurement instruments are integrated into the processing facilities.

Fig. 3: Equipment for different types of coating technology is available (PECVD, sputtering, thermal oxidation). The numerous processes specifically include methods for depositing silicon nitride, silicon oxide, amorphous silicon and aluminium.

Fig. 4: The wet-chemical cluster consists of in-line and batch-processing multi-purpose systems, as well as a chemicals supply module. Innovative functions such as single-sided etching are included as well as the standard etching processes for monocrystalline and multicrystalline silicon. The accompanying analytical methods include titration, chromatography, infrared and ultraviolet spectroscopy.

High-Resolution Short-Circuit Current Topography at the Laboratory and Service Centre in Gelsenkirchen

In our Laboratory and Service Centre in Gelsenkirchen, we have set up an LBIC system to measure the internal quantum efficiency (IQE) at a wavelength of 830 nm with a spatial resolution of 6 µm. LBIC is the abbreviation for "light beam induced current". The system is used to accurately quantify the effect of solar cell defects, such as grain boundaries, dislocations or impurities, which reduce the cell efficiency. This allows us to investigate the specific influence of solar cell production parameters on individual defects.

Dietmar Borchert, Daniel Dopmeier, Martin Hermenau, Stefan Müller, Maik Pirker, **Markus Rinio**, Marco Rossow, Kathrin Schmidt, Mark Scholz, Christian Staubach, Gerhard Willeke

We apply the LBIC (light beam induced current) method to identify the position of defects which reduce solar cell efficiency. In this method, the solar cell is scanned, line by line, with a laser beam, and the generated short-circuit current is recorded simultaneously as a function of the beam position. After careful calibration, this current value is used to calculate the external quantum efficiency, which corresponds to the proportion of incident photons converted to electricity by the solar cell.

The equipment set up in Gelsenkirchen (fig. 1) also includes a sophisticated set of reflection detectors, which additionally provide a topogram of the solar cell reflectance. The two sets of results are then used to calculate a topogram of the internal quantum efficiency IQE (fig. 2), which corresponds to the proportion of photons within the cell which are used.

The measurement of a topogram with typically 500 x 500 points lasts about 2 hours for a spatial resolution down to 6 µm. Solar cells with an area of approximately 30 x 30 cm^2 can be measured. The high spatial resolution makes it feasible to measure the effect of selected solar cell processing steps on individual types of defects in the raw material. We offer these measurements as a service of the Laboratory and Service Centre in Gelsenkirchen.

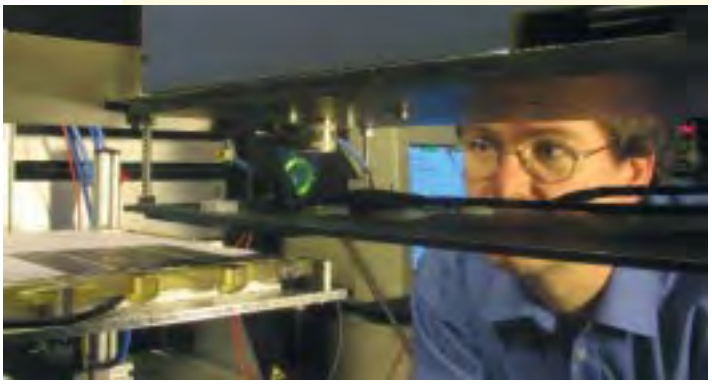


Fig. 1: LBIC system to measure the internal quantum efficiency of solar cells with a spatial resolution down to 6 µm. The solar cell sample (at the left of the photo) is scanned, line by line, with a laser beam. The reflectance of the sample at the different positions is measured simultaneously with several detectors (at centre of photo).

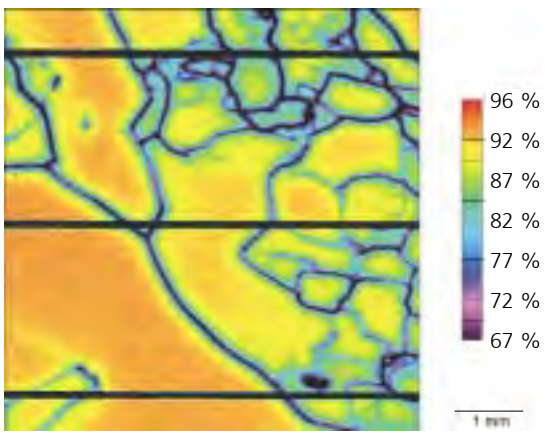


Fig. 2: Topogram of the internal quantum efficiency of a multicrystalline solar cell for a wavelength of 830 nm. The dark curved lines correspond to grain boundaries at which the photon yield is reduced. The dark patches between the lines indicate electrically active dislocation clusters. The three horizontal lines indicate the contact fingers of the solar cell.

Quality Control of Silicon Starting Material by Investigation of the Trap Distribution

We are pursuing a new approach to predict the later performance of a completely processed solar cell from the quality of the multicrystalline starting material. Up to now, there were limitations on such predictions because, depending on its local properties, the silicon material was strongly modified during the solar cell process. With the trap distribution, which we record with the help of an IR camera, we have now identified a parameter in the starting material which correlates with the areas of the cell that limit the efficiency value.

Martin Schubert*, **Wilhelm Warta,** Gerhard Willeke

* Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität Freiburg

The diffusion length of minority charge carriers in solar cells is a determining factor for their efficiency. It can be determined with the spectrally resolved light beam induced current (SR-LBIC) method (Fig. 2).

To date, determination of the carrier lifetimes in the starting material was the only method available to estimate the diffusion length in the subsequent solar cell from the properties of the silicon starting material. The preparation steps for this method are complex and time-consuming. In addition, it became evident that the lifetime was strongly changed by the various processing steps to produce the solar cell.

With the help of the carrier density imaging (CDI) method, we can gain a measure for the trap distribution in the starting material with a short measurement time and no special sample preparation (fig. 1). Traps are temporarily occupied by charges, so that they generate a measurement signal but do not cause recombination. For a well-defined process and comparable material, this measurement on the starting material can be used to predict the diffusion length in the solar cell (fig. 3). In particular, the areas with a short diffusion length, which determine the cell efficiency, can be identified by their high trap density. With this method, we have provided a new criterion to evaluate silicon for solar cells, which appears to offer the potential of identifying material with properties that may limit the cell efficiency.

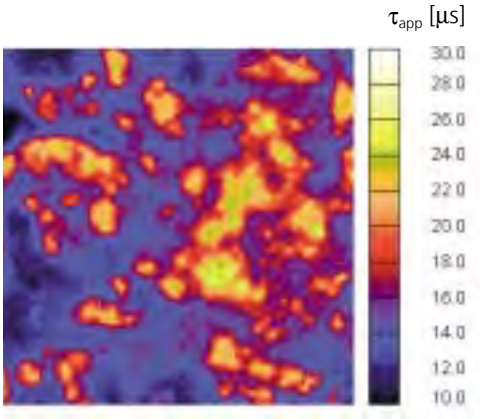


Fig. 1: Distribution of the traps in an unprocessed wafer of multicrystalline silicon. High values (in arbitrary units) indicate high measured values of the apparent lifetime, which are not caused by low recombination rates but by a high trap density. In previous work, we had proven that this correlates in turn with the density of crystal dislocations.

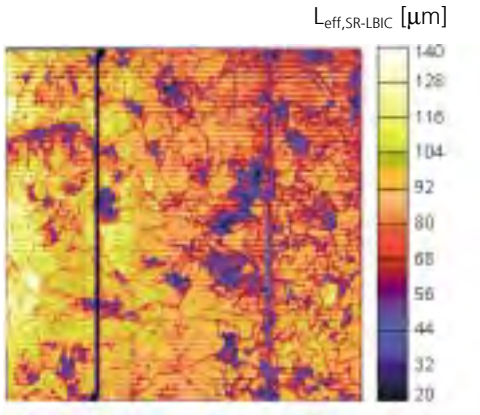


Fig. 2: In the map of the effective lifetime, measured for the completely processed solar cell, areas of lower material quality are visible (blue). They limit the efficiency value of the solar cell. Exactly these areas correlate well with those having a high trap density in the starting material (yellow/red in fig. 1).

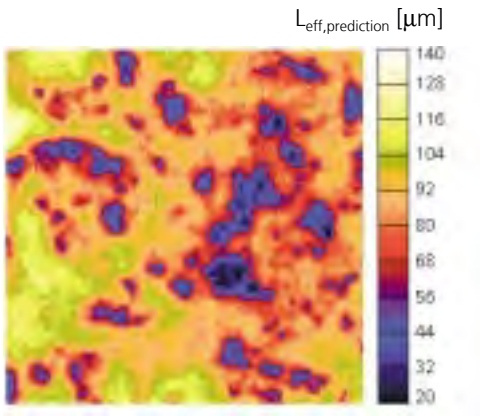


Fig. 3: With the help of a linear model, we have succeeded in calculating the predicted diffusion length in the solar cell from the trap distribution in the silicon starting material.

The work is supported by the German Federal Ministry for Education and Research BMBF.

Investigations and Developmental Work on Solar Cells for Space Applications

In space applications, silicon solar cells are only used occasionally nowadays. Instead, monolithic triple-junction solar cells of GaInP/GaInAs/Ge are in service. These cells achieve higher efficiency values and feature a better ratio of power to mass. We are working on improving this type of cell by introducing further pn junctions. In addition, we adapt the cell structures for special missions, for example the expeditions to Mars or Jupiter.

Carsten Baur, **Andreas Bett**, Armin Bösch, Frank Dimroth, Wolfgang Guter, Martin Hermle, Raymond Hoheisel*, Astrid Ohm, Eduard Oliva*, Manuela Scheer, Gerald Siefer, Jan Schöne, Gerhard Willeke

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Fig. 1: ExoMars is a planned European Mars-Rover, which should be started in 2013 from the Kourou Spaceport as part of the Aurora Programme. Electricity for the rover, which weighs about 190 kg, is generated by III-V multi-junction solar cells.

The ratio of generated electrical power to mass is a significant parameter for space solar cells, as it is expensive to transport mass in space. High efficiency values and light weight of the solar cells are thus important criteria for development. In addition, the solar cells in space are exposed to high-energy electron and proton radiation. Making solar cells more durable under these conditions is part of our work. For example, our triple-junction solar cells of GaInP/GaInAs/Ge now generate 88 % of their initial power after typical exposure to 1 MeV electrons (10^{15} cm^{-2}), 8% more than only two years ago. We also investigated novel quintuple-junction solar cells of AlGaInP/GaInP/AlGaInAs/GaInAs/Ge and demonstrated that even values of 93 % can be achieved. Figure 2 shows the measured external quantum efficiency of this type of solar cell before and after electron radiation. Table 1 documents the remaining factors after degradation for a triple-junction and a quintuple-junction solar cell today.

We are conducting investigations to identify the most suitable cells for special space missions, for example to Mars, Jupiter or Venus. To do this, we simulate the prevailing radiation and environmental conditions, which we then reproduce in our solar simulator. These investigations revealed that a triple-junction solar cell developed at Fraunhofer ISE, consisting of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As/Ge$, would generate the most electricity on Mars.

Our work on solar cells for space applications is supported by AZUR Space Solar Power, ESA-ESTEC and DLR (Bonn)/BMBF.

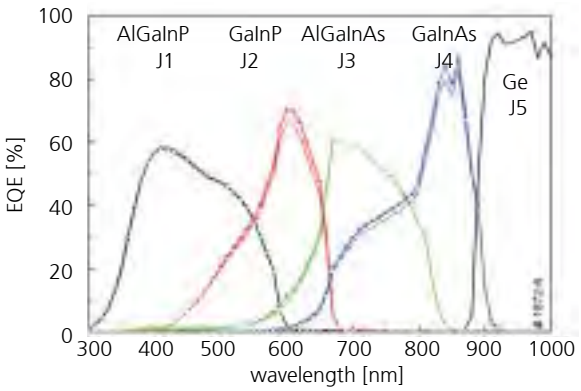


Fig. 2: External quantum efficiency (EQE) of a quintuple-junction solar cell before (solid symbols) and after (hollow symbols) electron irradiation (1 MeV, 10^{15} cm^{-2}). The germanium cell was not measured after irradiation.

		V_{OC}	J_{sc}	FF	η
	3-junction	0.95	0.96	0.97	0.88
	J1: GaInP		0.98		
	J2: GaInAs		0.85		
#1872	5-junction	0.95	0.98	1.00	0.93
	J1: AlGaInP		0.99	0.97	
	J2: GaInP		0.94		
	J3: AlGaInAs		0.99	0.97	
	J4: GaInAs		0.95		

Table 1: Comparison of the remaining factors for a triple-junction and a quintuple-junction solar cell. The cells were irradiated with electrons (1 MeV, 10^{15} cm^{-2}).

Highly Efficient Production of Solar Hydrogen

Hydrogen is interesting as an energy storage medium which can be applied in many areas. We are working on a concentrating photovoltaic system (HyCon®), which can generate hydrogen directly and very efficiently with solar energy. Our first HyCon® prototype is characterised by a high efficiency value of more than 18 %.

Frank Dimroth, Beatrice Hacker, Gerhard Peharz*, Achim Rastelli, Tom Smolinka, Ursula Wittstadt, Gerhard Willeke

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

In a sustainable energy supply system, which uses hydrogen as a fuel, it is imperative that the hydrogen be generated with renewable energy sources. Energy-efficient and cost-effective production of hydrogen presents a major challenge. We have developed a novel system for direct solar production of hydrogen, the HyCon® concentrator. In this system, sunlight is concentrated by lenses onto tiny cascade solar cells of III-V semiconductors. These are connected in turn to a PEM (polymer-electrolyte membrane) electrolyser for hydrogen production. In contrast to conventional combinations of photovoltaics and electrolysers, our very compact, integrated system does not require any power electronics.

The solar cells used are highly efficient III-V multi-junction solar cells. Each individual cell generates sufficient voltage to produce hydrogen, independent of the other cells. Electrical losses due to connections between the cells are thus avoided. HyCon® concentrator systems can be scaled to any dimensions and are particularly suitable for local hydrogen production in regions with high direct solar radiation levels.

Within an internal Institute project, we have constructed an initial HyCon® prototype with an active area of 96 cm^2 (fig. 1). This prototype generates hydrogen with an efficiency value (solar energy -> hydrogen) of more than 18% under outdoor conditions (fig. 2). At present, we are seeking funding to develop this concept further to commercial maturity.

Fig. 1: HyCon® prototype to generate solar hydrogen, during outdoor measurement.

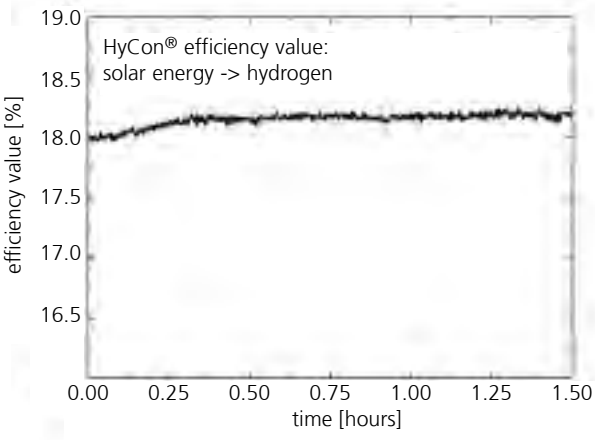


Fig. 2: The graph shows the efficiency value for hydrogen production by the HyCon® prototype during an outdoor measurement over a period of 1.5 hours.

Organic Solar Cells for Mobile, Energy-Autonomous Systems

Organic solar cells represent a new type of solar cell. The photoactive layer consists of a nanocomposite of organic semiconductor materials. The low material consumption and the application of cost-effective production technology open up a large potential for inexpensive production of organic solar cells. Further advantages include their mechanical flexibility arising from the film substrates used and their low mass. We see the first applications in power supplies for mobile, self-sufficient systems.

Markus Glatthaar*, Peter Hänni, Melanie Schumann*, Moritz Riede, Birger Zimmermann*, **Michael Niggemann**, Andreas Gombert

* Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität Freiburg

Organic solar cells are well suited as solar power supplies for small systems, due to the design possibilities offered by their mechanical flexibility, their small mass and their potential for efficiently connected modules. Potential applications include power supplies for off-grid microsystems and sensor networks, as well as for simple electronic circuits based on organic semiconductor components.

Monolithic connection of the solar cells to form modules allows the solar cell to be optimally matched to the load under the prevailing environmental conditions.

In the development of small, energy-autonomous systems, the emphasis is on the energy balance and integration of the individual components to form a complete system.

The goal of the Fraunhofer research project, "Smart Plastics", is to develop a stand-alone system which combines organic solar cells, organic light-emitting diodes and energy-efficient charging electronics, including a storage component, with sensors to form a measure-

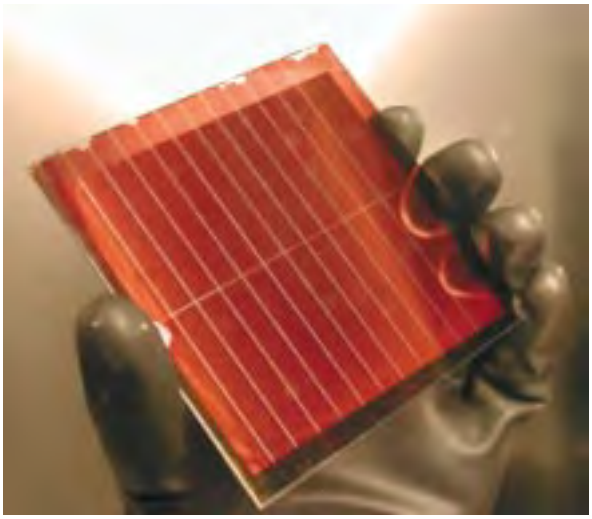


Fig. 1: Module of organic solar cells on a glass substrate. 22 single cells can be connected to each other in series with a monolithic circuit.

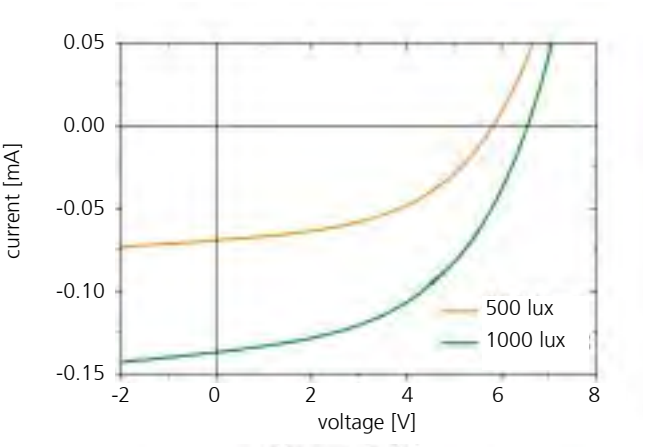


Fig. 2: Current-voltage characteristic curve of an organic solar cell module with 22 series-connected single cells under low-level illumination (500 lux and 1000 lux).

ment system. At Fraunhofer ISE, we are developing a solar cell module for this system. Under low lighting levels, for indoor applications, the module must supply the voltage of 5 V required to operate organic light-emitting diodes and charge a rechargeable battery. A sufficiently high voltage can be generated under office lighting conditions (fig. 2) by a module consisting of 22 series-connected solar cells (fig. 1). Under solar radiation conditions (1000 Wm^{-2}), we achieve a solar efficiency of more than 2 % for the active area. In the next step, this module is to be constructed on a flexible substrate and then integrated into the complete system.

For the production of cost-effective solar cells, two necessary conditions must be fulfilled: Low material costs and application of cost-effective production technology. To fulfil these conditions, we are developing new solar cell configurations, in which the expensive transparent electrode of indium tin oxide (ITO) is replaced. Efficient roll-to-roll coating technology and structuring methods can be used to manufacture these solar cells.

An "ITO-free" solar cell, which we are developing at Fraunhofer ISE, is based on replacing the ITO electrode by a transparent polymer electrode. The cell is electrically connected via holes in a perforated substrate (fig. 3). In order to guarantee that the cell can be produced efficiently, we have inverted the sequence of layers for the solar cell. The photoactive layer is deposited onto a metallised substrate, and is followed by the transparent, polymer anode. This transparent electrode, with a low sheet conductivity, is connected through holes in the solar cell to the back surface of the perforated substrate, where a second metal layer boosts the sheet conductivity of the transparent anode. In this way, a parallel circuit is created which can be upscaled. With this concept, we achieved a solar efficiency of 2 % for an area of 2 cm^2 (fig. 4). Higher voltages can be similarly generated by series connection via perforations.

Fig. 3: Organic solar cell on a flexible substrate with contacts through perforations. Electrical connection of the solar cell via holes allows inexpensive transparent electrodes with low sheet conductivity to be used. This solar cell concept combines the demands for inexpensive materials and efficient production technology applying roll-to-roll processes.

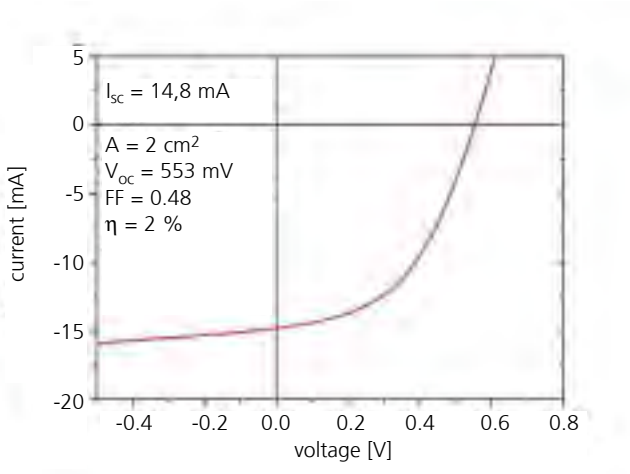


Fig. 4: Current/voltage characteristic curve for a 2 cm^2 organic solar cell contacted via perforations. Under solar radiation, an efficiency value of 2 % is attained (solar simulator with 1000 Wm^{-2}).

Off-Grid Power Supplies

Two thousand million people in rural areas, innumerable technical power supplies for telecommunications, environmental measurement technology or telematics, and four thousand million portable electronic appliances all have one feature in common: They require off-grid electricity. Increasingly, regenerative energy sources or innovative energy converters are being used to supply it.

Just on 20 % of the photovoltaic modules sold world-wide are used in these markets, some of which are already economically viable without external subsidies. In many cases, generating electricity from the sun is already more economic today than disposable batteries, grid extension or diesel generators.

In addition, more than one thousand million people without access to clean water for drinking and other purposes need decentralised technology for water desalination and purification. We power these systems with renewable energy, improve their energy efficiency and reduce the need for maintenance.

Although the quality of the components and systems for both rural electrification and technical power supplies has improved noticeably over the last few years, there is still great potential for development. Thus, we support companies in developing components, planning systems and penetrating new markets. Our special areas of competence encompass highly efficient power and control electronics, charging strategies for batteries, system operation management, energy management and system simulation.

Furthermore, we also offer analysis and advice on social and economic boundary conditions to aid successful market introduction of energy technology. New business models and appropriate market penetration strategies are particularly important for the companies which are involved in rural electrification. This is the only way to ensure establishment of a sustainable distribution and service network - and thus long-term operation of the installed systems.

Village power supply systems are becoming increasingly important in rural electrification. Fraunhofer ISE monitors newly installed systems as part of its contribution to international co-operation programmes. The acquired measurement data can be used to test the quality and reliability of the systems. The results are discussed with local staff during training courses on the monitoring procedures, so that the countries will be able to set up and operate the systems themselves on the medium term.

Miniature fuel cells, in particular, have great potential fo portable appliances. We are developing the necessary technology for this, including the associated power and control electronics. The advantage of miniature fuel cells compared to conventional battery systems is the high energy density of their storage units for hydrogen or methanol. This can significantly lengthen the operating time for the appliances, while the volume or mass remains unchanged. Further activities in this area are presented in the section on "Hydrogen Technology".

The facilities for our development work include:

- inverter laboratory
- highly accurate power measurement instruments for inverters and charge controllers
- precision instruments to characterise inductive and capacitive components
- measurement chamber for electromagnetic compatibility (EMC)
- burst and surge generators
- programmable solar simulators and electronic loads
- development environments for microcontrollers and digital signal processors (DSP)
- lighting measurement laboratory
- development environments for controls based on "embedded systems"
- thermostatted test stands for multiple-cell batteries and hybrid storage units
- test stands for fuel cells operating with hydrogen and methanol
- spatially resolved characterisation of fuel cells
- calibration laboratory for solar modules
- outdoor test field for solar components
- pump test stand
- testing and development laboratory for drinking water treatment systems

Off-Grid Power Supplies

The demand for off-grid power supplies for technical facilities is growing continually. Examples include measurement stations for environmental monitoring, forestry research and geophysical research, as well as facilities for telecommunications, traffic control and safety technology. Fraunhofer ISE is developing cost-effective, reliable and customised units for this market, based on photovoltaic hybrid systems with integrated energy management systems.

Our work ranges from designing "mobile energy packages" for brief usage to robust, stationary systems. For mobile applications, photovoltaic modules are mounted onto the roof and sides of a cabin on a trailer, while fuel cells and batteries are located inside the cabin (see adjacent photo). In stationary applications, we mount the photovoltaic modules directly onto the mast (see photo on p. 64) and install a connection box with auxiliary power generators and batteries (see article on p. 68).

Contacts

Off-grid power supply systems	Dr Matthias Vetter	Tel.: +49 (0) 7 61/45 88-56 00 E-mail: Matthias.Vetter@ise.fraunhofer.de
Power electronics and controls technology	Dr Bruno Burger	Tel.: +49 (0) 7 61/45 88-52 37 E-mail: Bruno.Burger@ise.fraunhofer.de
Electric storage systems	Dr Rudi Kaiser	Tel.: +49 (0) 7 61/45 88-52 20 E-mail: Rudi.Kaiser@ise.fraunhofer.de
Fuel cell systems	Dr Carsten Agert	Tel.: +49 (0) 7 61/45 88-53 46 E-mail: Carsten.Agert@ise.fraunhofer.de
Hydrogen production and storage	Dr Thomas Aicher	Tel.: +49 (0) 7 61/45 88-51 94 E-mail: Thomas.Aicher@ise.fraunhofer.de
Systems and electrical processes for water desalination and purification	Dr Matthias Vetter	Tel.: +49 (0) 7 61/45 88-56 00 E-mail: Matthias.Vetter@ise.fraunhofer.de
Thermal solar systems, processes for water desalination and purification	Matthias Rommel	Tel.: +49 (0) 7 61/45 88-51 41 E-mail: Matthias.Rommel@ise.fraunhofer.de
Photovoltaic modules	Dr Harry Wirth	Tel.: +49 (0) 7 61/45 88-51 93 E-mail: Harry.Wirth@ise.fraunhofer.de
Marketing	Dr Harald Schäffler	Tel.: +49 (0) 7 61/45 88-54 27 E-mail: Harald.Schaeffler@ise.fraunhofer.de

Interdisciplinary Co-ordination

Off-grid power supplies	Dr Günther Ebert	Tel.: +49 (0) 7 61/45 88-52 29 E-mail: Guenther.Ebert@ise.fraunhofer.de
Hydrogen technology	Dr Christopher Hebling	Tel.: +49 (0) 7 61/45 88-51 95 E-mail: Christopher.Hebling@ise.fraunhofer.de
Solar cells	Prof. Gerhard Willeke	Tel.: +49 (0) 7 61/45 088-52 66 E-mail: Gerhard.Willeke@ise.fraunhofer.de

"EVEREST" Supplies Reliable Power to Measurement Stations

Geographical measurement stations are often exposed to extreme environmental conditions. Our "EVEREST" power supply system, which we developed jointly with 14 research and industrial partners from Germany, Austria, Switzerland and Italy, guarantees reliable and cost-effective power throughout the year for such data acquisition units.

Matthias Vetter, Norbert Pfanner, Harald Schäffler, Simon Schwunk, Robert Thomas, Friedemar Schreiber, Günther Ebert

Weather forecasts, warnings of impending natural catastrophes, traffic information – no-one today wants to miss up-to-date information. People in flood-endangered areas want to know how high the water level will rise, scientists need accurate environmental data to give sufficient warning of natural catastrophes such as avalanches, investors demand wind data from the location of a planned wind park. The pre-requisite for obtaining all of these data is a close-meshed network of automatically operating measurement stations. However, this network has gaps because the energy to operate the instruments is lacking at many sites. At present, measurement stations remote from the grid are often powered by solar cells, which however cannot always meet the energy demand: Above all in winter, when snow and ice are lying on the modules and additional energy is needed to heat the sensors, solar energy alone is not sufficient. Incomplete data sets and high maintenance costs are the result.

Within the project entitled "EVEREST – hybrid energy supply system for autonomous measurement stations", we developed a modular energy supply system, which presents an inexpensive solution that also supplies energy under extreme environmental conditions. The so-called "EVEREST" boxes combine photovoltaic systems and

Fig. 1: Stand-alone wind measurement system, "Meteo-32" with the "Wicom" data logger from the Ammonit company (left). The power for this measurement station is supplied by the "EVEREST" Minibox (right), consisting of a photovoltaic generator with a power of 100 Wp, a direct methanol fuel cell with a power of 65 W and batteries with a capacity of 660 Ah.

Fig. 2: "Doppler-Sodar-Messsystem PCS.2000-24" from the Metek company. This mobile measurement station draws its power from the "EVEREST" Maxibox (fig. 3).

batteries with auxiliary power generators such as Stirling engines, wind turbines or thermoelectric generators and fuel cells in different power classes. The core of the power supply is an innovative energy management system (EMS), which connects the individual electricity generators with each other and controls them according to demand. In doing so, new improved procedures to determine the battery state of charge are applied. Similarly, the charging strategies and operation management concepts are adapted to the specifications of measurement stations on the basis of energy generation and consumption predictions. Furthermore, depending on the battery state of charge and the currently available generation capacity, the supply reliability is increased by allocating different priorities to the individual devices (data loggers, sensors, modem, mast illumination, heating) and applying load management strategies. At the same time, the energy consumption of the measurement station is minimised.

At present, two versions of the "EVEREST" boxes are being used as part of a field test at the station of the German Federal Environment Agency (UBA) on the Schauinsland mountain near Freiburg. The Minibox variant (fig. 1) consists of a photovoltaic generator, a direct methanol fuel cell and a battery. It supplies power to a wind measurement system with a data logger, modem, cup anemometer, wind vane, temperature and humidity sensors and mast illumination. The maximum load without heating is only 8 W, but if heating is required, the load can increase up to 60 W.

The installed Maxibox variant (fig. 3) also consists of a photovoltaic system, a fuel cell system and batteries, but provides more power than the Minibox. In the second field test, this system should be extended by a wind power system. This installation supplies power for a Doppler-Sodar measurement system (fig. 2), which is used to determine wind profiles on the basis of sonic measurements. The load for this system without heating is 75 W. When heating is required, it increases to about 350 W (fig. 4).

In addition to geographical measurement stations, "EVEREST" boxes can also supply power to facilities used in telecommunications, traffic control and safety technology.

The development work is funded by the German Federal Ministry for Economics and Technology BMWi within the InnoNet Programme.

Fig. 3: "EVEREST" Maxibox, consisting of a photovoltaic system (960 Wp) on the roof and the side of the trailer, and a direct methanol fuel cell (325 W) and batteries with a capacity of 1320 Ah inside. To transport the measurement system (fig. 2) for mobile applications, the Maxibox is constructed on a trailer.

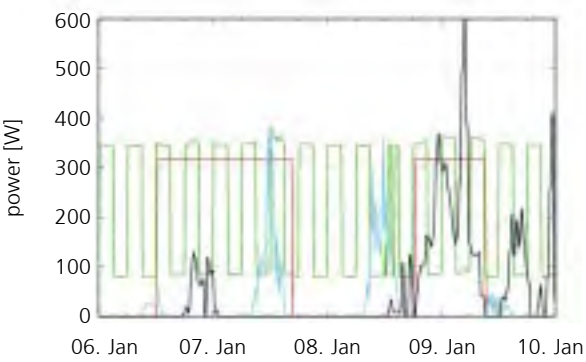


Fig. 4: System simulation of the "EVEREST" Maxibox. The load is shown in green. The heating component is switched on and off according to the ambient temperature. The operation duration of the fuel cell system (red curve) depends on the amount of energy available from the photovoltaic (light blue curve) and the wind energy systems (black curve).

Cost-Optimised Energy Management for Stand-Alone Photovoltaic Hybrid Systems

We apply a stock-exchange model in order to parameterise the energy management for stand-alone PV hybrid systems as simply as possible, to optimise the system operating costs and to simplify system extension. The cost functions for the generators and consumers are designed such that technical boundary conditions such as rapid complete charging of the battery are guaranteed.

Georg Bopp, Julien Gout, Rico Werner, Michael Zillgith, Christof Wittwer, Matthias Vetter, Günther Ebert

Fig. 1: This demonstration case shows a fully functional PV hybrid system with the Universal Energy Supply Protocol UESP. The individual components are connected with each other via a CAN bus and carry out the cost-optimised energy management with a standardised, manufacturer-independent protocol.

In stand-alone PV hybrid systems intended as power supplies for remote measurement stations or villages, an energy management system (EMS) controls the interaction between PV, auxiliary generators, battery and loads. Previous EMS's were based on purely technical criteria such as the battery state of charge or the predicted supply and demand profiles. They require individual adjustment of the control parameters, particularly when several auxiliary generators and controllable loads are included. Based on a stock-exchange approach, we are developing a new EMS, which ensures cost-effective operation while taking the technical boundary conditions into account. The determined price is initially purely virtual, but could be used as a basis for charging rates.

Our approach is divided essentially into two stages, a so-called "day ahead market" and a "spot market". In the "day ahead market", predictions for the electricity generation and costs of the individual generators, and information about the individual loads (time slot, priorities, etc.) are used to calculate a cost-optimised schedule for 24 hours, taking technical restrictions into account. In this step, the battery is considered only as a consumer. In the second step, the "spot market", the battery is viewed as a generating unit, which is then included if it can deliver electricity more favourably than the generators that had been foreseen by the "day ahead market". Initial results showed that the technical boundary conditions, such as rapid battery charging, were observed well, while the parameterisation effort was considerably lower.

The work is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety within the project, "Universal Energy Supply Protocol UESP".

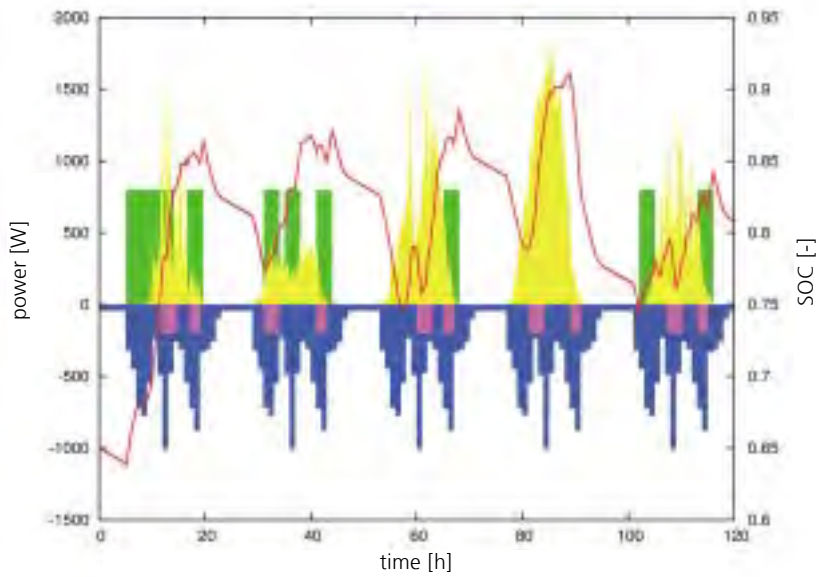


Fig. 2: Variation with time of the state of charge SOC (red), the auxiliary generator operation (green) and a shiftable load (pink), for a given solar radiation profile (yellow) and an unshiftable load (blue). The cost functions are designed such that the battery is charged rapidly and the shiftable load is connected during periods of high solar radiation or when the auxiliary generator is already operating.

Photovoltaic Village Power Supply for Mediterranean Countries

Together with local partners, we have investigated the electrification situation in Morocco, Algeria, Jordan and Lebanon in detail, in order to determine the potential for photovoltaic village power supply systems. For example, we have obtained data on the electricity demand in a Moroccan village and dimensioned a PV village power supply system.

Georg Bopp, Sebastian Gölz, Carolin Schenuit, Matthias Vetter, Günther Ebert

Fig. 1: The Moroccan village of Tiouardersine is located on a high plateau in the central Atlas mountain range. The access route from the nearest larger town is 44 km long, of which 26 km is untarred track which can only be negotiated by four-wheel-drive vehicles. About 17 families live in the village, i.e. 80 to 100 persons. Their main source of income is nomadic animal breeding.

The result of our investigations is that there are still about 5000 villages in Morocco and Algeria and about 5000 individual houses in Jordan without a grid connection. In Lebanon, all villages are connected to the public electricity grid. However, the power station and grid capacity there is limited or destroyed in some places, so that the power supply is interrupted for several hours on many days throughout the year.

With the exception of Morocco, which also uses coal, electricity generation in the investigated countries is based almost exclusively on gas and oil. Due to the rapidly rising oil prices, and the lack of national oil reserves with the exception of Algeria, there is strong interest in regenerative energy sources. The potential for photovoltaic village power supplies is particularly high in Morocco and Algeria, with a combined total of about 5000 villages that are not connected to the grid.

In Morocco, the ONE electricity utility is already carrying out a major programme of rural electrification with Solar Home Systems. The aim of the CRESMED project, which is funded by the EU, is to familiarise ONE with the technology and organisation of a central photovoltaic village power supply. A demonstration system is to be installed to fulfil this goal. Together with a local partner, Afrisol, we conducted a detailed local investigation to determine the electricity demand and dimension a PV system for the Berber village of Tiouardersine in the south-east of Morocco. The result is a plan for a photovoltaic system with 6 kWp, which will meet the daily demand of 14 kWh in future. In addition, a photovoltaically powered drinking water supply will also be installed.

Fig. 2: Typical living situation with daylight entering through an opening in the roof. The local survey revealed the following priorities for the electric power supply: 1) water supply, 2) lighting, 3) television/radio. The resulting daily demand for Tiouardersine is 14 kWh, which can be met by a 6 kWp photovoltaic system.

Fig. 3: The existing well is located 250 m away from the village and is 7 m deep. Today, every family transports its daily demand of 50 l by donkey into the village. In future, a photovoltaic system will supply power for the water to be pumped into the village.

Private-Public Partnership for Rural Electrification in the Mekong Countries

In the Mekong countries of Vietnam, Laos and Cambodia, we have developed a cost-effective solution for village power supply systems as part of a project on rural electrification. With the help of a public-private partnership approach, the medium-term goal is not that isolated individual systems be planned, but that the establishment of a market be supported. Operators and customers should be able to jointly design and operate systems according to their individual needs.

Sebastian Gölz, Matthias Vetter, Gisela Vogt, Christoph Weber, Günther Ebert

The most important aspect in establishing rural electrification with renewable energy is the economic incentive which the system offers the operator. If the system can be operated profitably, the operator has a "natural interest" in keeping the systems functional. Within the framework of a project that we are accompanying, the private-public partnership approach creates appropriate conditions for this. The public sector funds the components of the village power supply which must be permanently installed, the fixed assets such as the grid or the building to house the generators. By contrast, the transportable components, or movable assets, such as generators, batteries, etc., are financed by a private operator. This operator is also responsible for replacing components such as the battery, for example.

The second aspect is specific promotion of productive use of energy by the village community. Together with the customers, the operator of the electricity system searches for economic applications in which added value can be created by using electricity, e.g. to operate water pumps or mills. In this way, the customers not only earn money to pay their electricity rates, but also establish the pre-conditions for economic development and extension of the systems. This can represent the initial step to break out of the poverty cycle.

4-year load profile (dry season from September to May)

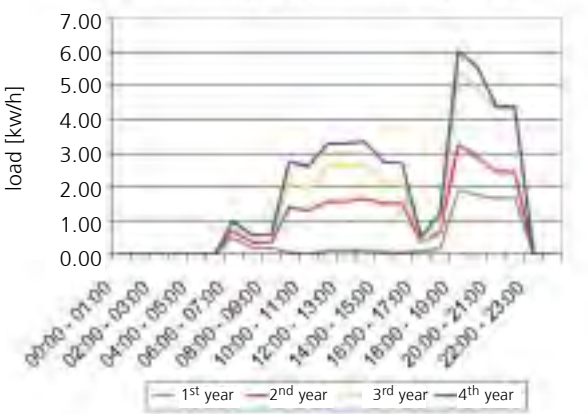


Fig. 1: Determining a load profile for a village power supply on the basis of a demand analysis. An increased energy demand is calculated for the years following the installation of the PV hybrid system, due to the establishment of commercially productive applications and higher private consumption.

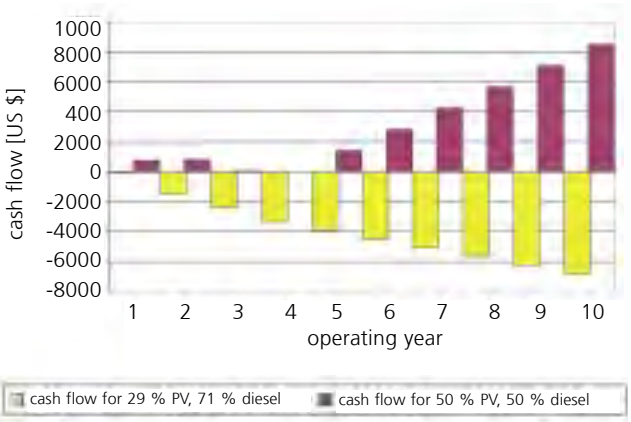


Fig. 2: Cash flow for a village power supply. Costs are created by the previous model (yellow bars), whereas the new model brings income (red bars), with the electricity tariff of 0.30 US$/kWh being affordable for the rural population and the business being profitable for the operating company. This is possible with optimised system dimensioning combined with an appropriate operating strategy.

The introduction of so-called PV-hybrid mini-grids is very suitable for this approach. The challenge is to design a technically optimal and cost-effective system and to define a tariff which is profitable for the operator and can be afforded by the customers. Based on more than 15 years of operating experience with PV hybrid systems and by applying modern simulation tools, we have succeeded in preparing a concept for village power systems to supply 1700 households, as part of a feasibility study for the Laotian province of Luang Prabang. By taking account of all available technical, social and economic data, it was possible to develop an optimal solution based on the local renewable energy resources.

The system, consisting of photovoltaics, a diesel generator and batteries, has been designed to match the local boundary conditions, and will generate electricity for a much lower price than before this adaptation. The photovoltaic share of the total supply was greatly increased and the battery capacity was significantly reduced (reduction of the autonomous period from three days to one day). Most of the photovoltaically generated electricity is consumed during the day in commercial applications.

Particular attention was paid to the operating strategies of the PV-hybrid mini-grid during the simulation-based dimensioning process and the development of the associated business plan. Not only was the duration of expensive diesel generator operation reduced, but the battery lifetime was appreciably lengthened by applying appropriate charging strategies. The battery will not need replacement before seven years.

The work was carried out as part of the DELTA PRO RES project, which is funded by the EC-ASEAN Energy Facility.

Website: www.energies-renouvelables.org/delta-prores

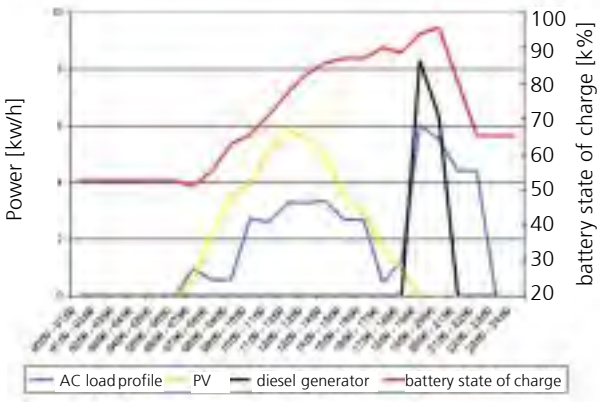


Fig. 3: Simulated operating performance (daily profile) of a PV-hybrid system for a village power supply. The photovoltaic system supplies power to the loads (primarily productive applications) during the day. Operation of the diesel generator is limited to the evening hours (peak loads due to private consumers). The results of these simulations over a time base of 15 years are used as the basis of lifetime cost analyses and for preparing business plans.

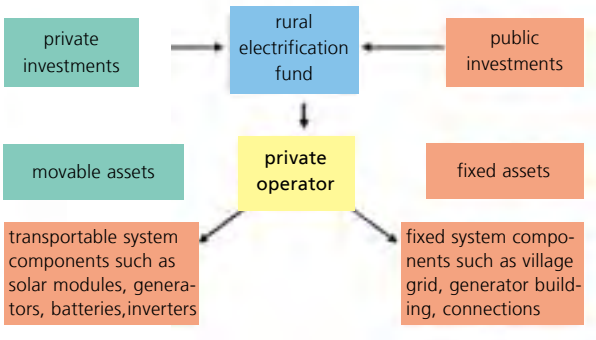


Fig. 4: Schematic diagram of a private-public partnership for rural electrification. Public and private investors pay into a commercial "Rural Electrification Fund", which makes it feasible for private operators to finance village power supplies (divided into movable and fixed assets).

Monitoring of Decentralised PV-Powered Water Purification Systems in Laos

The photovoltaically powered water pumping and purification system, WATERpps, is currently being tested at three locations in Laos. We developed a robust monitoring system for this field test. In addition, we are accompanying the field test phase with scientific evaluation.

Joachim Went, Matthias Vetter, Thomas Graf, Ansgar Rau*, Thomas Link*, Andy Schröter**, Günther Ebert

* Solar-Fabrik AG, Freiburg
** Sunlabob Solar Energy Systems, Vientiane, Laos

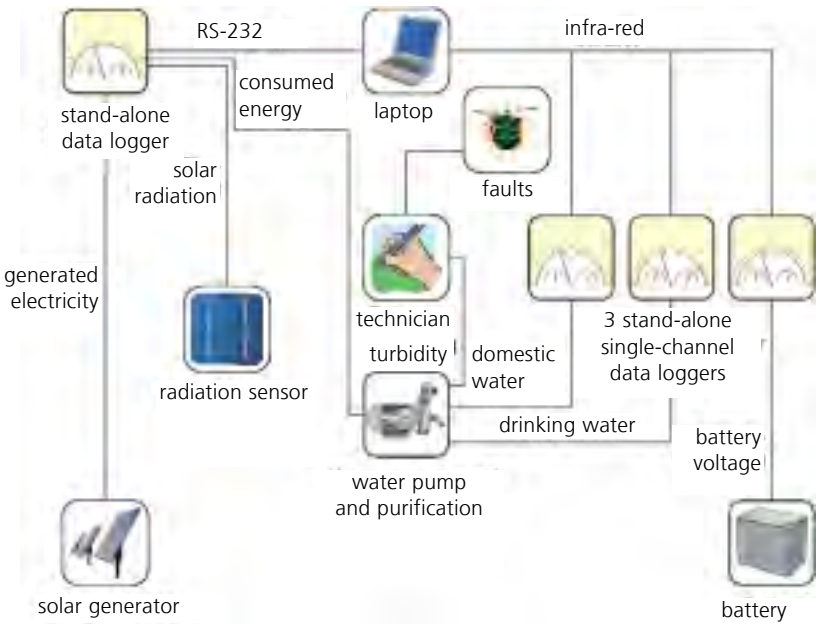


Fig. 1: Monitoring concept for the field test currently being conducted in Laos of the photovoltaically powered system for water pumping and purification WATERpps.

Fig. 2: Our Lao partners receive instruction on the WATERpps water pumping and purification system in Vientiane, Laos.

In order to make the field test feasible under real conditions in remote rural areas, we have designed a robust, autonomous and simply operated monitoring system for the photovoltaically powered water pumping and purification system WATERpps (fig. 1).

All of the relevant technical quantities are recorded to describe and evaluate the system performance. These include the solar radiation, the instantaneous power of the PV module, the electric power consumed by the pump, the battery voltage and the volumes drawn of domestic and drinking water. In addition, the flow volume can be read visually from a simple water meter. The aims of the field test are to identify the technical potential for optimising the system and to gain knowledge on typical user behaviour in rural areas.

After the field test has been successfully completed, it is planned to rent the WATERpps systems to local partners, analogously to the renting of Solar Home Systems.

As well as applying technical measures, we evaluate the systems according to socio-economic criteria which are important for the successful development and implementation of photovoltaically powered drinking water purification systems. The aim is to promote the development of a market for decentralised water purification systems in rural areas, thus making a significant contribution towards improving the living conditions of the inhabitants.

The WATERpps system was developed in cooperation with the Solar-Fabrik AG and with support from the "Innovationsfonds Klima und Wasserschutz" of the local utility, badenova AG & Co. KG. The Lao company, Sunlabob, is our partner in the field test and local implementation.

Stand-Alone Systems for Seawater Desalination in Real Operation

At present, already 50 million m³ of drinking water are prepared every day from seawater or brackish water. The technically mature desalination technology which is applied is almost always intended for supplying areas with a high population density and good technical infrastructure. At Fraunhofer ISE, we are working on desalination systems which operate with thermal solar energy or photovoltaics. They are thus completely energy-autonomous, and are designed to be used in regions with weak infrastructure to purify moderate amounts of drinking water.

Martin Hermle, Joachim Koschikowski*, Georg Mülhöfer, **Matthias Rommel**, Moritz Siegfried, Marcel Wieghaus*, Hans-Martin Henning

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

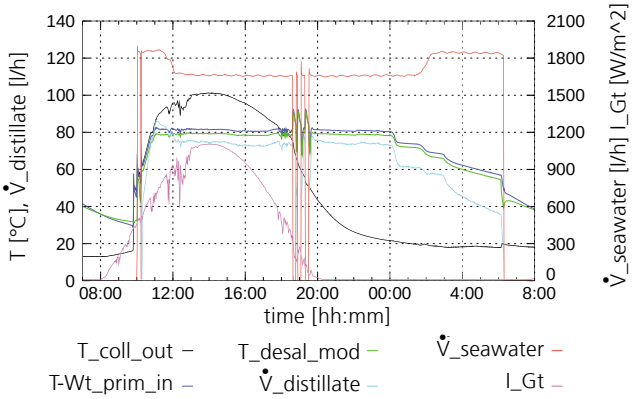


Fig. 1: 24-hour measurement results for a two-loop system on Gran Canaria. It can be seen that the foreseen operating temperature (blue line) for the desalination process of 80 °C is reached very soon after sunrise and can be kept very constant by charging the storage unit during the day and discharging it at night. On this day, 1240 l of drinking water was prepared.

There is an appreciable need to develop small desalination systems that can be installed decentrally, as the conventional desalination methods used for large technological applications cannot be simply downscaled for systems with small production capacities. In addition, the use of regenerative energy sources such as solar energy or wind power presents the problem of the power supply being discontinuous.

For the solar-driven desalination systems that have been developed at Fraunhofer ISE, we thus employ special desalination modules that have been adapted to these conditions and operate according to the principle of membrane distillation. These modules are not only further developed but are also produced at Fraunhofer ISE for prototype systems.

We differentiate between "compact systems" with capacities of up to 150 l per day and unit, and "two-loop systems", which can meet capacity demands between 1 and 10 m³ per day, depending on the system dimensions. Whereas the salt water flows directly through the solar collector in the compact systems, the two-loop systems have a heat exchanger incorporated between the collector loop and the brine loop. In addition, the two-loop system (unlike the compact system) includes a thermal storage unit, which stores excess energy from the midday hours for the darker hours of the day and the night.

Fig. 2: Five desalination modules are in operation in the two-loop system on Gran Canaria. The collector field has an area of 90 m² and consists of flat-plate collectors equipped with a double-glazed cover with anti-reflective coatings. This allows a good efficiency value of 50 – 60 % to be achieved even for high operating temperatures of 80 – 100 °C. The thermal storage tank has a volume of 4 m³.

Since 2005, seven of the systems that we have developed and constructed have been operating in different countries. Five of them are compact systems and there are two two-loop systems with daily capacities of 0.8 and 1.5 m³. The experience gained with them has demonstrated that the systems can operate over longer periods with very little maintenance and no external source of energy.

The work was funded by the European Union.

Distributed power generation

Grid-Connected Renewable Power Generation

Construction of grid-connected systems is the largest global market of the photovoltaic branch today. Well-implemented market introduction programmes, particularly in Japan, Germany and some States of the USA, but also in European countries such as Spain, Italy and Portugal, are ensuring high growth rates. To maintain this market growth while subsidies are decreased, the costs for the systems technology - including inverters, installation and cabling systems - must be reduced continually. At the same time, expectations on the quality and lifetime of the components are increasing.

Inverters to feed photovoltaic electricity into the grid are already of high quality today. Nevertheless, there is still considerable potential for improvement, which can be exploited with new circuit designs, digital controls technology, advances in power semiconductor components and passive components. To this purpose, we offer specialised know-how in the fields of circuit design and dimensioning, as well as configuring and implementing analog and digital controllers.

Quality assurance and operation monitoring of PV systems are playing increasingly important roles, particularly for large, commercial photovoltaic systems. Therefore, we are developing improved measurement procedures and more powerful simulation and information technology, which enable quality and yield assurance at all levels. We advise on system design, characterise solar modules and carry out technical assessment and performance tests of PV systems. Our yield predictions are regarded as a reference due to their high accuracy.

On the medium term, not only large-area photovoltaic systems but also concentrating photovoltaic systems and solar thermal power stations can make an important contribution to renewable generation of electricity. To achieve higher steam temperatures, we are conducting research to improve both the concentrator optics, including Fresnel lenses and reflector systems, and the absorber coatings for solar thermal power stations. We support the industry with our optical and thermal measurement services for quality control of the collector fields and with simulations to dimension and optimise complete systems. Together with our partner, PSE GmbH, we also prepare new concepts to control the reflectors for Fresnel collectors. We optimise the operation of concentrator PV and trackers with modern power electronics and controls technology.

Optically concentrating photovoltaic systems offer the potential to reduce the price of solar electricity for large power stations in sunny regions. We are developing high-efficiency solar cells for concentrator modules that are mounted on double-axis solar trackers. In combination with inexpensively manufactured Fresnel lenses, module efficiency values of 26 % are achieved. Concentrix Solar GmbH, the most recent spin-off company from Fraunhofer ISE, will construct the first power station based on this technology in 2007.

The liberalisation of the electricity markets and the entry of climate-protecting technology to the electricity-generation market mean that the proportion of PV systems and other distributed generators such as combined heat and power plants is increasing rapidly. Many small generators and controllable loads interact with each other and, in some cases, with the buildings in which they are integrated. This results in completely new demands on controls, operation management, communications and data management in electricity grids and buildings. We are working on control concepts, new simulation and management technology, and planning tools for these systems. Questions concerning costs, operating safety, supply reliability and voltage quality are major issues that are taken into account in doing so.

The facilities for our work on grid-connected renewable power generation include:

- inverter laboratory
- highly accurate power measurement instruments for inverters and charge controllers
- precision instruments to characterise inductive and capacitive components
- measurement chamber for electromagnetic compatibility (EMC)
- burst and surge generators
- programmable solar simulators and electronic loads
- development environments for microcontrollers and digital signal processors (DSP)
- calibration laboratory for solar modules
- outdoor test field for solar components
- development environments for controls based on "embedded systems"
- laboratory to develop battery charging and operation strategies
- test facilities for batteries over a wide range of current, voltage and temperature values

Grid-Connected Renewable Power Generation

One of the largest photovoltaic power stations in the world has been constructed on the roof of the BMW component warehouse in Dingolfing/Isar. The solar generator consists of more than 18000 modules and has a total rated power of 3.3 MW. Fraunhofer ISE carried out comprehensive measurements to guarantee the performance and quality of the system. These included:

- evaluation of the quality of the technical installations for the system (substructure, connection boxes, sub-distributors, cable cross-sections, compliance with the relevant standards)
- measurement of the characteristic curves for selected sections and strings of the solar generator to determine the supplied power and functionality (see article on p. 81).

Contacts

Distributed generation	Dr Thomas Erge	Tel.: +49 (0) 7 61/45 88-53 37 E-mail: Thomas.Erge@ise.fraunhofer.de
Power electronics and controls technology	Dr Bruno Burger	Tel.: +49 (0) 7 61/45 88-52 37 E-mail: Bruno.Burger@ise.fraunhofer.de
Electric storage systems	Dr Rudi Kaiser	Tel.: +49 (0) 7 61/45 88-52 20 E-mail: Rudi.Kaiser@ise.fraunhofer.de
Monitoring and demonstration projects	Klaus Kiefer	Tel.: +49 (0) 7 61/45 88-52 18 E-mail: Klaus.Kiefer@ise.fraunhofer.de
Solar power stations	Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fraunhofer.de
Marketing	Dr Harald Schäffler	Tel.: +49 (0) 7 61/45 88-54 27 E-mail: Harald.Schaeffler@ise.fraunhofer.de

Interdisciplinary Co-ordination

Grid-connected renewable power generation	Dr Günther Ebert	Tel.: +49 (0) 7 61/45 88-52 29 E-mail: Guenther.Ebert@ise.fraunhofer.de
Solar cells	Prof. Gerhard Willeke	Tel.: +49 (0) 7 61/45 88-52 66 E-mail: Gerhard.Willeke@ise.fraunhofer.de
Buildings and technical building components	Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-51 34 E-mail: Hans-Martin.Henning@ise.fraunhofer.de

"Performance": Rules for a Transparent Photovoltaic Market

Revision, extension and standardisation of procedures to characterise PV cells, modules and systems is the object of the extensive "Performance" project. An essential section of the work programme is concentrating on different types of thin-film solar cells and modules. Two main topics are the harmonisation of the measurement accuracy possible on a production scale with that achieved in the test laboratory, and the development of procedures for lifetime tests.

Christian Reise, Michael Köhl, **Günther Ebert**

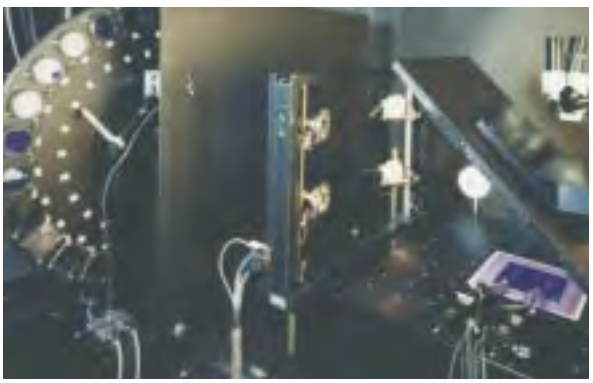


Fig. 1: PV cells and modules are measured with high accuracy in the calibration laboratory of Fraunhofer ISE. The measurement accuracy for crystalline silicon modules is ±2 %. Similar accuracy should be achieved for thin-film PV cells and for measurements in the production line.

Fig. 2: How many kWp of PV power have been installed here? The power extrapolated from the data sheets, the manufacturer's measurements on individual modules or random samples by certified measurement laboratories always give different results. The "Performance" project will help to establish clear rules for the evaluation of large PV systems.

How high is the value of the PV power for a system that has been installed and financed? How high is the average annual yield which can be expected? How are guaranteed yields verified?

Most of the existing measurement procedures and standards to answer these questions originate from the period when the first large demonstration systems were installed, and are restricted to PV modules made of crystalline silicon solar cells. However, the demands of the market have grown in the meantime. One aspect is that large numbers of PV systems based on thin-film modules are being installed. Another aspect is that for all types of module technology, tolerances of several percent in the installed power or the predicted yield are converted to large absolute values when many MW rather than a few kW are involved.

In the "Performance" project, we are revising and extending the relevant measurement procedures, regulations and standards. The spatial dimensions extend over nine orders of magnitude, ranging from the individual solar cell to complete systems located throughout Europe. The time scale ranges over eight orders of magnitude, from milliseconds in inverter controls to module lifetimes of 25 years and more.

Evaluation tolerances comparable to those for the established crystalline silicon technology are to be achieved for the new thin-film systems based on a-Si, CdTe, CuInGaSe and CuInS, which are rapidly entering the market. This applies both for the measurement of modules and also for the correct evaluation of the system yield. Equal importance is placed on questions concerning the aging of modules based on established and new types of technology. To this purpose, we are developing laboratory and outdoor test procedures, which will also provide reliable data with respect to the expected lifetime, even for modules that have yet to be developed.

The EU-funded "Performance" project has a duration of four years and is carried out in close co-operation with the European Photovoltaic Industry Association EPIA and numerous individual companies.

Yield Optimisation for Grid-Connected Photovoltaic Systems

With the cost pressure on photovoltaic systems rising, efficiency is playing an increasingly important role, as every percentage point sacrificed in performance immediately affects the project profit. Module power that is lower than the planned value is one of the most frequent causes for low system yields. Increasingly, failure analysis is demanded for faulty modules. Accordingly, we have further developed the procedures for in situ analysis, so that reliable information on the performance and functionality of the modules can be provided to investors and operators.

Andreas Steinhüser, Frank Neuberger, **Klaus Kiefer**, Günther Ebert

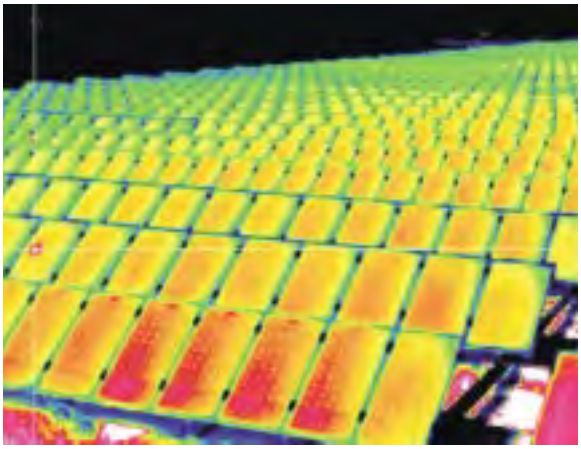


Fig. 1: Modules with hot-spot effects are identified by thermographic images of a large solar generator.

Yield predictions are based on the specifications provided by solar module manufacturers. In various test series, we have observed that although the module power was usually within the guaranteed tolerance range, more than half of the tested modules delivered power that was well below the rated value specified by the manufacturers. Thus, we offer a statistically representative test of solar modules for investors and operators. In this way, it is possible to guarantee that, on average, the supplied modules really generate the power with which the financial returns were calculated. After all, over an operating period of 20 years, a module power which is lower by one percentage point means a loss of around 100,000 euros for a megawatt system. In our calibration laboratory, we can measure individual modules with a very high measurement accuracy of ±2 %.

To monitor the power generated by large solar power plants, in situ measurements are needed for the characteristic curves of generator segments or individual strings of modules. With our mobile measurement equipment, we can determine the performance of generator segments with up to 100 kWp and 1000 V. By using accurate sensors to measure the solar radiation and carefully recording the module temperature at different positions of the solar generator, it is possible to obtain reliable results. To identify faulty modules – for example, those exhibiting "hot spot" effects – we measure the entire solar generator with a high-resolution infrared camera. This procedure reveals temperature gradients within a single module or within larger module arrays. Similarly, the cable dimensions for the solar generator circuit and the inverter connections can be checked. In this way, preventive measures can be taken before damage is caused by overloaded cables.

Applying the analytical methods that we have developed at Fraunhofer ISE, we investigated more than 40 systems last year, with a total power of more than 20 MWp.

Fig. 2: Fraunhofer ISE experts during performance measurement of the 3 MW system located on the roof of the BMW factory in Dingolfing.

Reliability and Durability of Photovoltaic Modules

Manufacturers of solar modules currently give a performance guarantee for 20 years and more. This is possible only because relevant experience for the service life has been gained for the materials used. If alternative, less expensive materials are to be used, it is very difficult to estimate their reliability. In order to create new opportunities here, we are co-operating with project partners to develop an accelerated aging test for solar modules.

Michael Köhl, Odon Angeles, Franz Brucker, Markus Heck, Tilmann Kuhn, Daniel Philipp, Marco Tranitz, Karl-Anders Weiß, Harry Wirth, Günther Ebert

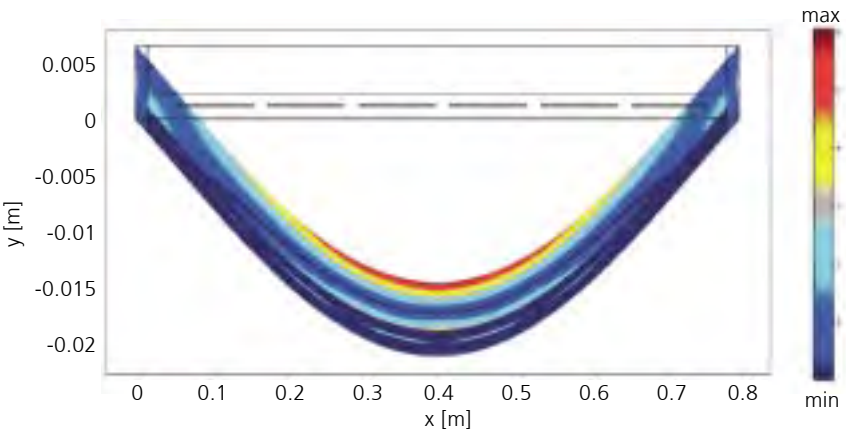


Fig. 1: Cross-sections through a photovoltaic module in its original position and under mechanical loading. The colour-coded representation indicates the modelled stresses in a module with a 4 mm glass cover for a load of 2400 Pa. The compressive stress at the upper glass surface and the tensile stress at the lower glass surface and at the solar cells can be seen. The colour legend from dark blue to dark red indicates increasing absolute values for the stress.

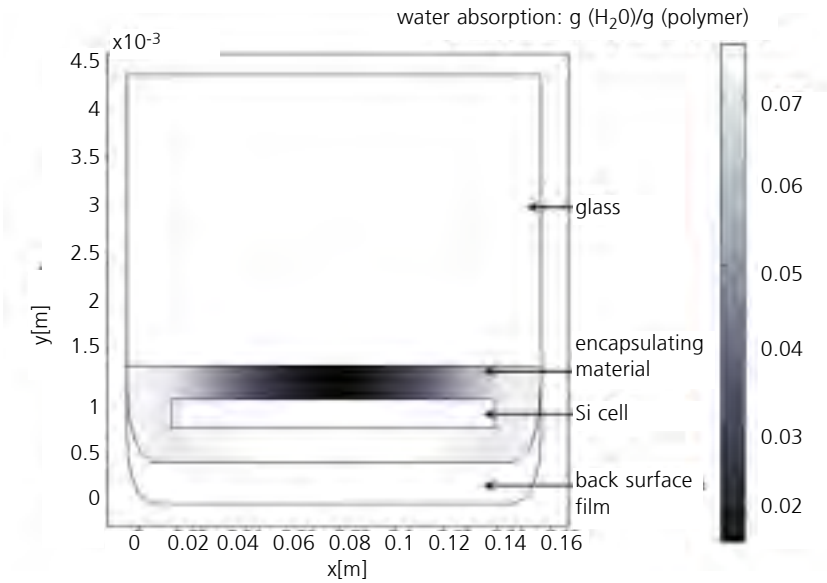


Fig. 2: Modelled distribution of the water concentration in the encapsulation material of a PV module. The instantaneous "snapshot" from a dynamic simulation shows the spatial distribution of the water concentration in the encapsulation material.

Aging processes in modules are mainly affected by the following factors: ultraviolet radiation, mechanical loading by snow and wind, internal stresses due to different thermal expansion coefficients, and diffusion of water and oxygen.

We thus initially concentrated on procedures to determine relevant material characteristics and the development of simulation programs which can be used to model the interaction of new materials in modules and their durability (figures 1 and 2).

To validate the simulation results and the accelerated aging tests, we have exposed commercial modules and test modules with innovative material combinations to outdoor weathering conditions in arid, tropical, alpine and urban environments. The climatic loads are monitored continuously. Tests of further interesting materials and modules with thin-film cells are planned.

The goal is to develop an accelerated test to determine the lifetime of solar modules and verify it by outdoor measurements, in cooperation with our project partners.

The cluster project entitled "Reliability of PV modules" is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU. The work within the integrated project, "Performance", is partly supported by the EU.

Bypass Circuit without Diodes for Solar Modules

Bypass diodes protect solar cells if the solar modules happen to be partly shaded. Due to the increasing cell dimensions and rising efficiency values, cell currents now reach values in the range between 10 and 15 A. With currents that are so high, it is difficult to remove the waste heat that is generated in bypass diodes when shading occurs, making it hard to comply with the regulations of IEC 61215. Together with industrial partners, we developed a bypass circuit without diodes, which reduces heat generation to a non-critical level.

Bruno Burger, **Heribert Schmidt**, Günther Ebert

Fig. 1: DIODLESS connection circuit without diodes with a rated current of 16 A, for two sub-groups of solar cells. Our industrial partner plans the development of a complete family of connection circuits without diodes which apply the new concept.

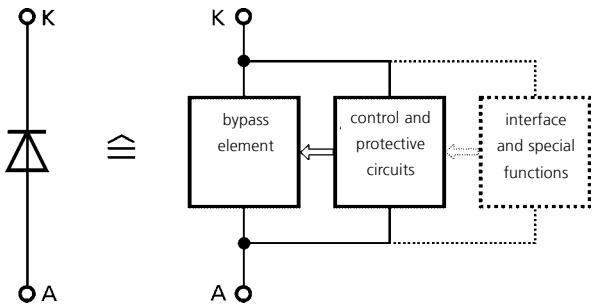


Fig. 2: The connection circuit without diodes is electrically compatible with conventional bypass diodes. The bypass element is powered from the voltage drop across the diode via a control and protective circuit. In future, special functions, e.g. short-circuiting the module, can be implemented with suitable interfaces.

Almost all solar modules include bypass diodes as components which are connected anti-parallel to groups of solar cells. In normal operation, no current flows through the diodes. If cells in a group are shaded, the bypass diode becomes conductive and protects the shaded cells against damage due to a high reverse voltage and the resultant heating ("hot spot"). To date, conventional silicon pn diodes and also Schottky diodes have been used as bypass diodes. The current from the photovoltaic generator which flows through the diodes causes significant warming due to their forward voltage of approximately 0.4 V to 1 V. As the cell dimensions and efficiency increase, it becomes more and more difficult to remove the resulting waste heat from the diodes. Already for currents of 8 to 10 A, considerable effort must be made to remain within the temperature limits specified by IEC 61215 for the diodes.

Our novel bypass circuit without diodes reduces heat generation for a 16 A circuit by a factor of 10 compared to conventional solutions. This low level of heat generation affects the circuit lifetime positively and means that several such circuits can be mounted in one conventional connection box. The circuit consists of only a few, generously dimensioned components. Thanks to integrated protection concepts, the circuit features great robustness to overvoltages compared to conventional bypass diodes. This makes bypass circuits without diodes interesting also for modules with lower current ratings.

Active Management of Decentralised Electricity Generation Systems

Increasing numbers of decentralised generating systems are delivering electricity to the grid, thereby raising the demands on the planning and operation management of electricity distribution grids. We developed a novel system for operation management of decentralised generation systems which is based on an algorithm that can be applied to achieve diverse optimisation targets. An initial test in a low-voltage grid ran successfully and provides a basis for predicting amortisation periods of three to four years for the system.

Thomas Erge, Rainer Becker, Malte C. Thoma, Anselm Kröger-Vodde*, Bernhard Wille-Haussmann, Christof Wittwer, Günther Ebert

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Fig. 1: Field test of PoMS in a grid operated by the utility, MVV Energie.

Fig. 2: Selected parameters are shown locally on a display board, so that residents of the estate can see how much power the system is supplying.

The newly developed Power Flow and Power Quality Management System PoMS helps to integrate and manage the continually increasing number of decentralised generating systems in existing electricity distribution grids. The target criteria for optimised management can be quite different, e.g. cost minimisation of grid operation, reduction of the control energy demand, minimisation of the primary energy consumption, minimisation of CO_2 emission. In addition, PoMS can actively improve the voltage quality with existing grid components. For example, overvoltages or undervoltages can be reduced. Simultaneously, the system allows the voltage quality to be monitored continuously.

The decisive innovation in PoMS is the calculation of optimised schedules for the controllable components. We have used methods of mixed-integer linear optimisation to do this. Its great advantage is that it ensures that a global minimum and not just a local minimum will be found. This approach is being applied increasingly in other industrial sectors also.

Our partner in the development and testing of PoMS is the utility, MVV Mannheim. The system was tested in a low-voltage grid near Karlsruhe from September to December 2005. This revealed that savings of several thousand euros per year are possible in comparison to conventional grid operation. This result leads to the prediction that the amortisation period for the system will be only three to four years. Encouraged by the promising results, MVV Mannheim will now subject the system to a long-term test lasting until June 2007.

Implementation of a Virtual Power Plant

With decentralised electricity systems expanding continually and regenerative energy sources being integrated in increasing numbers, the need for active grid management is growing. In co-operation with an energy utility, we have developed an intelligent operation management system for its electricity distribution grid, which combines distributed generators to form a virtual power plant.

Thomas Erge, Lena Kitzing, Malte C. Thoma, Bernhard Wille-Haussmann, Christof Wittwer, Günther Ebert

The increasing number of decentralised electricity generators imposes new demands on grid operation management. Aspects of grid usage at the higher-order levels and new boundary conditions (e.g. incentive regulation) are playing increasingly important roles. These changing boundary conditions offer the distribution grid operator the opportunity for active system optimisation.

We have investigated the feasibility of optimising the complete grid operation according to technical and economic criteria, based on predictions of the thermal and electric loads and prognoses for the electricity generated by wind and photovoltaic systems. We have evaluated the strategies that we developed to optimise this "virtual power system" on the basis of earlier operating data, and showed that profitability can be improved, at times appreciably, for both the system operators and the grid operators. The greatest potential is offered by optimised control of combined heat and power systems.

For day-to-day operation of the "virtual power plant", we have developed and implemented customised optimisation strategies, using the mixed-integer linear optimisation approach mentioned on page 84. It allows flexible target functions to be specified for the optimisation, such as financial savings or a reduction in CO_2 emission from the generator.

The communications infrastructure for the "virtual power plant" is being set up and regular continuous operation is being prepared.

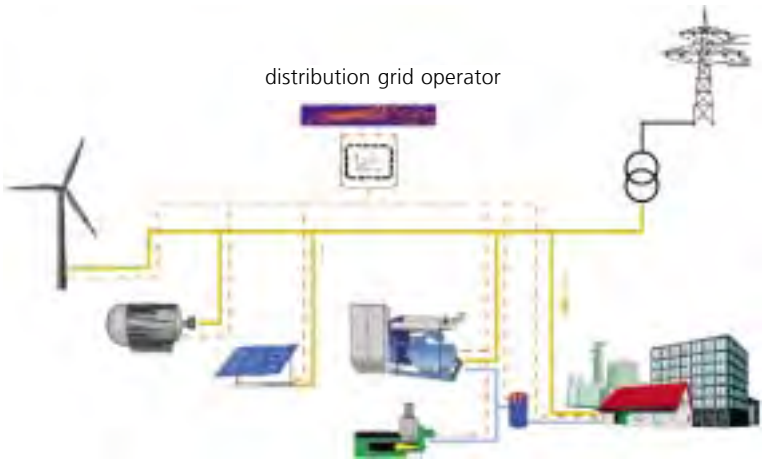


Fig. 1: "Virtual power plants" encompass many decentralised generators drawn from a wide range of technology. From the operator's perspective, they are combined to form a concentrated, controllable generation unit by connection to a central communications unit and intelligent operation management.

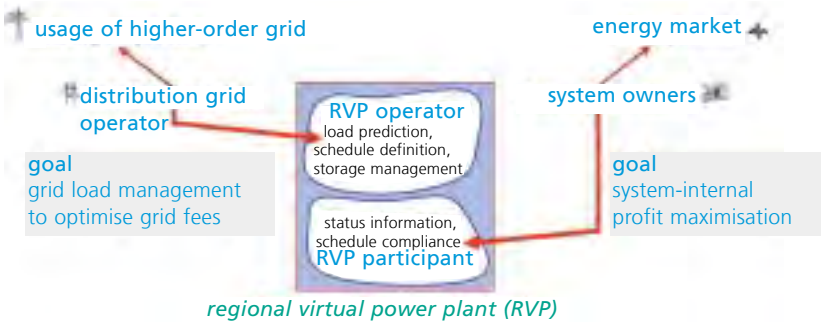


Fig. 2: In "regional virtual power plants" (RVP), the interests of both the system owners and the local grid operator must be taken into account in the grid management. The higher-level operation management system that we have developed can ensure that these interests are balanced.

Our partner, the Freiburg utility, badenova GmbH & Co. KG, is supporting the project from its innovation fund.

Support for Municipal Authorities in Implementing Renewable Energy Schemes

Municipal authorities often lack the knowledge to identify assets for using renewable energy technology and subject them to a cost-benefit analysis. Together with partners from five EU countries, we have developed an Internet-based tool that supports municipal authorities in implementing activities to counteract global warming which are appropriate to their situation.

Sebastian Gölz, Iryna Shymkiv, Gisela Vogt, Günther Ebert

Fig. 1: Municipal authorities have many resources available which have seldom been considered for the implementation of sustainable energy systems. With the help of the LETIT tool, the London Borough of Merton developed a strategy to mitigate climatic change, in which three wind energy systems (each of 6 kW) with modern vertical-axis turbines were installed, among other measures. (Source: XCO2, GB)

Europe expects to be confronted with growing difficulties if it intends to reach the ambitious goals concerning renewable energy, energy efficiency and climatic change which it has agreed upon over the past years. One reason for this is that the responsibility for planning, authorisation and implementation of projects lies with local decision-makers from municipal authorities, and not at the EU level.

Against this background, we have developed an evaluation approach and an Internet-based tool which supports municipal authorities in carrying out appropriate activities to mitigate climatic change. Not only technical possibilities but also risks are taken into account, which can be associated with implementation of sustainable energy technology. The developed instrument makes it feasible to conduct a risk analysis with several interest groups. It reveals where there is agreement between which groups on different topics and where there is conflict potential. This creates the basis for a transparent discussion of risks and their avoidance.

In an initial application of the new development, we succeeded in developing a "Climate Change Strategy" with the Borough Council of Merton in London, and involving blocks of flats and small commercial enterprises. In addition to construction of a combined heat and power station based on biogas technology, the strategy foresees the installation of 150 kWp PV and wind power systems within the Borough. Applying the climate change strategy, new buildings in the south-east of the Borough can be supplied with electricity and heat without causing large CO_2 emissions. The use of local resources also results in cost savings for the Borough.

The work is being carried out within the EU-funded project, "Local New Energy Technology Implementation LETIT".

http://letit.energyprojects.net

The tool is available to the public at the following website: http://www.rgesd-sustcomm.org/LETIT/TK_ENG_LETIT.htm

Further Development and Demonstration of the Linear Fresnel Collector

In our work on solar thermal power stations, one of our main topics in recent years was optimisation of the linear Fresnel collector on the basis of theoretical investigations. Parallel to this, the key components comprising the absorber pipe, secondary reflectors, primary reflector array and their control were developed to technical maturity. Now a direct-evaporation prototype is being constructed. We will analyse its power and operating performance in practice to establish a reliable basis for commercial power station projects. (Information on Fresnel collectors can also be found on page 38.)

Andreas Georg, Wolfgang Graf, Anna Heimsath, Christina Hildebrandt, Gabriel Morin, **Werner Platzer**, David Tovar, Andreas Gombert

Fig. 1: Photorealistic simulation of a linear Fresnel collector array.

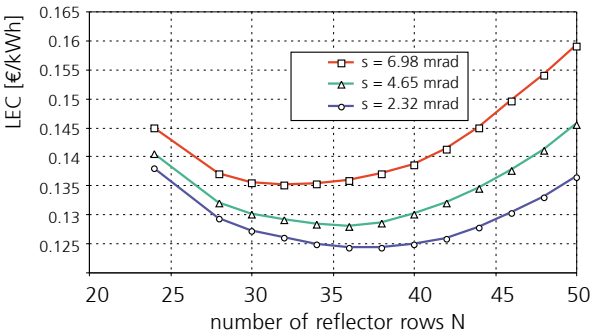


Fig. 2: Optimisation of the number of reflector rows with the goal of reducing the levellised electricity costs LEC. The curves are calculated for different values of the statistical deviation (s) from the ideal reflector form and position – the greater the deviation, the less accurate is the positioning of the sun's reflection on the receiver by the reflectors.

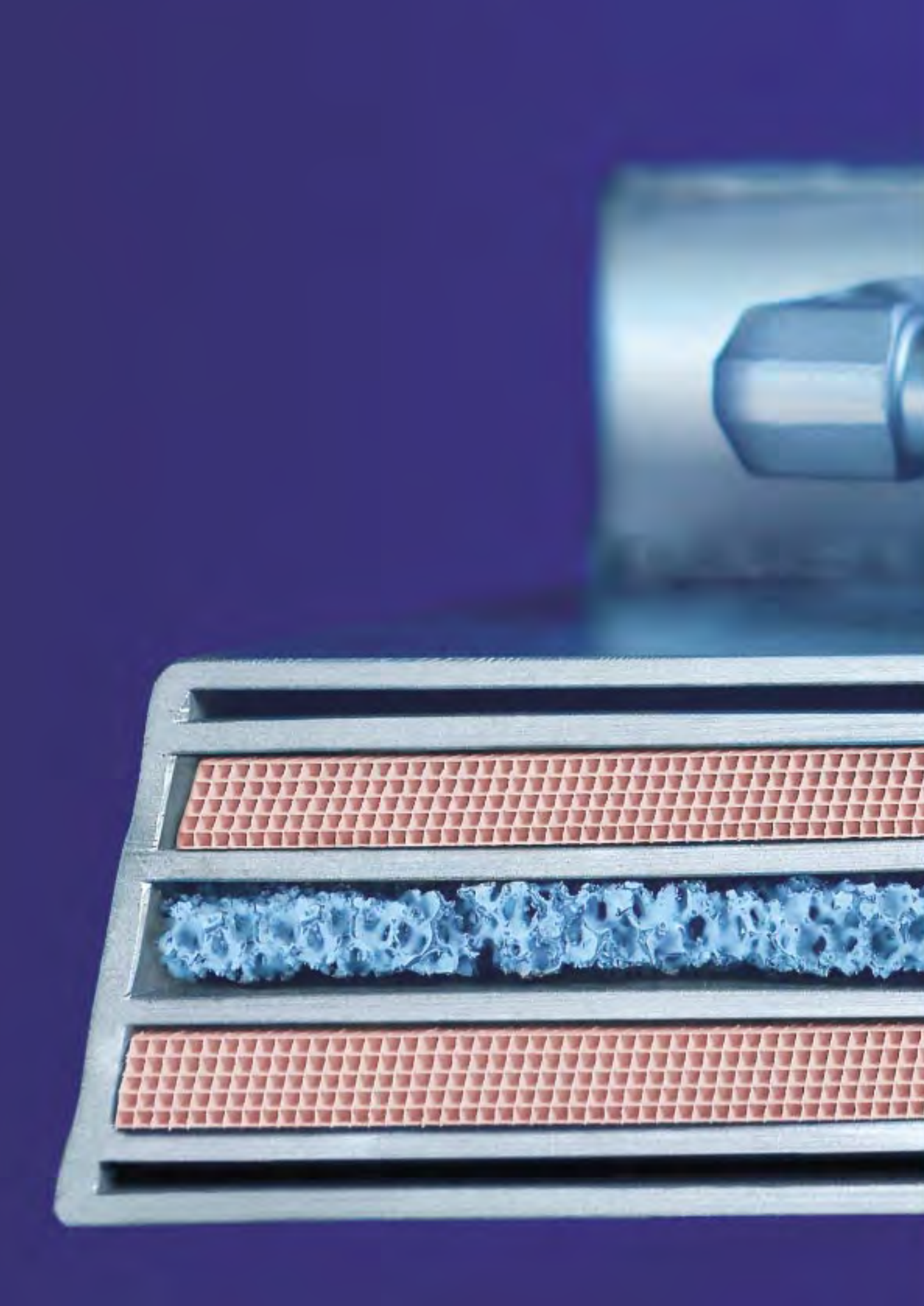
Single-axis tracking flat mirrors are used to concentrate solar radiation in solar thermal power stations with linear Fresnel collectors. A large proportion of the components needed consist of inexpensive standard items which are available almost everywhere in the world, allowing a high local share of added value and thus offering advantages compared to competing types of technology. Furthermore, the Fresnel technology is not sensitive to wind loads and allows parallel land use to a large extent.

Theoretically calculated, levellised electricity costs down to 0.12 €/kWh provide a basis for expecting that this type of collector will occupy a large share of the solar-thermal electricity generation market on the medium term. Nevertheless, this still has to be proven technically under real operating conditions.

Drawing on the materials development and component optimisation which has already occurred, we are constructing and monitoring a demonstration collector at the Plataforma Solar Almeria, co-operating with our industrial partner, MAN Ferrostaal Power Industries, and the German Aerospace Center DLR. In this project, Fraunhofer ISE is applying coated absorber pipes which are stable on exposure to air. The optimised secondary concentrator with a 14 cm absorber pipe, and primary reflectors which are configured and controlled as strings, ensure maximum absorption of the solar radiation.

The generated power and operating performance in practice will be analysed. Techniques for optical and thermal quality control of the Fresnel array, which can contribute significantly to reducing the costs and risks for future investors, are also being developed by Fraunhofer ISE.

Construction of the power station in Almeria is being supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU.



Electricity from hydrogen

Hydrogen Technology

Hydrogen releases usable energy in the form of electricity and heat when it reacts with oxygen in a fuel cell. As hydrogen is not found in its pure form in nature, it must be extracted from its diverse chemical compounds. This is achieved by applying energy. Ideally, regenerative energy is used in the form of renewably generated electricity for electrolysis. A second approach is the reforming of gaseous or liquid fuels, so-called hydrocarbons.

Although hydrogen is not a source of energy, as a universal fuel it will be an important component in the sustainable energy economy of the future. For example, a long-term perspective is that hydrogen be used to store fluctuating forms of renewable energy, so that all desired energy services can be provided with the accustomed reliability. The application potential of hydrogen is enormous: In distributed power supplies, fuel cells can supply heat and electricity from natural gas with a total efficiency value of up to 80 %. Fuel cells, combined with electric motors, serve in mobile applications as non-polluting engines for cars, trucks and buses. In addition, fuel cells in auxiliary power units (APU) provide electricity aboard ships. Finally, miniature fuel cells are

excellent alternatives or supplements to rechargeable batteries in off-grid power supplies or electronic appliances, due to the high energy density of hydrogen or methanol. Even though this application does not immediately represent a large contribution to our total energy supply, it is important in paving the way for the introduction of hydrogen systems.

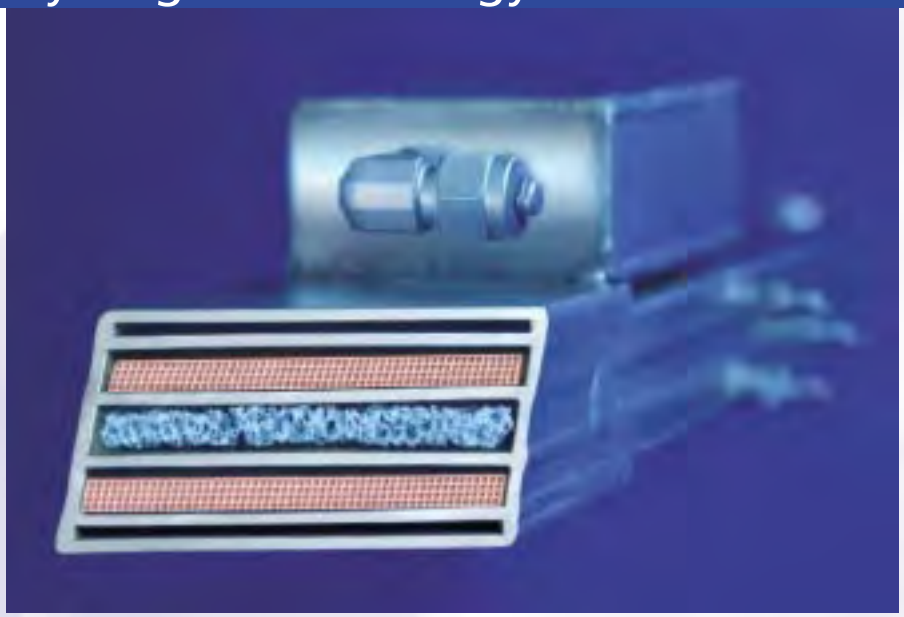
Innovative technology to obtain hydrogen and convert it efficiently to electricity and heat forms the core of our research for the hydrogen market sector. Together with our partners from science and industry, we develop components and complete fuel-cell systems, mainly for off-grid, portable and mobile applications.

We develop reformer systems to convert liquid hydrocarbons to gas. The systems consist of the actual reforming reactor and, depending on the type of fuel cell connected, gas treatment to raise the hydrogen concentration and reduce the amount of harmful compounds in the reformate gas. Such systems can be used in applications ranging from stationary combined heat and power plants, through auxiliary power units, to off-grid power supplies.

To obtain hydrogen from water, we construct controlled membrane electrolysis systems supplying power from a few watts up to about 2 kW, corresponding to the production of several hundred litres of hydrogen per hour. To gain deeper understanding of the processes occurring at the electrodes, we apply different characterisation methods, including scanning electron microscopy or cyclovoltammetry.

The membrane fuel cell, operating with hydrogen or methanol, is our favoured energy converter in the power range from milliwatts to several hundred watts, being efficient, environmentally friendly, quiet and requiring little maintenance. In addition to the well-known system configuration based on fuel cell stacks, we have focussed on flat, series-connected fuel cells in a single plane. This design is very suitable for integration into the surface of a casing or as part of a hybrid system in combination with a battery.

In addition to developing components and systems, we also work on the integration of fuel-cell systems into higher-order systems. We design and implement the electric infrastructure, including power conditioning and safety technology. In this way, we create the basis for commercially viable fuel cell systems. We offer fuel-cell systems for power supply aboard cars, trucks, ships or aeroplanes, stand-alone power supplies for off-grid applications, and miniature systems as portable power supplies.



Miniature steam reformer with a burner unit to convert ethanol and water into a gas rich in hydrogen. The carbon monoxide content of the product gas is reduced in subsequent gas purification steps. The reformer is combined with our PEM fuel cell to form a complete system with 300 W_{el}. The photo shows the central porous ceramic burner between two parallel honeycomb structures that are coated with catalyst. The system generates electricity for applications where high energy density, rapid start-up and high availability over long periods of time are demanded (see article on p. 96).

Contacts

Fuel cell systems	Dr Carsten Agert	Tel.: +49 (0) 7 61/45 88-53 46 E-mail: Carsten.Agert@ise.fraunhofer.de
Hydrogen production and storage	Dr Thomas Aicher	Tel.: +49 (0) 7 61/45 88-51 94 E-mail: Thomas.Aicher@ise.fraunhofer.de
Integration of fuel cells into stand-alone power supplies	Dr Matthias Vetter	Tel.: +49 (0) 7 61/45 88-56 00 E-mail: Matthias.Vetter@ise.fraunhofer.de
Power and control electronics for fuel cells	Dr Bruno Burger	Tel.: +49 (0) 7 61/45 88-52 37 E-mail: Bruno.Burger@ise.fraunhofer.de
Control strategies for fuel-cell CHP plants in buildings	Dr Christof Wittwer	Tel.: +49 (0) 7 61/45 88-51 15 E-mail: Christof.Wittwer@ise.fraunhofer.de
Marketing	Ulf Groos	Tel.: +49 (0) 7 61/45 88-52 02 E-mail: Ulf.Groos@ise.fraunhofer.de

Interdisciplinary Co-ordination

Hydrogen technology	Dr Christopher Hebling	Tel.: +49 (0) 7 61/45 88-51 95 E-mail: Christopher.Hebling@ise.fraunhofer.de
Off-grid power supplies	Dr Günther Ebert	Tel.: +49 (0) 7 61/45 88-52 29 E-mail: Guenther.Ebert@ise.fraunhofer.de
Buildings and technical building components	Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-51 34 E-mail: Hans-Martin.Henning@ise.fraunhofer.de

Planar Direct-Methanol Fuel Cells

Fuel cells in a planar configuration are particularly well suited to lengthen the operating time of portable electronic devices in the low power range beyond the values dictated today by rechargeable batteries. Continuing our previous work, in 2006 we developed a functional planar fuel cell system, which is based on printed circuit board technology that is suitable for mass production and uses liquid methanol as the fuel.

Carsten Agert, Steffen Eccarius, Thomas Jungmann, Martin Langhoff, **Michael Oszcipok**, Michael Schweighöfer, Andreas Wolff*, Mario Zedda, Christopher Hebling

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Fig. 1: Planar fuel cells can be integrated into the housing of devices and can be operated passively, i.e. without ventilators or pumps. We use inexpensive circuit boards and polymer materials with channel structures which we coat by individually optimised processes. Eight single cells are connected in series within one plane. This results in a higher voltage which is adapted to the specific load.

Planar fuel cells are particularly suitable for integration into device housing structures. They offer great potential for passive system configurations. This means that most of the energy-consuming peripheral components can be eliminated from the system design.

In our developments, we use mass-producible, inexpensive materials such as polymers. Our fuel cell designs based on printed circuit boards ensure that planar cells can also be operated safely with liquid fuels. In this respect, we have not only optimised the configurations with respect to fluid dynamics, but have also conducted extensive investigations of suitable coating technology to achieve stable and highly conductive surfaces for our basic components.

The fuel which we use for our planar fuel cell system is methanol, which features a high energy density. The fuel is stored in a separate, removable tank, which can be refilled. To achieve stable, continuous operation, we have developed electronic controls with a low power consumption. In this way, we have succeeded in reducing the internal peripheral losses to less than 10 % of the output power.

Our system is suitable both for connection to GPS navigation modules and to supply other electronic devices via a USB connection.

The work is supported within an InnoNet joint project by the German Federal Ministry for Economics and Technology BMWi.

Fig. 2: Clear structures and solid materials dominate the appearance of our planar direct-methanol fuel cell system. We can equally well integrate it into a logistics container to operate GPS/GPRS navigation modules or design it as a desktop variant with an elegant stand to charge electronic devices, e.g. via a USB connection. The tank in the upper part can be removed for refilling.

Fuel Cells for Robotics Systems

Service robotics, a major market for the future, is only at the beginning of its development today. Powerful, portable units supplying power of several hundred watts are a pre-requisite for the development of this sector. At Fraunhofer ISE, we have developed a fuel cell system that is adapted to these applications, where energy-efficient operation and optimised heat management are crucial.

Carsten Agert, Marco Zobel,
Jan Hesselmann, Chris Stöckmann,
Stefan Keller, Christopher Hebling

Mobile service robots represent a market of the future. Today, already autonomous vacuum-cleaning robots are commercially available, for example, and further products in the medical and safety sectors will follow in the near future. These applications generally have a high energy demand which must be supplied off-grid, and which cannot be met adequately by today's battery technology.

Together with the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS, we have developed a power supply based on fuel cells for the mobile VolksBot platform. The VolksBot is a robotics building-block system conceived by IAIS for educational and production development purposes. For this application, we have extended the power range of our hydrogen-based fuel cell systems at Fraunhofer ISE up to 500 W.

The core of the development was a fuel cell stack which was optimised for off-grid, portable applications. The stack is distinguished, for example, by very stable operation with relatively small amounts of excess air on the cathode side, which minimises the electric power losses due to the air compressor in the system. In addition, co-ordinated simulation and experimentation resulted in optimisation of the heat removal structures, allowing heat to be transported away by ventilator-driven air cooling.

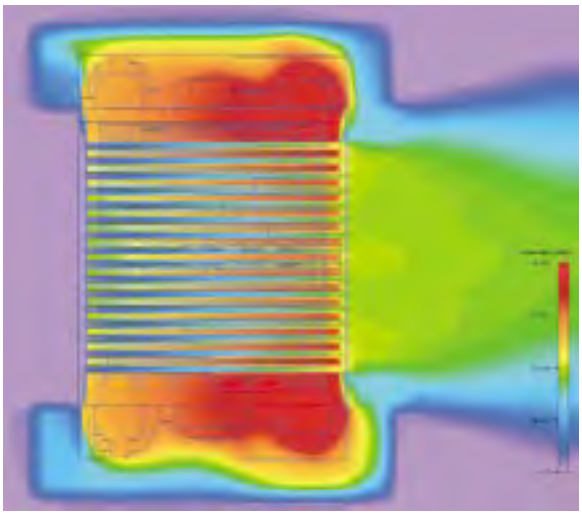


Fig. 1: Simulation of the thermal budget of the fuel cell stack that we have newly developed. The view from above is for a plane which passes directly through the cooling slits. To the left of the image is a ventilator which sends the cooling air to the right through the stack.

Fig. 2: Together with Fraunhofer IAIS, we are developing a fuel-cell power supply for the robotics platform, "VolksBot RT". The photo shows a three-wheeled version (w x h x d: 540 x 410 x 630 mm^3), in which the fuel cell has already been integrated. The laser scanner in the blue unit at the front is used for navigation purposes.

The developed fuel cell system is also suited to supply power in the range up to 500 W for other off-grid applications. In future, it can be combined in a further step with reformer systems for liquid fuels, which would again significantly improve the operational power of the connected applications.

Model-Based Design of Fuel Cell Systems

We develop multi-scale simulation tools to accelerate the design process for fuel cells and fuel cell systems. Based on integrated simulations from the micro-structure scale to the systems scale, we optimise fuel cell components, fuel cell stacks and complete systems.

Carsten Agert, Dietmar Gerteisen, Tim Heilmann, Julia Hermann, Simon Philipps, Kay Steinkamp, **Christoph Ziegler**, Christopher Hebling

Development and construction of fuel cells is currently based to a large extent on experimental experience gained during the construction of prototypes. Improvements are usually achieved by iterating construction cycles, an expensive and time-consuming process. This development process can be supported by available computer models, which are used to analyse power losses, diagnose operating states and manage operation safely and efficiently. The models mostly describe either the components of the fuel cell, an individual fuel cell, a fuel cell stack or a fuel cell system. By contrast, the development of models which describe the microstructure of the materials used in fuel cells is only just beginning.

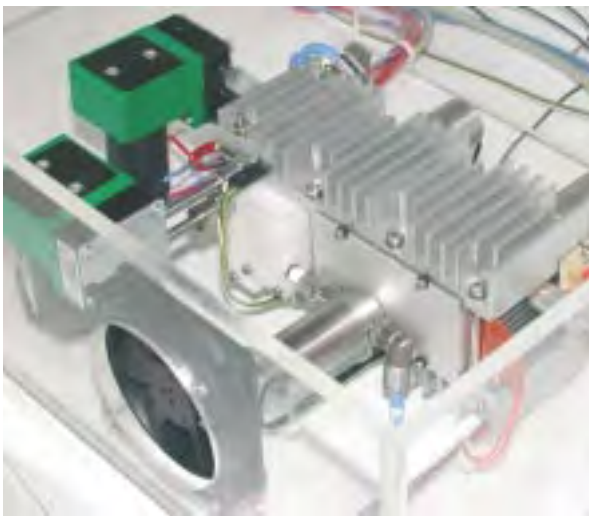


Fig. 1: The photo shows a portable fuel cell system, which was housed in transparent PMMA for demonstration purposes. The fuel cell stack with its cooling fins and the peripheral system components, pumps and fans, are clearly visible.

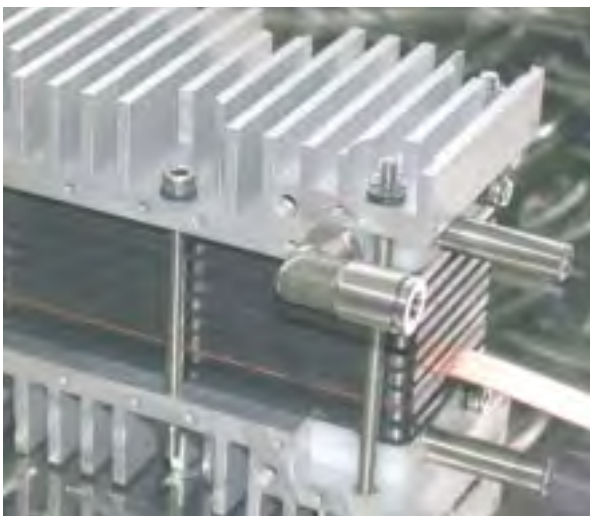


Fig. 2: Close-up photo of a fuel cell stack. The individual cells of the stack are located between the end plates, which also act as cooling elements. The cells are connected to each other by conductive plates, so-called bipolar plates.

Time-dependent simulation of fuel cell stacks, which takes the stack geometry completely into account, exceeds the computing capacity which can be managed by established models. However, highly developed computer models are needed for targeted and rapid optimisation of fuel cells and their components, which reproduce all essential aspects from the material microstructure through to the functional system. The concept needed here is called scale transition.

Within a joint project led by Fraunhofer ISE, computer models for fuel cell systems are being prepared which allow, for the first time, simulations to be made for all scales from the component micro-structure through to a complete fuel cell system.

By following an interdisciplinary approach, we can couple the models at the system scale, the stack scale and the component scale. Networking between scientists working in fundamental mathematical research and applied scientists is a notable feature of this project. On the one hand, this makes the development of novel, specific mathematical methods feasible, and on the other hand, it ensures that they will be applicable to fuel cell technology.

The project on which this report is based is supported by funding from the German Federal Ministry for Education and Research BMBF.

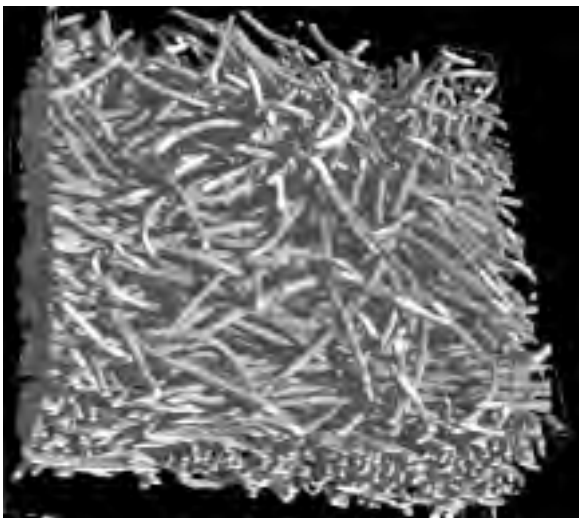


Fig. 3: Synchrotron tomographic image of a porous transport layer or a gas diffusion layer. The high spatial resolution allows the individual carbon fibres to be identified very clearly. The figure shows a section with an edge length of 600 micrometres.

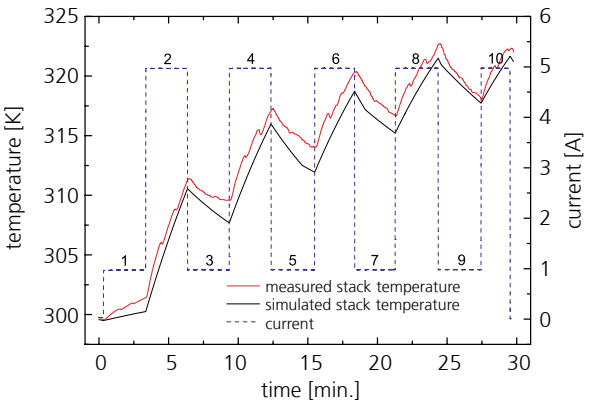


Fig. 4: The temperature of a fuel cell stack is decisive for the stack power and for reliable and efficient control. The figure allows comparison of the measured (red) and simulated (black) temperatures.

Portable Fuel Processor for Hydrogen Production

Fuel cells in combination with a fuel processor present an option for supplying power when neither photovoltaics nor batteries are suitable. We have now established the scientific basis at Fraunhofer ISE for developing a portable, off-grid fuel processor. The fuel processor, or reformer, can process a variety of liquid fuels and produces hydrogen-rich gas that can be used as a fuel for PEM fuel cells, when it includes appropriate gas purification steps.

Thomas Aicher, Lisbeth Rochlitz,
Achim Schaadt, Christopher Hebling

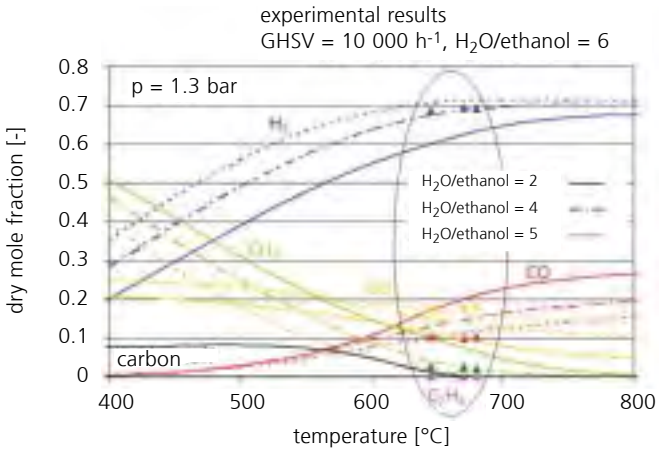


Fig. 1: Measured (symbols) and calculated (curves) values for the dry composition of the product gas from ethanol steam reforming at 1.3 bar. The measurements show that thermal equilibrium has been achieved with the catalyst used and the chosen operating conditions. However, the ethylene measured in the experiment should not have been formed according to the equilibrium simulation.

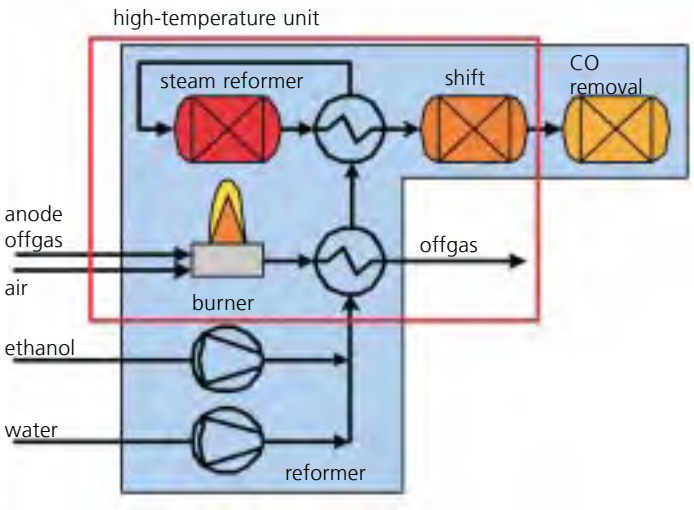


Fig. 2: Schematic diagram of the miniature reformer. The system components which were combined within the high-temperature unit are identified by the red frame. The burner is operated with the offgas from the anode of the fuel cell, and provides the heat that is needed for steam reforming.

In many applications, fuel cells combined with a miniature reformer offer considerable advantages, when compared to photovoltaic modules or batteries, as electric power supplies in the range between 100 and 500 W. This is the case when the required electric power would demand very large PV modules or when the electricity must be available over periods of time that would result in rapid discharging of the batteries. Reformer-fuel cell systems present decisive benefits for such situations, because they exploit the high storage density of liquid fuels. Measurement stations located at sites with difficult access are one example for such applications. Equipment with a power demand of several hundred watts which is used off-grid, for example for emergency medical services, on yachts, for camping, in robotics or disaster control systems, also falls into this category.

In this context, we are developing a small, portable steam reformer which converts ethanol to a hydrogen-rich gas that can be used to generate electricity in a fuel cell.

We started by establishing the scientific basis for designing the reformer system. Optimal operating conditions were determined for the catalysts used and their long-term performance was investigated. Drawing on this information, we are now developing a fully automated, miniature reformer system. Important results are summarised briefly in the following paragraphs.

In our miniature reformer, three different catalysts are used (for the steam reforming, shift and selective methanisation processes). We initially investigated their operating behaviour in laboratory test rigs. We concentrated on maximising the conversion rate and minimising the reactor volume. The investigated catalysts are commercially available, and are deposited on ceramic honeycomb structures or pellets.

Results for the steam reforming catalyst are presented in fig. 1. It is evident that chemical equilibrium is achieved in the selected temperature range under the chosen operating conditions (gas hourly space velocity GHSV = 10000 h^{-1}, water/ethanol ratio of 6). We determined the chemical equilibrium by simulation with CHEMCAD. The proportion of undesired by-products was negligible in the chosen temperature range.

To investigate the long-term stability of catalysts for the CO shift process, we designed a test rig which can be operated fully automatically. With it, a catalyst can be subjected to certain operating conditions for hundreds of hours, and the change in the conversion rate and the product gas composition can be monitored. In a long-term experiment lasting 400 hours, we tested a CO shift catalyst at 320 °C in a typical reformate gas mixture consisting of H_2O, H_2, CO_2, CO, CH_2 and C_2H_4. The initial concentration of CO in the dry gas was 6.7 mole percent. The CO conversion rate dropped from 87 % to 85 % and the CO content increased from 0.9 to 1.1 mole percent.

Knowing the best operating conditions and the expected conversion rates for the catalysts, we designed a miniature reformer system for a PEM fuel cell with a net electric power rating of 300 W. The reforming reactor itself was integrated, together with the evaporator and superheater for the product flows (water and ethanol) and the burner, in a high-temperature unit.

The work is supported by the German Federal Ministry for Economics and Technology BMWi as part of an InnoNet project and by the Deutsche Bundesstiftung Umwelt DBU (German Federal Environmental Foundation) with a Ph.D. scholarship.

Fig. 3: High-temperature unit. The evaporator and superheater can be seen to the left. The actual steam reforming reactor is connected at the lower right. Above it is the two-stage shift reactor. The various pipe connectors serve as inlets and outlets for the various reactants and products, and also for connecting temperature sensors.

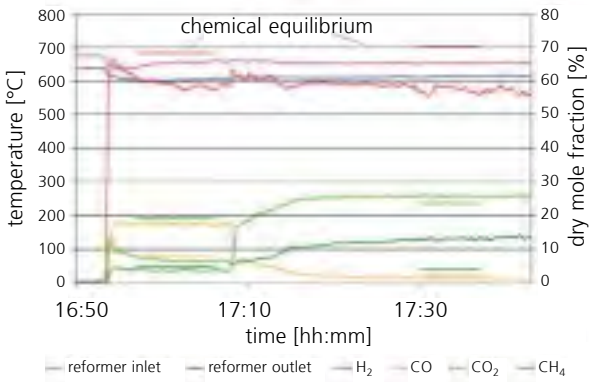


Fig. 4: Measured gas composition at the outlet of the reformer (until shortly before 17:10) and the shift reactor (subsequent values). The temperature difference between the inlet and outlet to the catalyst honeycomb is 50 K. Thermodynamic equilibrium is not achieved completely. This can be attributed to the inhomogeneous temperature distribution in the reactors and the fact that the catalyst already produces methane from CO, in addition to the shift reaction.

Portable PEM Pressure Electrolyser for a Decentralised Supply of Hydrogen

In addition to energy applications in fuel cells, hydrogen is required in many other applications, e.g. in laboratories, for medical technology or for welding. However, a pressurised gas cylinder is not always available and often its capacity is insufficient. For this reason, we have developed a compact unit, which can reliably produce very pure hydrogen, is simple to operate and requires minimal maintenance.

Beatrice Hacker, Jan Hesselmann, **Thomas Jungmann**, Tom Smolinka, Christopher Hebling

Fig. 1: Microprocessor-based control and safety monitoring make reliable operation feasible.

The core of the hydrogen generator is a PEM cell stack for pressure electrolysis, consisting of injection-moulded bipolar plates. The cell stack is integrated into a completely automated and user-friendly system. The controls are operated via a display and buttons. The pressure electrolyser is designed to charge metal hydride storage capsules for fuel cell applications with hydrogen. The hydrogen is supplied at approximately 10 bar with a rate of max. 100 Nl/h and a purity of 4.0. Storage units with a capacity of up to 250 Nl can be charged. An integrated gas drying unit, consisting of a membrane module and a molecular sieve, guarantees low-maintenance operation. If required, an ion exchanger module can be included, so that it is not necessary to use de-ionised water.

With this system, the final consumer can independently produce the hydrogen he/she requires, and does not depend on complicated and expensive logistic infrastructure.

The project was supported by the German Federal Ministry for Economics and Technology BMWi and was carried out together with partners from industry and research within the InnoNet Programme.

Fig. 2: Cell stack for the pressure electrolyser, in which the distribution structures are made cost-effectively out of polymer materials. The stack consists of 15 single cells.

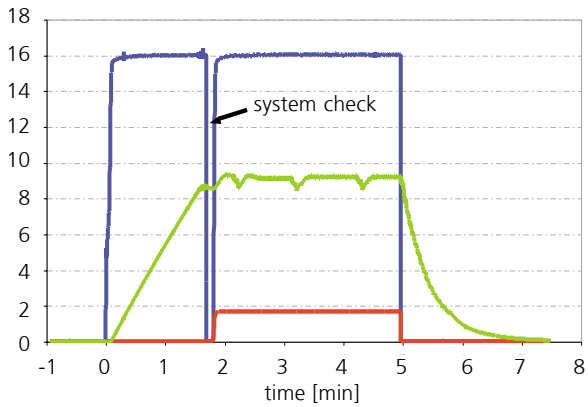


Fig. 3: Variation of operating parameters while the pressure electrolyser is switched on and off (blue: current [A]; red: H_2 production rate [Nl/min]; green: system pressure [bar]).

From Diesel to Synthesis Gas

At Fraunhofer ISE, we have succeeded in developing a very simple process which converts diesel to synthesis gas with the help of partial oxidation. We have subjected this process to extensive tests in the laboratory, which showed promising results. There is now nothing to prevent the process from being applied in the automobile industry to treat exhaust gas or to produce hydrogen for fuel cell systems.

Thomas Aicher, Henri Schiemann, Christopher Hebling

Catalytic partial oxidation (CPO) is the preferred reforming process for auxiliary power units based on fuel cells in mobile applications. It is then unnecessary to transport water or recover it by complex procedures. This process also presents a promising approach for treating car exhaust by preparing a combustible gas for subsequent oxidation.

However, partial oxidation is a reforming process which tends to form soot readily, particularly when the fuel contains many aromatic and long-chained hydrocarbon molecules. This is particularly critical for diesel, because it cannot be evaporated, in contrast to other liquid hydrocarbons. For this reason, diesel has had to be injected in liquid form into the reactor chamber of the reformer through nozzles. This could not guarantee formation of a homogeneous mixture over a large load range.

Our novel process, which was developed jointly with a Swiss engineering office, starts at just this point. The patented process converts diesel to the gas phase and subsequently reforms it by CPO without formation of soot or residues. The diesel is evaporated from the bottom of a slightly tilted cylinder by thermal radiation from above. The resulting diesel "vapour" is then mixed with a little air and oxidised sub-stoichiometrically in a CPO honeycomb catalyst (fig. 1).

Soot deposits were not observed anywhere when the reactor was inspected at the end of each experiment. The concentration of unsaturated hydrocarbons is also very low – the ethylene (C_2H_4) concentration (< 0.2 vol. %) is shown in fig. 2 as an example. It can be assumed from this that no soot is deposited in the reformer catalyst either.

The diesel reformer has already been developed to the stage that we could now co-operate with industrial partners to bring it to series production.

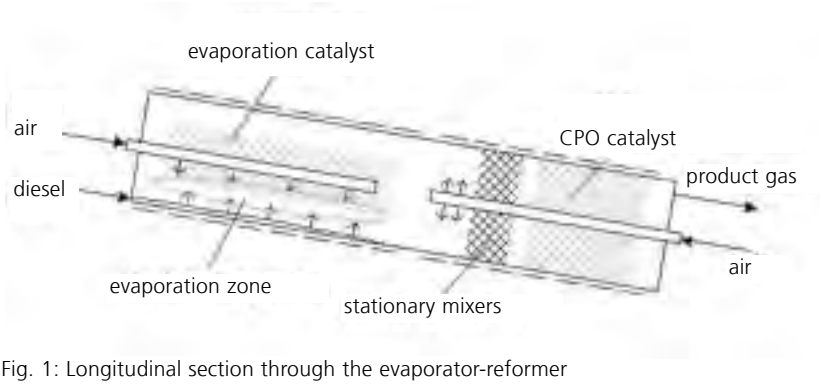


Fig. 1: Longitudinal section through the evaporator-reformer reactor. The internal diameter of the reactor is 30 mm, the total length is about 300 mm. It can be used to convert diesel with a rate of up to 10 kW (lower heating value).

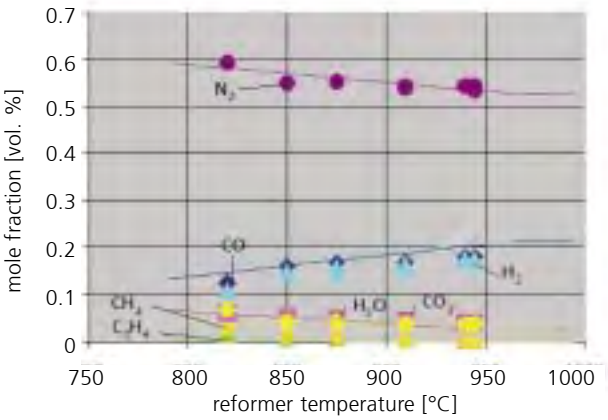


Fig. 2: Experimentally determined gas composition (symbols) for reformer temperatures between 825 and 950 °C. It agrees well with thermodynamic equilibrium (lines).

Quality convinces

Service Units

In the booming solar industry, the role of materials testing, certification and quality control is becoming increasingly significant. As a complement to our research and development work, we offer our clients associated testing and certification services. At present, Fraunhofer ISE has four accredited testing units: the Testing Centre for Thermal Solar Systems, the Thermal-Optical Measurement Laboratory, the Test Centre for Photovoltaics and the ISE Calibration Laboratory CalLab. Further service units include a test facility for compact heating and ventilation units, a laboratory for quality control of phase change materials (PCM) and a battery testing laboratory.

Beyond the services provided, these units have a strategic function for us. While the client can have products characterised and certified, we benefit from information about the current state of the technology and the market. In turn, the insights gained can become the kernel for new research topics, be it in product development, further development of testing methods and standards, or theoretical analysis and modelling.

The Testing Centre for Thermal Solar Systems has been accredited by DAP (Deutsches Akkreditierungssystem Prüfwesen GmbH) since May 2005. The testing facilities include:

- outdoor test stand with a tracker
- indoor test stand with a solar simulator (max. aperture area 3 m x 3.5 m)
- collector test stand up to 200 °C
- system and storage tank test stand

Most of the work involves commissions from the industry to test collectors according to European collector standards such as the SOLAR KEYMARK label. A new feature is the extension of the collector test stand to allow testing at temperatures up to 200 °C. This makes it feasible to test new applications such as generating process heat and to conduct stagnation tests (see article on p. 107).

The Thermal-Optical Measurement Laboratory TOPLAB was accredited according to DIN EN ISO/IEC 17025 in 2006. It offers a comprehensive range of characterisation for innovative building components and materials to developers and planners of façades, façade components and windows, including shading devices (see article on p. 108).

The following properties can be tested at TOPLAB:
- g value: calorimetric measurement
- transmittance: spectral and broadband measurements
- reflectance: spectral and broadband measurements
- U value: guarded hot-plate measurement

The Test Centre for Photovoltaics was also accredited in 2006, including testing for product type approval of PV modules according to IEC 61215 and 61646. The Test Centre is part of an entire complex concentrating on durability analysis of PV modules. The goal of the facility is to ensure the quality and reliability of PV modules. It is closely linked to ISE CalLab - Modules and to module development at the Institute. Tests are carried out to accompany the development of modules and module components. Similarly, quality assurance is carried out in co-operation with module producers. The co-operating "Certification Body" is the VDE (see article on p. 105).

The fourth accredited laboratory, having gained this status in November 2006, is ISE CalLab, which is one of the international leaders in this field. The calibration of solar cells and modules plays an important role in product comparisons and for quality assurance of PV systems. Cell calibration serves as a reference for industry and research. We are continually improving the measurement techniques to calibrate modules. At present, the accuracy of our precision measurement, including a correction for the spectral response, is ± 2 % (see article on p. 104).

Service Units

Solar calorimeter to determine the total solar energy transmittance (g value). This test rig is part of the Thermal Optical Measurement Laboratory at Fraunhofer ISE. The laboratory has been accredited according to DIN EN ISO/IEC 17025 since 2006. The internationally recognised accreditation of the laboratory's testing expertise encompasses tests of the g value, transmittance, reflectance and thermal transmittance (U value). It is a so-called "flexible accreditation", which covers not only standard procedures but also the further-reaching procedures which we have developed at Fraunhofer ISE. The g value measurement is an example for such a procedure (see article on p. 24).

Contacts

ISE CalLab			
	Cell calibration	Dr Wilhelm Warta	Tel.: +49 (0) 7 61/45 88-51 92 E-mail: Wilhelm.Warta@ise.fraunhofer.de
		Astrid Ohm	Tel.: +49 (0) 7 61/45 88-54 23 E-mail: Astrid.Ohm@ise.fraunhofer.de
	Module calibration	Klaus Kiefer	Tel.: +49 (0) 7 61/45 88-52 18 E-mail: Klaus.Kiefer@ise.fraunhofer.de
		Frank Neuberger	Tel.: +49 (0) 7 61/45 88-52 80 E-mail: Frank.Neuberger@ise.fraunhofer.de
Durability analysis			
	Test Centre for Photovoltaics (TZPV)	Michael Köhl	Tel.: +49 (0) 7 61/45 88-51 24 E-mail: Michael.Koehl@ise.fraunhofer.de
Testing Centre for Thermal Solar Systems (PZTS)			
	Indoor and outdoor test stands for solar collectors	Matthias Rommel	Tel.: +49 (0) 7 61/45 88-51 41 E-mail: Matthias.Rommel@ise.fraunhofer.de
		Arim Schäfer	Tel.: +49 (0) 7 61/45 88-53 54 E-mail: Arim.Schaefer@ise.fraunhofer.de
	Solar air collector test stand	Matthias Rommel	Tel.: +49 (0) 7 61/45 88-51 41 E-mail: Matthias.Rommel@ise.fraunhofer.de
Measurement of building façades and transparent components			
	Thermal-Optical Measurement Laboratory (TOPLAB)	Tilmann Kuhn	Tel.: +49 (0) 7 61/45 88-52 97 E-mail: Tilmann.Kuhn@ise.fraunhofer.de
	Daylighting measurement rooms	Jan Wienold	Tel.: +49 (0) 7 61/45 88-51 33 E-mail: Jan.Wienold@ise.fraunhofer.de
Ventilation units and heat pumps			
	Test stand	Dr Benoît Sicre	Tel.: +49 (0) 7 61/45 88-52 91 E-mail: Benoit.Sicre@ise.fraunhofer.de
Photovoltaic system components			
	Inverter characterisation	Dr Bruno Burger	Tel.: +49 (0) 7 61/45 88-52 37 E-mail: Bruno.Burger@ise.fraunhofer.de
Qualification testing and optimisation of PV systems			
	Battery testing laboratory	Dr Rudi Kaiser	Tel.: +49 (0) 7 61/45 88-52 28 E-mail: Rudi.Kaiser@ise.fraunhofer.de

ISE CalLab - Calibration of Solar Cells and Modules

The characterisation of solar cells and modules plays an important role in research and development, as well as production. It is vital for product comparison, and quality assessment of photovoltaic systems.

Jochen Hohl-Ebinger, Britta Hund, Jürgen Ketterer, Klaus Kiefer, Frank Neuberger, Peter Raimann, Wilhelm Warta

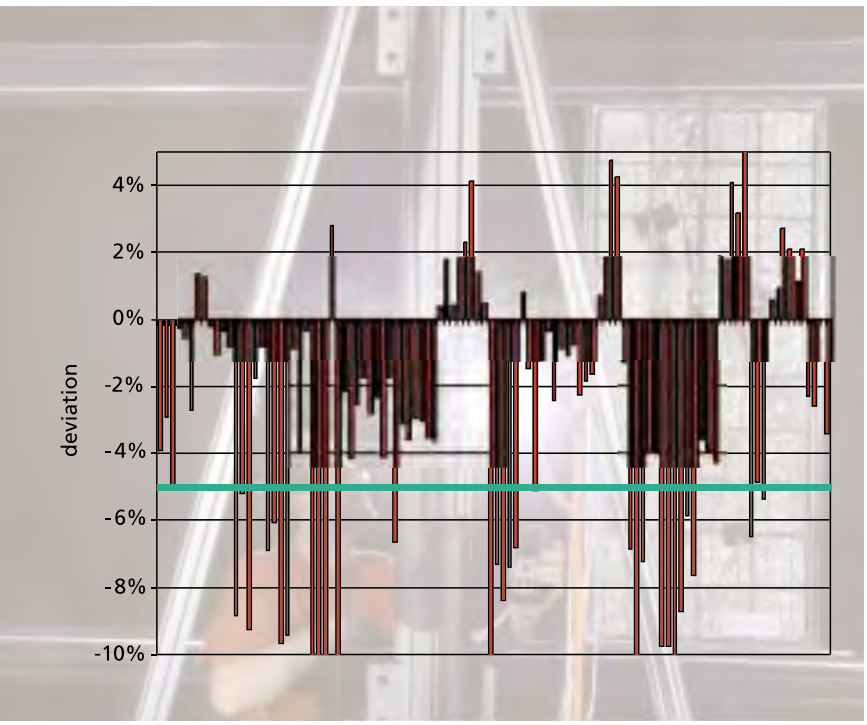


Fig. 1: The performance of photovoltaic modules with an area of up to 4 m² can be measured at Fraunhofer ISE with a high-precision, pulsed solar simulator. The measurement accuracy is ± 2% for precision measurements of the power under standard test conditions STC. A measurement test series of 100 PV modules demonstrated that quality control is important. Many modules do not deliver the rated power and even fall outside the tolerance range of -5 %. On average, the module power was 3.4 % below the rating.

ISE CalLab is one of the internationally leading photovoltaic calibration laboratories. Module and cell manufacturers commission us to calibrate their reference modules and cells for production. Also TÜV Rheinland, the German technical authorisation body, has its reference cells measured by ISE CalLab. Our clients receive exceptional service and security, because

- we guarantee the accuracy of our results by participating regularly in round-robin tests with other internationally recognised measurement laboratories
- we observe international standards in all calibration steps and in the use of reference elements and measurement facilities
- we process clients' enquiries rapidly and without unnecessary bureaucracy, and guarantee confidentiality.

Cell calibration - references for research and industry

We undertake complete characterisation of solar cells and detectors with areas up to 16x16 cm². Our service offer includes:

- calibration of reference cells, standard solar cells, concentrator cells and tandem cells
- spectral response measurement
- determination of the temperature dependence of the output power

Module calibration - an efficient quality control method

For PV modules up to an area of 2x2 m², our range of services comprises:

- precise module measurement with a pulsed solar simulator
- determination of the NOCT temperature and power
- measurement of the angular and temperature dependence of the module parameters
- measurement of the dependence of module parameters on the irradiation intensity

In November 2006, ISE CalLab - Modules was accredited according to DIN EN ISO/IEC 17025:2005. The accreditation of ISE CalLab – Cells will be completed soon.

Detailed information on our services can be found under www.callab.de.

Test Centre for Photovoltaics

A new centre to test the reliability of photovoltaic modules has been established. With the completion of the accreditation process in 2006 according to ISO 17025 and IEC EE, it has become an authorised "Testing Laboratory" for the "Certification Body", VDE, and carries out tests for product type approval complying with IEC 61215 and 61646.

Michael Köhl, Stefan Brachmann, Markus Heck, Tilmann Kuhn

The enormous growth in the photovoltaic industry has greatly increased the need to test the performance and durability of photovoltaic modules, to guarantee quality for the consumers in a global market. Thus, Fraunhofer ISE has extended its relevant testing facilities and offers its services to module manufacturers in co-operation with VDE, which is a "Certification Body" of the IEC EE.

The following module tests are conducted in the Test Centre:
- insulation resistance
- wet leakage currents
- mechanical loads
- temperature cycling
- damp heat
- humidity-freeze cycling
- UV irradiation (fig. 1)
- nominal operating cell temperature (NOCT, fig. 2)
- hot spot endurance
- bypass diode thermal test
- robustness of connection box
- outdoor exposure

The ISE CalLab (see p. 104), one of the leading laboratories for power measurements of modules, carries out the STC (standard test conditions) power measurements after the individual tests.

In setting up the module tests, we have ensured that the standard test procedures can be applied reproducibly, simply and safely. At the same time, we have allowed ourselves sufficient freedom for variation of the testing parameters, so that we can participate actively in the further development of tests within relevant research projects or co-operate in company-specific R&D projects to develop innovative module concepts.

Fig. 1: UV test stand for photovoltaic modules with dimensions up to 1.4 x 2.4 m².

Fig. 2: Outdoor test stand to determine the "nominal operating cell temperature" (NOCT). The single-axis tracker allows the required testing times to be shortened.

Characterisation and Qualification Testing of Electric Components

In addition to photovoltaic cells and modules, we measure, test and evaluate complete PV systems as well as individual system components. These include not only inverters and charge controllers, but also DC components such as lamps, batteries or television sets.

Rudi Kaiser, Bruno Burger, Heribert Schmidt

Measurement and Testing of Ventilation Equipment

We make test-stand and field measurements for manufacturers and developers of compact ventilation units with integrated heat pumps.

Andreas Bühring, Martina Jäschke*, Christian Bichler, Matthias Schubert, Daniel Kühn, Sebastian Herkel

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Battery Testing Laboratory

We test and qualify all common technological types and designs of batteries for manufacturers, system integrators and users. Flexibly programmable systems are available to apply whichever charging and load profiles are needed. We also offer long-term tests lasting several months in the laboratory and the field. Developers of charge controllers and charging devices can have their equipment tested and optimised in connection with the corresponding batteries.

Fig. 1: In the climatic chamber, not only efficiency and capacity but also the aging and charging performance of storage batteries can be investigated under variable conditions.

Test facility for compact ventilation and heating units

With our automated test facility, we measure the energy efficiency of complete units and their components. We can choose from a wide spectrum of testing conditions. From the measurements, we derive recommendations to optimise the components and their interaction. We support our clients in implementing new developments. Skilled staff with expertise on cooling technology and the necessary technical equipment are available.

Monitoring

In numerous occupied houses, we are measuring the performance of ventilation equipment with heat pumps from various manufacturers in practice. Possible fault causes are identified and corrected. From these measurements, we prepare proposals to optimise the equipment and controls.

Measurements of air tightness and air exchange rate

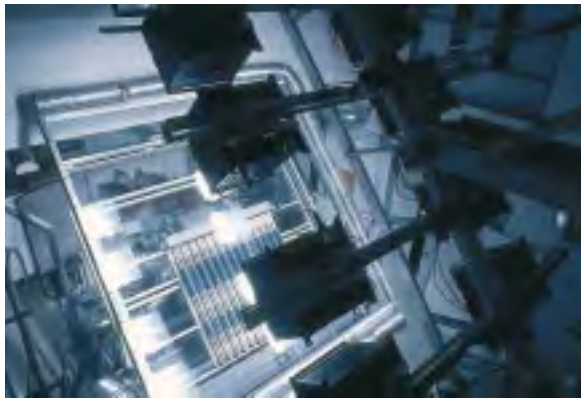
We measure the air tightness of ventilation units under real operating conditions with the help of a tracer gas, applying the constant injection method. This can be done either with the test stand or in situ in the building. We use the same equipment to determine the air exchange rate in buildings according to the concentration decay method.

Testing Centre for Thermal Solar Systems

We operate an outdoor test stand for thermal solar collectors. Our testing centre is authorised by DIN CERTCO and is fully accredited by DAP (Deutsches Akkreditierungssystem Prüfwesen). We certify solar collectors and support our clients in developing solar thermal system components. The indoor test stand with a large solar simulator has proved to be very valuable for testing and development work.

Korbinian Kramer*, Matthias Rommel, Arim Schäfer, Thorsten Siems

* PSE GmbH Forschung Entwicklung Marketing, Freiburg



Indoor test stand with solar simulator.

Certification of solar collectors

We test solar collectors and complete systems according to national or international standards and standard procedures:

- SOLAR KEYMARK label
- collector testing according to DIN EN 12975, parts 1 and 2
- all relevant functionality tests
- determination of the thermal performance
- calculation of the annual energy yield
- direct measurement of the incidence angle modifier (IAM) with a tracker
- DIN tested label
- system test according to DIN EN 12976, parts 1 and 2

Collector and system development

We co-operate closely with manufacturers of solar systems, both within projects or as part of individual product development. We offer:

- detailed thermographic investigations (e.g. of thermal bridges)
- determination of the collector efficiency factor F' of absorbers
- optimisation and calculation of the reflector geometry for collectors
- identification of collector heat capacity by dynamic response measurements
- characterisation of dynamic collector performance (low-flow, high-flow, matched-flow)

Indoor collector test stand with a solar simulator

We operate an indoor test stand with a solar simulator. Its great advantage, particularly for collector development, is the high reproducibility of the measurement conditions. This allows us to carry out targeted developmental work to improve collector constructions very efficiently and quickly.

The most important technical data are:

- test plane dimensions: 2.4x2 m^2. Other configurations of the test plane are possible (up to 3.5x3 m^2).
- irradiance: 1200 Wm^{-2} without the artificial sky, 1000 Wm^{-2} with the artificial sky
- homogeneity: ± 10 %
- lamp array tilt angle: 0–90 °

High-Temperature Testing Unit up to 200 °C

We have set up a new test rig, with which we can measure efficiency curves for temperatures up to 200 °C. This means that it is now feasible to carry out experimental development of process heat collectors.

Test stand for solar air collectors

We operate a test stand for solar air collectors. It is integrated into the indoor test stand with the solar simulator, so we can guarantee short measurement times, independent of the weather. The solar air collectors are tested analogously to DIN EN 12975. Air flow rates of 50 m^3h^{-1} to 1000 m^3h^{-1} can be measured with a maximum uncertainty of ± 1 %.

Beyond that, we offer the following services

- measurement of the pressure loss of solar air collectors as a function of the throughput
- determination of air leakage rates
- support for manufacturers in new and further development of products
- calculation of the annual energy yield for different solar air collectors

Measurement of Building Façades and Transparent Components

We offer a comprehensive range of detailed and accurate characterisation for innovative building components and materials to developers and planners of façades, façade components and solar components. A special laboratory, which has been accredited according to DIN EN ISO IEC 17025, is available to determine the optical and thermal properties of transparent components and sun-shading systems. Further equipment includes a daylighting measurement container and an outdoor test facility.

Ulrich Amann, Angelika Helde, Tilmann Kuhn, Werner Platzer, Jan Wienold, Helen Rose Wilson

Thermal-Optical Measurement Laboratory TOPLAB and Lighting Laboratory

Existing measurement procedures such as those specified in DIN EN 410 or DIN EN 13363 do not describe the properties of advanced glazing and façade constructions sufficiently reliably. Thus, we have developed testing and evaluation procedures to characterise energy and lighting-technology effects accurately. Our equipment allows us to measure elements of more than 1 m^2 area, which have the following properties:

- light scattering and light redirection
- macroscopic structures and patterns
- angle-selective properties
- properties which change with time such as switchable transmittance (photochromic, thermotropic or electrochromic)
- air flow within the façade
- integrated photovoltaics

Different user profiles can also be taken into account in the evaluation procedures.

Standard testing procedures round off our range of services. We determine the spectral properties of glazing, films and surfaces for our clients with UV-vis-IR spectrometers.

Fig. 1: Solar calorimeter to determine the total solar energy transmittance (g value). The corresponding methodology developed by Fraunhofer ISE has been accredited according to DIN EN ISO IEC 17025 since 2006.

Examples of equipment

- solar calorimeter to determine the total solar energy transmittance of transparent components and sun-shading devices
- thermal resistance measurements on glazing units according to EN 674
- angle-dependent transmittance and reflectance measurements with a large integrating sphere
- measurement of the angular distribution of transmitted and reflected light with a photogoniometer

The laboratory has been accredited according to DIN EN ISO IEC 17025 since 2006. It is a so-called "flexible accreditation", which encompasses not only standard procedures but also the further-reaching procedures which we have developed at Fraunhofer ISE to determine g value, transmittance, reflectance and U value. The German building code recognises our laboratory's determination of the g value (total solar energy transmittance). Some of the development of testing procedures was publicly funded.

Daylighting measurement rooms

The daylighting measurement rooms consist of two identical office rooms, located side-by-side in a container. They can be rotated, so that any desired façade orientation can be chosen. Meteorological data and the global illuminance on the vertical plane of the façade is measured and recorded. The following investigations are conducted in the measurement rooms:

- glare protection tests
- user acceptance studies
- comparison of the lighting situation behind two façade systems

Façade testing facility

In addition to laboratory measurements, we offer the measurement of complete façades under real climatic conditions. Long-term investigations provide information on the stability, switching performance and loads on the façade. The optimisation of controllers can be experimentally validated.

Facts and Figures

Visiting Scientists

Kevin Beard
University of South Carolina
Columbia, South Carolina USA
15.7. - 15.12.2006
Research area: Electrocatalysis

Benjamin Gonzales Diaz
Universidad de La Laguna
Tenerife, Spain
31.1.2005 - 31.12.2007
Research area: Solar cell technology

Prof. Gregor Henze
University of Nebraska
Omaha, Nebraska, USA
1.9.2005 - 30.6.2006
Research area: Building technology

Dr Thoi H. Lee
University of Nebraska
Omaha, Nebraska, USA
1.4.2005 - 30.9.2006
Research area: Building technology

Darja Markova
Technical University of Riga
Riga, Latvia
1.2.2006 - 31.1.2007
Research area: Micro-reformers

Isabel Salamoni
Universidade Federal de Santa Catarina UFSC
Florianópolis-SC, Brazil
1.5.2006 - 31.3.2007
Research area: Potential for renewable energy in Brazil

Prof. Shu Bifen
Sun Yat-sen University
Guangzhou, China
11.12.2006–11.12.2007
Research area: Thermal storage

Participation in National and International Organisations

Bavaria California Technology Center (BaCaTec)
- Board of Governors

BERTA AK – Brennstoffzellen: Entwicklung und Erprobung für stationäre und mobile Anwendungen (Arbeitskreis des BMWi)
- Mitglied

Bundesverband Kraft Wärme Kopplung (B.KWK)
- Mitglied

CAN in Automation (CiA)
- Mitglied

Club zur Ländlichen Elektrifizierung C.L.E.
- Mitglied

Deutsche Elektrotechnische Kommission (DKE)
- Komitee 373: »Photovoltaische Solarenergiesysteme«
- Komitee 384: »Brennstoffzellen«
- Arbeitsgruppe »Portable Fuel Cell Systems«

Deutsche Gesellschaft für Sonnenenergie
- »Fachausschuss Wärmepumpen«

Deutscher Wasserstoff- und Brennstoffzellen-Verband e.V.
- Mitglied

Deutsches Institut für Normung DIN, Fachnormenausschuss Heiz- und Raumluft-technik (NHRS AA1.56) »Solaranlagen«
- Mitglied

Deutsches Institut für Normung DIN, Fachnormenausschuss Lichttechnik (FNL 6) »Innenraumbeleuchtung mit Tageslicht«
- Mitglied

Deutsches Institut für Normung DIN, Normenausschuss Bau NABau 00.82.00 »Energetische Bewertung von Gebäuden«
- Mitglied

EU PV Technology Platform, Steering Committee, Brussels
- Vice-Chairman

EU PV Technology Platform, Working Group Science, Technology & Applications (WG3)
- member

European Committee for Standardisation CEN TC33 / WG3 / TG5
- member

European Desalination Society
- member

European Fuel Cell Group
- member

European H2/FC Technology Platform
- member

European Photovoltaic Industry Association (EPIA)
- associate member

European Solar Thermal Industry Federation (ESTIF)
- member

Evergreen Solar, Marlboro, USA
- scientific advisory board

Fachinstitut Gebäude-Klima (FGK)
- Arbeitskreis »Sorptionsgestützte Klimatisierung«

Fachverband Transparente Wärme-dämmung e.V.
- Mitglied
- Fachausschuss »Produktkennwerte«

»Perspektiven für Zukunftsmärkte« Fraunhofer Innovationsthemen: Mikroenergietechnik
- Mitglied und Leitung

FiTLicht – Fördergemeinschaft innovative Tageslichtnutzung
- Mitglied

Förderprogramm »Haus der Zukunft« des Österreichischen Bundesministeriums für Verkehr, Innovation und Technologie
- Mitglied in der Jury

Forschungsallianz »Brennstoffzellen«, Baden-Württemberg
- Mitglied

ForschungsVerbund Sonnenenergie (FVS)
- Mitglied

Fraunhofer-Gesellschaft
- Senat (bis März 2006)

Fraunhofer-Verbund Energie
- Geschäftsführung

Freiburger Verein für Arbeits- und Organisationspsychologie
- Vorstand

German Scholars Organization (GSO)
- President

Global Research Alliance (GRA)
- Co-ordination of Thematic Focus on Energy (until March 2006)

Global Village Energy Partnership (GVEP)
- member

GMM VDE/VDI Gesellschaft Mikroelektronik, Mikro- und Feinwerktechnik
- Fachausschuss 4.8 »Werkstoffe und Fertigungsverfahren«

Hauptkommission des Wissenschaftlich-Technischen Rates der Fraunhofer-Gesellschaft
- Vorsitz (bis März 2006)

IEC TC82 WG/ for IEC Qualification Standard: Concentrator Photovoltaic (PV) Receivers and Modules – Design Qualification and Type Approval
- member

Institut für Solare Energieversorgungstechnik (ISET)
- Wissenschaftlicher Beirat

International Commission on Glass (ICG)
- TC10 »Optical Properties of Glass«

International Energy Agency IEA, Paris, France:
Solar Heating & Cooling Programme SHCP
- Task 25: »Solar Assisted Air-Conditioning of Buildings«
- Task 27: »Performance of Solar Façade Components«
- Task 28: »Sustainable Solar Housing«
- Task 33/4 »Solar Heat for Industrial Processes«
- Task 37 »Advanced Housing Renovation«
- Task 38 »Solar Air-Conditioning and Refrigeration«

Energy Conservation in Buildings and Community Systems Programme ECBCS
- Annex 47 »Cost Effective Commissioning«
  Energy Conservation through Energy Storage Programme ECES
- Annex 18 »Transportation of Energy utilizing Thermal Energy Storage Technology«
  Heat Pump Programme HPP
- Annex 32 »Economical Heating and Cooling Systems for Low Energy Houses«

International Program Committee of GADEST (International Conference on Gettering and Defect Engineering in Semiconductors)
- member

International Program Committee of ICDS (International Conference on Defects in Semiconductors)
- member

International Advisory Committee of SIMC (Semiconducting and Insulating Materials Conference)
- member

International Science Panel on Renewable Energies (ISPRE)
- Chairman

Kompetenz- und Innovationszentrum Brennstoffzelle (KIBZ), Stuttgart
- Mitglied

Kompetenzfeld Photovoltaik NRW
- Mitglied

Kompetenznetzwerk Brennstoffzelle NRW
- Mitglied

Lichttechnische Gesellschaft
- Mitglied

M&EED Monitoring and Evaluation Working Group for Global Village Energy Partnership (GVEP) and European Union Energy Initiative (EUEI)
- member

MST Mikrosystemtechnik
- Beirat

Strategierat Wasserstoff – Brennstoffzellen
- Mitglied
- AK Wasserstoffbereitstellung
- AK Wasserstoffspeicherung

Symposium Photovoltaische Solarenergie
- Wissenschaftlicher Beirat

VDE-ETG Fachausschuss V.I.I. Brennstoffzellen
- Mitglied

VDI-Gesellschaft Technische Gebäudeausrüstung
- Richtlinienausschuss 6018

VDMA - The German Engineering Federation
Productronics Association / Dachverband Deutsches Flachdisplay-Forum (DFF);
Arbeitsgemeinschaft Organic Electronics Association (OE-A)
- Mitglied

Verein Deutscher Elektrotechniker
- ETG-Fachausschuss »Brennstoffzellen«

Verein Deutscher Ingenieure (VDI)
VDI-Gesellschaft Energietechnik
- Fachausschuss »Regenerative Energien« (VDI-FARE)

Verein Deutscher Ingenieure VDI-TGA 6018 »Behaglichkeit in Räumen«
- Mitglied

VMPA – Verband der Materialprüfämter e.V.
- Sektorgruppe »Türen, Fenster und Glasprodukte«

Weiterbildungszentrum (WBZU) »Brennstoffzelle«, Ulm
- Mitglied im Aufsichtsrat

Zentrum für Sonnenenergie- und Wasserstoffforschung (ZSW)
- Kuratorium

Congresses, Conferences and Seminars organised by the Institute

OTTI-Fachforum »Lüftungstechnik«
Regensburg, 24.–25.1.2006

Tagung der Katholischen Akademie Freiburg
»Zukunft für möglich halten«
Freiburg, 3.–4.2.2006

Kooperationsforum Hocheffiziente Photovoltaik
Garching, 22.2.2006

Workshop SiliconFOREST2006
Fortschritte in der Entwicklung von Solarzellen-Strukturen und Technologien
Falkau, 19.–22.2.2006

21. Symposium Photovoltaische Solarenergie
Bad Staffelstein, Kloster Banz 8.–10.3.2006

4th World Conference on Photovoltaic Energy Conversion
Hawaii, USA, 7.–12.5.2006

3rd European Conference PV-HYBRID and MINI-GRID,
Aix-en-Provence, France, 11.–12.5.2006

16. Symposium Thermische Solarenergie
Bad Staffelstein, Kloster Banz 17.–19.5.2006

13th SolarPACES International Symposium
Sevilla, Spain, 20.–23.6.2006

OTTI-Profiseminar »Photovoltaik-Anlagen«
NOVOTEL Freiburg, 21.6.2006

Intersolar 2006
OTTI-Seminar »Solar Air-Conditioning – Experiences and Practical Application«
Freiburg, 22.6.2006

Intersolar 2006
Fraunhofer ISE-Kompaktseminare
»Photovoltaik-Anlagen – Optimale Erträge von PV-Anlagen. Ergebnisse aus dem Freiburger Performance Check«
»Solarzellentechnologien – Stand der Entwicklung und neue Konzepte«
Freiburg, 23.6.2006

Intersolar 2006
»PV Training für angehende Profis der Solarindustrie«
Freiburg, 22.6.2006

ENOB Workshop »Betriebsführung von Gebäuden«
Frankfurt, 6.–7.7.2006

OTTI-Profiseminar
»Leistungselektronik für erneuerbare Energiesysteme«
Regenstauf, 6.–7.7.2006

7th Conference on Phase Change Materials and Slurries
Dinan, France, 13.–15.9.2006

PTJ-Workshop »Wärmespeicherung und -transformation mit mikro- und mesoporösen Adsorbentien – Stand der Entwicklung und zukünftiger FuE-Bedarf«
Technische Fachhochschule Wildau,
19.–20.9.2006

ForschungsVerbund Sonnenenergie (FVS)
Jahrestagung 2006
»Forschung und Innovation für eine nachhaltige Energie«
Berlin, 21.–22.9.2006

OTTI-Profiseminar
»EMV und Blitzschutz für Solaranlagen«
Regensburg, 22.–23.9.2006

OTTI-Profiseminar
»Netzferne Stromversorgung mit Photovoltaik«
Freiburg, 27.–28.9.2006

2. Fachforum Solare Kühlung und Klimatisierung RENEXPO 2006
Augsburg 28.9.2006

Symposium zum Verbundvorhaben des BMWi LowEx – Heizen und Kühlen mit Niedrigenergie
Hamburg, 4.10.2006

Fraunhofer Symposium
Mikroenergietechnik »Power to Go«
Berlin, 10.10.2006

4. Forum Wärmepumpe
Berlin, 26.–27.10.2006

Statusseminar »Thermische Energiespeicherung« Projektträger Jülich und Ministerien BMWi, BMU
Freiburg, 2.–3.11.2006

Trade Fairs and Exhibitions

Swiss Innovation Forum
Baden, Switzerland, 27.1.2006

Nanotech 2006
Tokyo, Japan, 21.–23.2.2006

Hanover Trade Fair HMI 2006
»Hydrogen + Fuel Cells«
Joint stand with other Fraunhofer Institutes and the University of South Carolina
Hanover, 24.–28.4.2006

Hanover Trade Fair HMI 2006
»CLEAN ENERGY Themenpark«
Farbstoffsolarzellen
Hanover, 24.–28.4.2006

VDI Bautechnik – Bauen mit Glas
Transparente Werkstoffe im Bauwesen
Baden-Baden, 29.–30.5.2006

Healthy Buildings 2006
Lisbon, Portugal, 4.–8.6.2006

OPTATEC 2006
International Trade Fair for Future Optical Technologies, Components, Systems and Manufacturing
Frankfurt/Main, 20.–23.6.2006

Intersolar 2006
International Trade Fair and Congress for Solar Technology
Freiburg, 22.–24.6.2005

21st European Photovoltaic Solar Energy Conference and Exhibition
Dresden, 4.–8.9.2006

Fuel Cell Science & Technology
Torino, Italy, 13.–14.9.2006

f-cell – Die Brennstoffzelle
6. Forum für Produzenten und Anwender
Stuttgart, 25.–26.9.2006

Fraunhofer Symposium
Mikroenergietechnik »Power to Go«
Berlin, 10.10.2006

Glasstec
Düsseldorf, 24.–28.10.2006

Electronica 2006
München, 14.–17.11.2006

Lecture Courses and Seminars

Dr. Bruno Burger
»Leistungselektronische Systeme für regenerative Energiequellen«
Vorlesung WS 06/07
Universität Karlsruhe
Fakultät für Elektrotechnik und Informationstechnik

Dr. Andreas Bühring
»Technische Gebäudeausrüstung«
Vorlesung WS 06/07
Fernstudiengang Energiemanagement
Universität Koblenz-Landau

Dr. Dietmar Borchert
»Photovoltaik«
Vorlesung SS 06
TFH Georg Agricola zu Bochum
Fachbereich Maschinentechnik

Priv. Doz. Dr. Andreas Gombert
»Optische Eigenschaften von Mikro- und Nanostrukturen«
Vorlesungen SS 06 und WS 06/07
Albert-Ludwigs-Universität Freiburg
Fakultät für Angewandte Wissenschaften

Elke Gossauer
»Solare Energiesysteme«
Vorlesung SS 06
Staatliche Akademie der Bildenden Künste Stuttgart
Fachbereich Architektur und Design

Prof. Dr. Joachim Luther
Dr. Stefan Glunz
»Photovoltaische Energiekonversion«
Vorlesung SS 06
Albert-Ludwigs-Universität Freiburg
Fakultät für Physik

Dr. Jens Pfafferott
»Solares Bauen«
Vorlesung WS 06/07
Fernstudiengang Energiemanagement
Universität Koblenz-Landau

Dr. Werner Platzer
»Modul Solarthermie im Master-Fernstudiengang Energiemanagement«
Präsenzveranstaltung WS 05/06 und WS 06/07
Universität Koblenz-Landau

Prof. Dr. Roland Schindler
»Halbleitertechnologie I (Technologie)«
Vorlesung WS 06/07
»Halbleitertechnologie II (Bauelemente)«
Vorlesung SS 06
»Photovoltaik I«
Vorlesung WS 06/07
»Photovoltaik II«
Vorlesung SS 06
Fernuniversität Hagen
Fakultät für Mathematik und Informatik
Fachrichtung Elektrotechnik und Informationstechnik

Dr. Heribert Schmidt
»Photovoltaische Systemtechnik«
Vorlesung SS 06
Universität Karlsruhe
Fakultät für Elektrotechnik und Informationstechnik

Priv. Doz. Dr. Volker Wittwer
Dr. Stefan Glunz
»Innovative Energieversorgungssysteme«
Vorlesung WS 05/06
Albert-Ludwigs-Universität Freiburg
Fakultät für Angewandte Wissenschaften

Prof. Dr. Gerhard Willeke
»Grundlagen von Halbleiterbauelementen und der optischen Datenübertragung«
Vorlesung SS 06
Universität Konstanz
Fachbereich Physik

Doctoral Theses

Alexander Hakenjos
"Entwicklung und Anwendung impedanzspektroskopischer und anderer Charakterisierungsmethoden für PEM-Brennstoffzellen"
(Development and application of impedance-spectroscopic and other characterisation methods for PEM fuel cells)
University of Freiburg, 2006

Stefan Janz
"Amorphous Silicon Carbide for Photovoltaic Applications"
University of Constance, 2006

Thomas Kieliba
"Zone-Melting Recrystallization for Crystalline Silicon Thin-Film Solar Cells"
University of Constance, 2006

Jörg Mick
"Interferenzlithographie mit hochaufbauenden Resistsystemen" (Interference lithography with photoresist suitable for structures of high aspect ratio)
University of Freiburg, 2006

Michael Oszcipok
"Start- und Abschaltvorgänge in außentauglichen, portablen Brennstofzellen unter 0 °C"(Starting and stopping processes in portable fuel cells suitable for outdoor conditions below 0 °C)
University of Freiburg, 2006

Moritz Riede
"Identification and analysis of key parameters in organic solar cells"
University of Constance, 2006

Ronald Sastrawan
"Photovoltaic modules of dye solar cells"
University of Freiburg, 2006

Günther Walze
"Mikrostrukturierte Oberflächen in Kombination mit optischen Schaltungsmechanismen zum Tageslichtmanagement" (Micro-structured surfaces in combination with optical switching mechanisms for daylighting management)
University of Freiburg, 2006

Winfried Wolke
"Kathodenzerstäubung zur Beschichtung von kristallinen Silizium-Solarzellen" (Application of sputtering to coat crystalline silicon solar cells)
University of Freiburg, December 2005

Uli Würfel
"Untersuchung zum Elektronentransport im nanoporösen TiO_2 von Farbstoffsolarzellen"
(Investigations on electron transport in the nanoporous TiO_2 of dye solar cells)
University of Freiburg, 2006

Patent Applications

Alexander Susdorf, Peter Hübner, Albert Chigapov, Brendan Carberry
"Modified hopcalite catalyst, procedure for its production and its application"

Hans-Martin Henning, Walter Mittelbach
"Thermally driven heat pumps for heat transformation and cooling. Application and implementation forms for vehicle air-conditioning"

Frank Dimroth, Andreas Bett, Matthias Meusel (AZUR Space Solar Power GmbH), Gerhard Strobl (AZUR Space Solar Power GmbH)
"Monolithically integrated semiconductor reflectors for monolithic multi-junction solar cells of III-V semiconductor compounds"

Kuno Mayer, Sybille Baumann, Daniel Kray, Bernd O. Kolbesen
"Procedure for micro-structuring of solid surfaces"

Axel Maurer, Klaus Wanninger, Herbert Wancura
"Reforming higher hydrocarbons with added water from combustion flue gas"

Heribert Schmidt, Bruno Burger
"Protective switching device for a solar module"

Stefan Reber, Gerhard Willeke
"Procedure for dry-chemical treatment of substrates and its application"

Ferdinand Schmidt, Hans-Martin Henning, Gunter Munz, Andrea Berg, Gerald Rausch
"Adsorption heat pump, adsorption chiller and adsorption elements for them based on an open-pored, thermally conductive solid"

Andreas Georg, Wolfgang Graf, Josef Steinhart, Volker Wittwer
"Optically transparent, lightweight construction element"

Heribert Schmidt, Bruno Burger
"Circuit design to convert DC voltage into AC voltage or AC current"

Heribert Schmidt, Bruno Burger
"Circuit design to generate an AC voltage or an AC current"

Uli Würfel, Marius Peters
"Solar cell"

Daniel Kray, Daniel Biro, Ansgar Mette
"Procedure and device to structure a surface layer"

Daniel Kray, Stefan Reber
"Procedure and device for local doping of solids and its application"

Kuno Mayer, Sybille Baumann, Daniel Kray, Bernd O. Kolbesen
"Procedure to ablate material from solids and its application"

Steffen Eccarius, Christian Litterst, Peter Koltay
"Procedure and operation of a direct oxidation fuel cell and corresponding design"

Kuno Mayer, Daniel Kray, Bernd O. Kolbesen
"Procedure to ablate material from solids and its application"

Tilmann Kuhn, Christoph Mayrhofer, Jürgen Frick, Michael Hermann, Jan Wienold, Volker Wittwer
"Splinter shield with optical and thermal functionality"

Steffen Eccarius
"Direct oxidation fuel cell for convection-free transport of the fuel and procedure to operate the fuel cell"

Steffen Eccarius, Christian Litterst, Peter Koltay
"Direct oxidation fuel cell and procedure for its operation"

Kuno Mayer, Sybille Baumann, Daniel Kray
"Etching procedure to ablate material from solids and its application and the corresponding device"

Kuno Mayer, Bernd O. Kolbesen
"Liquid-jet guided etching procedure to ablate material from solids and its application"

Philipp Ettel, Markus Bergmann, Daniel Kray, Fridolin Haas
"Wire saw with variable wire pitches"

Ferdinand Schmidt, Tomas Núñez, Lena Schnabel, Gunther Munz
"Adsorption heat pump with thermal storage unit"

Andreas Wolff, Marco Tranitz, Thomas Jungmann, Michael Oszcipok
"Fuel cell module and its application"

Ansgar Mette, Christian Schetter, Stefan Glunz, Philipp Richter
"Procedure to produce a metallic contact structure of a solar cell"

Michael Hermann, Tilmann Kuhn
"Partly transparent solar collector with a sun-shading function"

Michael Hermann, Tilmann Kuhn
"Partly transparent stationary sun-shading device"

Daniel Kray
"Procedure and device for drying a work piece and/or keeping a work piece dry during liquid-jet guided processing of a work piece"

Tilmann Kuhn
"Glazing unit/pane with angle-selective transmission"

Rüdiger Löckenhoff
"Solar cell module with solar cells in a shingled configuration"

Mónica Alemán, Ansgar Mette, Stefan Glunz, Ralf Preu
"Procedure to apply electric contacts to semi-conductive subtrates, semi-conductive substrate and application of the procedure"

Ivan Brovchenko, Alla Oleinikova, Alfons Geiger, Ferdinand Schmidt, Stefan Henninger
"Adsorbent and its application in thermal storage units and heat pumps"

Andreas Hahn, Ferdinand Schmidt, Stefan Henninger
"Adsorbent, procedure to produce it and application in thermal storage units and heat pumps"

Harry Wirth
"Cell connector for electrically contacting planar current sources and its application"

Andreas Grohe, Jan-Frederik Nekarda, Oliver Schultz
"Procedure for metallisation of semiconductor components and its application"

Patents Granted

Michael Hermann
"Procedure for designing a hydraulic network for optimised heat transfer and material transport"

Adolf Goetzberger, Thomas Kuckelkorn
"Device for light redirection and obstruction for stationary application in a translucent building façade for targeted lighting of an interior room"

Ralf Preu, Eric Schneiderlöchner, Stefan Glunz, Ralf Lüdemann
"Procedure to produce a semiconductor-metal contact through a dielectric layer"

Ralf Lüdemann, Sebastian Schaefer
"Procedure to produce contact structures in semiconductor components"

Andreas Schmitz, Christopher Hebling, Bruno Burger, Robert Hahn
"Fuel cell system constructed with printed circuit boards"

Frank Dimroth
"Device and procedure for photovoltaic generation of hydrogen"

Axel Heitzler, Christopher Hebling, Andreas Schmitz
"Fuel cell system and procedure to regulate pressure in fuel cell systems and application of the fuel cell system"

Heribert Schmidt, Christoph Siedle, Jürgen Ketterer
"Inverter and procedure to convert an electric DC voltage to an AC current"

Adolf Goetzberger, Thomas Kuckelkorn
"Device for light redirection for illumination of an interior room"

Mario Zedda, Angelika Heinzel, Roland Nolte
"Fuel cell for high output voltages"

Andreas Hinsch, Andreas Georg, Michael Niggemann
"Solar cell and procedure to produce it"

Armin Zastrow
"Measurement device to measure photo catalytic activity of a photocatalytic film"

Adolf Goetzberger, Manuel Goller, Michael Müller
"Optical element of the type of a linear Fresnel lens and application of the optical element as protection against glare from direct sunlight"

Dominik M. Huljic
"Procedure for structured application of a thermoplastic paste onto a substrate and its application"

Lothar Matejcek, Angelika Heinzel, Konstantin Ledjeff-Hey
"Electrochemical cell"

Tilmann Kuhn, Hans-Peter Baumann, Rolf Brunkhorst
"Slat for a venetian blind"

Daniel Biro, Catherine Voyer, Jörg Koriath
"Doping mixture for doping semiconductors"

Press Releases

www.ise.fraunhofer.de/english/press/index.html

06.03.2006
2006 Solar Heating and Cooling Award Recipient, Dr. Volker Wittwer – International Energy Agency IEA acknowledges outstanding achievements for solar thermal energy

21.03.2006
Research Factory for Solar Cells – German Minister for the Environment, Sigmar Gabriel, inaugurates the Photovoltaic Technology Evaluation Center PV-TEC

26.03.2006
Communications instead of copper – Fraunhofer ISE electronics manages new energy sources in existing grid

12.04.2006
Advances in the manufacture of dye solar cells – Dye solar modules with glass frit sealing offer new design possibilities

20.04.2006
Fuel for micro fuel cells – Miniature electrolyzer for filling metal hydride storage systems

06.06.2006
Eicke Weber to be new director of Fraunhofer Institute for Solar Energy Systems ISE

22. 06.2006
Fraunhofer Institute for Solar Energy Systems in Freiburg 25 Years Old – From a Pioneer to the Technological Leader of a New Industry

26.06.2006
More Reliability with Hybrid PV – "EVEREST" supplies measurement station with electricity

03.07.2006
Ready for Take-Off – Fraunhofer ISE and DLR have developed a combined reformer fuel-cell system

12.09.2006
Adolf Goetzberger receives SolarWorld Einstein Award – SolarWorld Einstein Junior Award presented to young scientist Oliver Schultz

15.09.2006
Farewell ceremony for Joachim Luther as the Director of Fraunhofer ISE – A vision has become reality: booming solar sector on his 65th birthday

29.09.2006
PV as a Way to Alleviate Poverty – Solar Electricity Fosters Individual Economic Initiative in Lower Mekong

20.12.2006
EUROSOLAR honors Goetzberger with the European Solar Award 2006

Publications in reviewed journals

Aicher, T.; Lenz, B.; Gschnell, F.; Groos, U.; Federici, F.[1]; Caprile, L.[1]; Parodi, L.[1]
»Fuel Processors for Fuel Cell APU Applications«, in: Journal of Power Sources, Vol. 154 (2006), pp. 503–508
([1]: Ansaldo Fuel Cells, Genova, Italy)

Bardos, R.[1]; Trupke, T.[1]; Schubert, M.; Roth, T.
»Trapping Artifacts in Quasi-Steady-State Photoluminescene and Photoconductance Lifetime Measurements on Silicon Wafers«, in: Applied Physics Letters, 88, 053504 (2006),
([1]: Centre of Excellence for Advanced Silicon Photovoltaics and Photonics, University of New South Wales, Sydney, Australia)

Borchert, D.; González, B.[1]; Guerrero-Lemus, R.[1]; Haro-González, P.[1]; Hernández-Rodríguez, C.[1]
»Down-Conversion Properties of Luminescent Silicon Nanostructures Formed and Passivated in HNO_3-Based Solutions«, in: Thin Solid Films, Vol. 511–512 (2006), p. 473
([1]: Departamento de Física Básica, Universidad de La Laguna de Tenerife, Spain)

Burger, B.; Rüther, R.[1]
»Inverter Sizing of Grid-Connected Photovoltaic Systems in the Light of Local Solar Resource Distribution Characteristics and Temperature«, in: Solar Energy Journal, 80 (2006), pp. 32–45
([1]: Universidade Federal de Santa Catarina UFSC, Florianopolis, Brazil)

Fath, H.; El-Shall, F.; Vogt, G.; Seibert, U.
»A Stand Alone Complex for the Production of Water, Food, Electrical Power & Salts for the Sustainable Development of Small Communities in Remote Areas«, in: Desalination, Vol. 183 (2005), pp.13–22

Forberich, K.; Diem, M.[1]; Crewett, J.[2]; Lemmer, U.[3]; Gombert, A.; Busch, K.[1]
»Lasing Action in Two-Dimensional Organic Photonic Crystal Lasers with Hexagonal Symmetry«, in: Applied Physics B, Vol. 82, 3/2006, pp. 539–541
([1]: Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, Germany)
([2]: Photonics and Optoelectronics Group, LMU München, Germany)
([3]: Lichttechnisches Institut, Universität Karlsruhe, Germany)

Georg, A.; Georg, A.[1]; Krasovec, U.[2]
»Photoelectrochromic Window with Pt Catalyst«, in: Thin Solid Films, Vol. 502 (2006), pp. 246–251
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
([2]: Faculty of Electrical Engineering, University of Ljubljana, Slovenia)

Gschwander, S.; Schossig, P.; Henning, H.-M.
»Micro-Encapsulated Paraffin in Phase Change Slurries«, in: Solar Energy Materials & Solar Cells, 89/2006, pp. 307–315

Guter, W.; Bett, A. W.
»IV-Characterization of Tunnel Diodes and Multi-Junction Solar Cells«, in: IEEE Transactions on Electron Devices, Vol. 53, Issue 9, 2006, pp. 2216–2222

Hinsch, A.; Hore, S.[1]; Kern, R.[1]
»Implication of Device Functioning Due to Back Reaction via the Conducting Glass Substrate in Dye Sensitized Solar Cells«, in: Applied Physics Letters, 87, 263504 (2005)
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Hogarth, W. H. J.[1]; Steiner, J.; Benziger, J. B.[2]; Hakenjos, A.
»Spatially Resolved Current and Impedance Analysis of a STR and Serpentine Fuel Flow Field at Low Relative Humidity«, in: Journal of Power Sources, Vol. 164 (2007), pp. 464–471
([1]: Centre for Functional Nanomaterials, University of Queensland, Australia)
([2]: Department of Chemical Engineering, Princeton University, New Jersey, USA)

Hoppe, H.[1]; Glatzel, T.[2]; Niggemann, M.; Schwinger, W.[3], Schäffler, F.[3]; Hinsch, A.; Lux-Steiner, M.[2]; Sariciftci, N.[1]
»Efficiency Limiting Morphological Factors of MDMO-PPV: PCBM Plastic Solar Cells«, in: Thin Solid Films, Vol. 511–512 (2006), pp. 587–592
([1]: Linz Institute for Organic Solar Cells LIOS, Linz, Austria)
([2]: Hahn-Meitner Institut, Berlin, Germany)
([3]: Institut für Halbleiter- und Festkörperphysik, Linz, Austria)

Hore, S.[1]; Vetter, C.; Kern, R.[1]; Smit, H.[2]; Hinsch, A.[1]
»Influence of Scattering Layers on Efficiency of Dye-Sensitized Solar Cells«, in: Solar Energy Materials & Solar Cells, 90/2006, pp. 1176–1188
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
([2]: Energy Research Center ECN, Solar Energy, Petten, The Netherlands)

Isenberg, J.; van der Heide, A.[1]; Warta, W.
»Investigation of Series Resistance Losses by Illuminated Lock-In Thermography«, in: Progress in Photovoltaics, Vol. 13 (2005), p. 687
([1]: Energy Research Center ECN Solar Energy, Petten, The Netherlands)

Janz, S.; Riepe, S.; Hofmann, M.; Reber, S.; Glunz, S.
»Phosphorous Doped SiC as an Excellent P-Type Si-Surface Passivation Layer«, in: Applied Physics Letters 88, 133516 (2006)

Janz, S.; Reber, S.; Lutz, F.; Schetter, C.
»Conductive SiC as an Intermediate Layer for CSITF Solar Cells«, in: Thin Solid Films, Vol. 511–512 (2006), pp. 271–274

Kieliba, T.; Riepe, S.; Warta, W.
»Effect of Dislocation on Minority Carrier Diffusion Length in Practical Silicon Solar Cells«, in: Journal of Applied Physics, 100, 063706 (2006)

Kray, D.
»Investigation of Laser-Fired Rear-Side Recombination Properties Using an Analytical Model«, in: Progress in Photovoltaics, Vol. 14 (2006), pp. 195–201

Kuhn, T. E.
»Solar Control: Comparison of Two Systems with the State of the Art on the Basis of a New General Evaluation Method for Facades with Venetian Blinds or Other Solar Control Systems«, in: Energy and Buildings, Vol. 38, (6/2006), pp. 661–672

Kuhn, T. E.
»Solar Control: A General Evaluation Method for Facades, Blinds or Other Solar Control Systems«, in: Energy and Buildings, Vol. 38, (6/2006), pp. 648–660

Litterst, C.[1]; Eccarius, S.; Hebling, C.; Zengerle[1], R.; Koltay, P.[1]
»Increasing DMFC Efficiency by Passive CO_2 Bubble Removal and Discontinuous Operation«, in: Journal of Micromechanics and Microengineering, Vol. 16 (2006), pp. 248–253
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Niggemann, M.; Glatthaar, M.; Lewer, P.; Müller, C.[1]; Wagner, J.[2]; Gombert, A.
»Functional Microprism Substrate for Organic Solar Cells«, in: Thin Solid Films, Vol. 511–512 (2006), pp. 628–633
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)
([2]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Núñez, T.; Mittelbach, W.; Henning, H.-M.
»Development of a Small-Capacity Adsorption System for Heating and Cooling Applications«, in: HVAC&R Research, An International Journal of Heating, Ventilating, Air-Conditioning and Refrigerating Research, Vol. 12 (2006), pp. 749–765

Lectures

Oszcipok, M.; Zedda, M.; Hesselmann, J.; Huppmann, M.; Wodrich, M.; Junghardt, M.; Hebling, C.
»Portable Proton Exchange Membrane Fuel-Cell Systems for Outdoor Applications«, in: Journal of Power Sources, Vol. 157 (2006), pp. 666–673

Oszcipok, M.; Zedda, M.; Riemann, D.; Geckler, D.
»Low Temperature Operation and Influence Parameters the Cold Start Ability of Portable PEMFCs«, in: Journal of Power Sources, Vol. 154 (2006), pp. 404–411

Papetrou, M.[1]; Epp, C.[1]; Teksoy, S.[2]; Sözen, S.[2]; Ortin, V.[3]; Seibert, U.; Vogt, G.
»Market Analysis for Autonomous Desalination Systems Powered by Renewable Energy in Southern Mediterranean Countries. Case Study on Turkey«, in: Desalination, Vol. 183 (2005), pp. 29–40
([1]: WIP – Erneuerbare Energien, München, Germany)
([2]: ITU Istanbul Technical University, Istanbul, Turkey)
([3]: ITC Canary Island Institute of Technology, Santa Lucía, Gran Canaria, Spain)

Reber, S.; Eyer, A.; Haas, F.
»High-Throughout Zone-Melting Recrystallization for Crystalline Silicon Thin-Film Solar Cells«, in: Journal of the Crystal Growth, Vol. 287/2006, pp. 391–396

Rein, S.; Glunz, S.
»Electronic Properties of Interstitial Iron and Iron-boron Pairs Determined by Means of Advanced Lifetime Spectroscopy«, in: Journal of Applied Physics, 98, 113711(1–12) 2005

Sastrawan, R.; Renz, J.; Prahl, C.; Beier, J.[1]; Hinsch, A.; Kern, R.
»Interconnecting Dye Solar Cells in Modules – I-V Characteristics under Reverse Bias«, in: Journal of Photochemistry and Photobiology A: Chemistry, Vol. 178 (2006), pp. 33–40
([1]: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany)

Sastrawan, R.[1]; Beier, J.[2]; Belledin, U.[1]; Hemming, S.[3]; Hinsch, A.; Kern, R.; Vetter, C.[2]; Petrat, F.[4]; Prodi-Schwab, A.[4]; Lechner, P.[5]; Hoffmann, W.[5]
»A Glass Frit-Sealed Dye Solar Cell Module with Integrated Series Connections«, in: Solar Energy Materials & Solar Cells, 90/2006, pp.1680–1691
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
([2]: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany)
([3]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)
([4]: Degussa AG, Creavis, Marl, Germany)
([5]: RWE Schott Solar GmbH, Alzenau, Germany)

Schmitz, A.; Tranitz, M.; Eccarius, S.; Weil, A.; Hebling, C.
»Influence of Cathode Opening Size and Wetting Properties of Diffusion Layers on Performance of Air-Breathing PEMFCs«, in: Journal of Power Sources, Vol. 154 (2006), pp. 437–447

Schossig, P.; Henning, H.-M.; Gschwander, S.; Hausmann, T.
»Micro-Encapsulated Phase-Change Materials Integrated into Construction Materials«, in: Solar Energy Materials and Solar Cells, 89/2006, pp. 297–306

Schubert, M.; Riepe, S.; Bermejo, S.; Warta, W.
»Determination of Spatially Resolved Trapping Parameters in Silicon with Injection Dependent Carrier Density Imaging«, in: Journal of Applied Physics, Vol. 99, 114908(1–6) 2006

Trupke, T.; Bardos, R.; Schubert, M.; Warta, W.
»Photoluminescence Imaging of Silicon Wafers«, in: Applied Physics Letters, 89, 44107(1–3) 2006

Wienold, J.; Christoffersen, J.
»Evaluation Methods and Development of a New Glare Prediction Model for Daylight Environment with the Use of CCD Cameras«, in: Energy and Buildings, Vol. 38 (7/2006), pp. 743–757

Yu, H.[1]; Schumacher, M.; Zobel, M.; Hebling; C.
»Analysis of Membrane Electrode Assembly (MEA) by Environmental Scanning Electron Microscope (ESEM)«, in: Journal of Power Sources, Vol. 145 (2005), pp. 216–222
([1]: Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China)

Yu, H.[1]; Ziegler, C.; Oszcipok, M.; Zobel, M.; Hebling, C.
»Hydrophilicity and Hydrophobicity Study of Catalyst Layers in Proton Exchange Membrane Fuel Cells«, in: Electrochimica Acta, Vol. 51(2006), pp. 1199–1207
([1]: Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China)

Yu, H.[1]; Ziegler, C.
»Transcient Behavior of a Proton Exchange Membrane Fuel Cell under Dry Operation«, in: Journal of the Electrochemical Society, Vol. 153(3) 2006, pp. A570–A575
([1]: Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China)

Ziegler, C.; Yu, H.[1]; Schumacher, J.
»Two-Phase Dynamic Modeling of PEMFCs and Simulation of Cyclo-Voltammograms«, in: Journal of Electrochemical Society, Vol. 152 (8) 2005, pp. A1555–A1567
([1]: Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China)

Aicher, T.; Rochlitz, L.
»Micro Reformer Fuel Cell System with a Few Hundred Watts Power Output«, 9th International Conference on Microreaction Technology IMRET, Berlin, Germany, 6.–8.9.2006

Aicher, T.; Rochlitz, L.
»Development of a Micro Reformer for PEM Fuel Cells«, 9th International Conference on Microreaction Technology, Potsdam, Germany, 6.–8.9.2006

Bett, A. W.
»Hochkonzentrierende PV mit Mehrfachsolarzellen auf Basis von GaAs-Zellen«, Hocheffiziente Photovoltaik Kooperationsforum, Garching, Germany, 22.2.2006

Bett, A. W.; Burger, B.; Dimroth, F.; Siefer, G.; Lerchenmüller, H.
»High-Concentration PV Using III-V Cells«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Bett. A. W.
»Mehrfachsolarzellen und Quantenstrukturen in Solarzellen«, Rundgespräch der Deutschen Forschungsgesellschaft – Grundlagenforschung für Photovoltaik, Bonn, Germany, 20./21.7.2006

Beyer, H.[1]; Friesen, G.[2]; Gottschalg, R.[3]; Williams, S.[3]; Reise, C.; Guerin de Montgareuill, A.[4]; van de Borg, N.[5]; de Moor, H.[5]; Koloenny, W.[6]; Prorok, M.[6]; Tdanowicz, T.[6]; Herrmann, W.[7]; Huld, T.[8]; de Kaizer, C.[9]
»Vergleich von Verfahren zur Abschätzung der Jahreserträge unterschiedlicher PV-Technologien im Rahmen des Projektes Performance – Ergebnisse eines ersten ›Round Robin‹ Tests«, OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006
([1]: Institut für Elektrotechnik, Hochschule Magdeburg-Stendal, Germany)
([2]: Scuola Universitaria Professionale Svizzera Italiana SUPSI , Lugano, Switzerland)
([3]: Loughborough University, United Kingdom)
([4]: Commissariat à l'Énergie Atomique, CEA, Cadarache, France)
([5]: Energy Research Center (ECN), Solar Energy, Petten, The Netherlands)
([6]: University of Technology, Wroclaw, Poland)
([7]: TÜV Rheinland, Köln, Germany)
([8]: European Commission, DG JRC, Ispra, Italy)
([9]: University Utrecht, The Netherlands)

Bopp, G.; Gabler, H.[1]; Haugwitz, F.[2]; Hong, L.[3]; Zhiming, L.[3]; Müller, H.[2] ; Steinhüser, A.
»Technical Monitoring of PV Village Power Supply in China«, PV Industry Forum, Intersolar, Freiburg, Germany, 21.6.2006
([1]: Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Stuttgart, Germany)
([2]: Deutsche Gesellschaft für Technische Zusammenarbeit, Beijing, China)
([3]: Qinghai Provincial New Energy Research Institute, Xining, China)

Bopp, G.
»Welche EMV-Normen und Grenzwerte sind für Solaranlagen relevant?«, OTTI Profiseminar, Regensburg, Germany, 22./23.11.2006

Bopp, G.
»Erzeugen PV-Anlagen Elektrosmog?«, OTTI Profiseminar, Regensburg, Germany, 22./23.11.2006

Bopp, G.
»Beispielhaft ausgeführter Blitzschutz bei Kollektoranlagen und netzgekoppelten PV-Anlagen«, OTTI Profiseminar, Regensburg, Germany, 22./23.11.2006

Bühring, A.; Bichler, C.; Jäschke, M.
»Aktueller Stand der Weiterentwicklung von Lüftungs-Kompaktgeräten«, Internationale Passivhaustagung, Hannover, Germany, 19./20.5.2006

Bühring, A.; Miara, M.; Russ, C.; Bichler, C.; Becker, R.
»Zwei Feldmessungen neuer Wärmepumpen gestartet«, Deutsche Kälte-Klima-Tagung, Dresden, Germany, 23.11.2006

Dimroth, F.; Peharz, G.; Wittstadt, U.; Hacker, B.; Bett, A. W.
»Solar Hydrogen Production in the Photovoltaic Concentrator HyCON«, E-MRS IUMRS ICEM; Symposium M: Materials, Devices and Prospects for Sustainable Energies, Nice, France, 29.5.–2.6.2006

Dimroth, F.; Baur, C.; Bett, A. W.; Köstler, W.[1]; Meusel, M.[1]; Strobl, G.[1]
»Thin 5-Junction Solar Cells with Improved Radiation Hardness«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006,
([1]: RWE Schott Solar GmbH, Alzenau, Germany)

Ebermeyer, M.; Koschikowski, J.; Rebman, H.; Wieghaus, M.; Rommel, M.
»Aufbau und Betrieb von energieautarken, solar betriebenen Meerwasserentsalzungsanlagen«, in: OTTI Energie-Kolleg, 16. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 17.–19.5.2006

Ebert, Günther
»Kraft-Wärmekopplung für den Wohnbereich – eine lohnende Investition?«, FVS-Jahrestagung, Berlin, Germany, 21./22.9.2006

Ebert, G.
»Integrated Energy Systems« CAE-Fraunhofer Workshop on Energy Efficient Technology, Chinese Academy of Engineering, Beijing, China, 29.6.2006

Ebert, G.
»Energy Efficiency in Photovoltaics«, CAE-Fraunhofer Workshop on Energy Efficient Technology, Chinese Academy of Engineering, Beijing, China, 29.6.2006

Ebert, G.
»Integration der Strom- und Wärmeerzeugung in den Wohnbereich – dezentrale Versorgungssicherheit« FVS-Jahrestagung 2006, Berlin, Germany, 21./22.9.2006

Eccarius, S.; Garcia, B.[1]; Manurung, T.; Weidner, J.[1]; Hebling, C.
»Crossover Phenomena in Direct Methanol Fuel Cells«, Fuel Cell Science & Technology, Turin, Italy, 13./14.9.2006
([1]: University of South Carolina, USA)

Ell, J.; Georg, A.
»Reasons for Specific Kinetics of Switchable Mirrors of Magnesium Nickel Films«, Photonics Europe, Strasbourg, France, 3.–7.4.2006

Fernández, J.; Dimroth, F.; Oliva, E.; Hermle, M.; Bett, A. W.
»Back Surface Optimization of Germanium TPV Cells«, 7th International Conference on the Thermophotovoltaic Generation of Electricity (TPV 7), San Lorenzo de El Escorial, Madrid, Spain, 25.9.–27.9.2006

Gerteisen, D.; Walter, M.
»Charakterisierung von porösen Gasdiffusionselektroden in Polymer-Elektrolyt-Brennstoffzellen mit Hilfe der Impedanzspektroskopie in einer Referenzelektrodenanordnung«, 1. Symposium – Impedanzspektroskopie Grundlagen und Anwendung, Haus der Technik – Außeninstitut der RWTH Aachen, Germany, 16./17.5.2006

Gerteisen, D.; Walter, M.; Wolff, A.; Melke, J.
»Investigation of the Performance of RuSe Catalyst for the ORR Using a Reference Electrode Measurements Set-up«, Workshop O2-RedNet, Ulm, Germany, 6./7.4.2006

Glatthaar, M.[1]; Riede, M.[1]; Keegan, N.; Sylvester-Hvid, K.[1]; Zimmermann, B.[1]; Niggemann, M.; Hinsch, A.; Gombert, A.
»Efficiency Limiting Factors of Organic Bulk Heterojunction Solar Cells Identified by Electrical Impedance Spectroscopy«, European Conference on Hybrid and Organic Solar Cells ECHOS, Paris, France, 28.–30.6.2006
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Glunz, S.
»Solarzellentechnologien – Stand der Technik und neue Konzepte«, Fraunhofer ISE Kompaktseminar Photovoltaik-Technologie, Intersolar, Freiburg, Germany, 23.6.2006

Gölz, S.; Bopp, G.; Buchholz, B.[1]; Pickhan, R.[1]
»Waschen mit der Sonne – Direkter Verbrauch von lokal erzeugtem PV Strom durch gezielte Lastverschiebung in Privathaushalten«, OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006
([1]: MVV Energie AG, Mannheim, Germany)

Goetzberger, A.
»Total Area Efficiency, an Extension of the Effiency Concept«, Photovoltaics , 3rd Generation and the way to it, Berlin Adelsdorf, Germany, 5.5.2006

Goetzberger, A.
»Selected Topics about the Future of PV«, GE-Seminar, Munich, Germany, 19.9.2006

Goldschmidt, J.
»Solarzellen: Alte Rekorde und neue Konzepte«, Vortrag im Rahmen des Graduiertenkollegs – Nichtlineare Optik und Ultrakurzzeitphysik, Technische Universität Kaiserslautern, Germany, 11.1.2006

Goldschmidt, J.; Glunz, S.; Hermle, M.; Gombert, A.; Willeke, G.
»Advanced Fluorescent Concentrators«, 18th Workshop on Quantum Solar Energy Conversion, Quantosol, Rauris, Salzburg, Austria, 19.–25.3.2006

Goldschmidt, J.
»Neuartige Solarzellenkonzepte«, DBU Stipendiatenseminar, Papenburg, Germany, 11.–16.6.2006

Goldschmidt, J.; Glunz, S.; Gombert, A.; Willeke, G.
»Advanced Fluorescent Concentrators«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Gombert, A.
»Diffractive Optical Elements for Large Area Applications«, Symposium On Photonics Technologies for the 7th Framework Programme, Wroclaw, Poland, 12.–14.10.2006

Grohe, A.; Knorz, A.; Alemán, M.; Harmel, C.; Glunz, S. W.; Willeke, G. P.
»Novel Low Temperature Front Side Metallisation Scheme Using Selective Laser Ablation of Anti Reflection Coatings and Electroless Nickel Plating«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006

Grohe, A.; Fleischhauer, B.; Preu, R.; Glunz, S.; Willeke, G.
»Boundary Conditions for Industrial Production of LFC Cells«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Guter, W.
»Optimierung von III-V-basierten Hochleistungssolarzellen«, DBU Stipendiatenseminar, Papenburg, Germany, 11.–16.6.2006

Hakenjos, A.
»Impedanzmesseung an PEM Brennstoffzellenstacks«, 1. Symposium – Impedanzspektroskopie Grundlagen und Anwendung, Essen, Germany, 16./17.5.2006

Hebling, C.
»Power to Go – Energie für unterwegs«, Fraunhofer Symposium Mikroenergietechnik 2006, Berlin, Germany, 10.10.2006

Hebling, C.
»Mikrobrennstoffzellen zur Energieversorgung portabler und netzferner elektronischer Geräte«, Technologieforum Leica Geosystems, Heerbrugg, Switzerland, 12.5.2006

Henning, H.-M.
»Thermisch aktive Materialien: Grundlagen und Anwendungen«, Physikalisch-Chemisches Kolloquium, LMU München, Munich, Germany, 14.12.2005

Henning, H.-M.
»Solar Thermal Energy for Air-Conditioning of Buildings – Advanced Technologies Adapted to Local Climatic Conditions«, Intelligent Building Middle East, Manama, Kingdom of Bahrain, 5.–7.12.2005

Henning, H.-M.
»Solar Cooling and Air Conditioning – Overview with Special Focus on a New Concept for Solar Cooling with high Temperature«, International Conference on Energy Saving Technologies for Heating and Air Conditioning, Milan, Italy, 2.3.2006

Henning, H.-M.
»Solarthermische Kühlung und Klimatisierung – Grundlagen, Verfahren und Anwendungen insbesondere im Mittelmeerraum», Branchen und Exportforum Erneuerbare Energien, Hannover Messe, Hannover, Germany, 27.4.2006

Henning, H.-M.
»Solares Kühlen und Klimatisieren«, 8. Internationales Symposium für Sonnenenergienutzung, Gleisdorf, Austria, 6.–8.9.2006

Henning, H.-M.
»Components and Systems – Overview and Thermodynamic Analysis«, Intersolar 2006, Freiburg, Germany, 22.7.2006

Henning, H.-M.
»Thermodynamische Grundlagen der solaren Kühlung – ein Weg zur Systemauswahl«, Fachforum Solare Kühlung und Klimatisierung (RENEXPO), Augsburg, Germany, 28.9.–1.10.2006

Herkel, S.
»Energieeffizienz in Laborgebäuden – Erfahrungen aus EnBau: Monitor«, Low Energy High Efficiency Lab, Bad Nauheim, Germany, 9./10.11.2006

Hesselmann, J.
»Leistungselektronik für Brennstoffzellen«, Fachseminar Leistungselektronik für erneuerbare Energiesysteme, OTTI Energie-Kolleg, Regenstauf, Germany, 6./7.7.2006

Hindenburg, C.; Geßner, D.
»Betriebsergebnisse einer Flüssigsorptions-Pilotanlage«, 4. Symposium Solares Kühlen in der Praxis, Hochschule für Technik, Stuttgart, Germany, 3./4.4.2006

Hinsch, A.
»Dye Solar Cells – Photovoltaics for Creative Applications«, Export Forum Renewable Energy, Hannover Messe, Hannover, Germany, 27.4.2006

Hinsch, A.; Siegers, C.[1]; Würfel, U.[1]; Sastrawan, R.[1]; Peters, M.[1]; Gerhard, D.[2]; Himmler, S.[2]; Wasserscheid, P.[2]; Gores, H.[3]; Zistler, M.[3]; Rau, U.[4]; Einsele, F.[4]; Koch, D.[5]; Schauer, T.[5]; Behrens, S.[6]; Khelashvili, G.[6]; Putira, P.[7]; Skupien, K.[7]; Walter, J.[7]; Opara-Krasovec, U.[8]; Nasmudinova, G.[9]; Sensfuß, S.[9]; Drewitz, A.[10]; Faßler, D.[10]; Bönnemann, H.[11]
»Developments for Dye Solar Modules: Results from an Integrated Approach«, 21st European Photovoltaic Solar Energy Conference and Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
([2]: Universität Erlangen, Germany)
([3]: Universität Regensburg, Germany)
([4]: Institut für Physikalische Elektronik IPE, Universität Stuttgart, Germany)
([5]:Forschungsinstitute für Pigmente und Lacke FPL, Stuttgart, Germany)
([6]: Forschungszentrum Karlsruhe, Germany)
([7]: University of Technology, Cracow, Poland)
([8]: Faculty of Electrical Engineering, University of Ljubljana, Slovenia)
([9]: Thüringisches Institut für Textil- und Kunststoff-Forschung, Rudolfstadt, Germany)
([10]: Gesellschaft zur Förderung von Medizin-, Bio- und Umwelttechnologien e.V. GMBU, Dresden, Germany)
([11]: Max-Planck-Institut für Kohlenforschung, Mülheim, Germany)

Hinsch, A.; Belledin, U.; Brandt, H.; Sastrawan, R.[1]; Hemming, S.[2]; Koch, D.[3]; Schauer, T.[3]; Rau, U.[4]; Einsele, F.[4]
»Glass Frit Sealed Dye Solar Modules with Adaptable Screen Printed Design«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
([2]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)
([3]: Forschungsinstitute für Pigmente und Lacke, FPL, Stuttgart, Germany)
([4]: Institute für Physikalische Elektronik IPE, Universität Stuttgart, Germany)

Hinsch, A.
»Farbstoffsolarzellen: Photovoltaik für gestalterische Anwendungen im Fenster- und Fassadenbau«, Rosenheimer Fenstertage, Institut für Fenstertechnik IFT e.V., Rosenheim, Germany, 20.10.2006

Hinsch, A.; Niggemann, M.; Gombert, A.
»Topics Related to the Technological Road Map for Dye and Organic Solar Cells«, 2nd International Plastic Electronics Conference & Showcase, Messe Frankfurt, Frankfurt, Germany, 25.10.2006

Hinsch, A.
»Photovoltaik und Solarthermie als integraler Bestandteil für Gebäude und Fassaden«, glasstec-Symposium: ENERGY – Glas und Energie, Düsseldorf, Germany, 26.10.2006

Hinsch, A.
»Injektionssolarzellen», DFG-Rundgespräch: Grundlagenforschung für die Photovoltaik, Gustav-Stresemann-Institut, Bonn, Germany, 20.7.2006

Hofmann, M.; Glunz, S.; Preu, R.; Willeke, G.
»21%-Efficient Silicon Solar Cells Using Amorphous Silicon Rear Side Passivation«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Janz, S.; Reber, S.; Glunz, S.
»Amorphous SiC: Applications for Silicon Solar Cells«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Jaus, J.; Fleischfresser, U.; Peharz, G.; Dimroth, F.; Lerchenmüller, H.; Bett, A. W.
»Heat Sink Substrates for Automated Assembly of Concentrator Modules«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Jungmann, T.
»Wasserstoff – eine Alternative zu den fossilen Brennstoffen?«, Physikalisches Seminar, Hochschule für Technik und Wirtschaft, Dresden, Germany, 8.12.2005

Kiefer, K.
»Ergebnisse aus dem Freiburger Performance Check«, Workshop Klimaschutz durch das Handwerk – Schwerpunkt Photovoltaik, Handwerkskammer Freiburg, Germany 3.2.2006

Kiefer, K.
»Erträge von netzgekoppelten Photovoltaik-Anlagen«, OTTI-Profiseminar Photovoltaik-Anlagen, Freiburg, Germany, 21.6.2006

Kiefer, K.
»Optimale Erträge von PV-Anlagen, Ergebnisse aus dem Freiburger Performance Check«, Fraunhofer ISE Kompaktseminar Photovoltaik-Technologie, Intersolar, Freiburg, Germany, 23.6.2006

Klaz, D.; Pfafferot, J.; Schossig, P.; Herkel, S.
»Thermally Activated Building Components Using Phase-Change-Materials«, Eurosun 2006, Glasgow, Scotland UK, 27.–30.6.2006

Klaz, D.; Pfafferot, J.; Schossig, P.; Herkel, S.
»Flächenkühlsysteme mit integrierten Phasenwechselmaterialien – Eine Simulationsstudie«, BauSIM 2006, Technische Universität München, Munich, Germany, 9.–11.10.2006

Köber, M.; Hermle, M.; Isenberg, J.; Kasemann, M.[1]; Cárdenes, H.; Warta, W.
»Analysis of the Effects Caused by Parameter Inhomogeneity with a 2D Modelling Tool Based on Circuit Simulation«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Köhl, M.
»Clusterprojekt: Lebensdauer von PV-Modulen«, 2. Workshop Photovoltaik-Modultechnik, Cologne, Germany, 1.12.2005

Köhl, M.
»Polymeric Materials for Solar Applications«, IEA SHC Industry Seminar, Sydney, Australia, 5.12.2005

Köhl, M.
»Solar Thermal Collectors, New Materials, Integration and Combination«, Meeting of the IEA Solar Heating & Cooling Programme and Solar Thermal Trade Associations, Malaga, Spain, 23.5.2006

Köhl, M.
»Subproject 5: Service Life Assessment of PV Modules«, Industry Information Workshop ›Performance‹, Freiburg, Germany, 22.6.2006

Köhl, M.
»Polyurethane-Based Thickness Insensitive Spectrally Selective Paints for Coloured Solar Absorbers«, Eurosun 2006, Glasgow, UK, 27.6.2006

Köhl, M.
»Temperature Dependent Permeation of Water Vapour Through Barrier Foils«, THERMO INTERNATIONAL 2006, Boulder, USA, 1.8.2006

Köhl, M.
»Temperature Dependent Permeation of Water Vapour into PV Modules«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Kontermann, S.; Emanuel, G.; Benick, J.; Preu, R.; Willeke, G.
»Characterisation of Silver Thick-Film Contact Formation on Textured Monocrystalline Silicon Solar Cells«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Kuhn, T. E.
»Solar Control: Two New Systems and a General Evaluation Method for Facades with Venetian Blinds or Other Solar Control Systems to Be Used Stand Alone or within Building Simulation Program«, VDI Wissensforum Bauen mit Glas – Transparente Werkstoffe im Bauwesen, Baden-Baden, Germany, 29./30.5.2006

Kuhn, T. E.
»Solar Control: Two New Systems and a General Evaluation Method for Facades with Venetian Blinds or Other Solar Control Systems«, Konferenz BauSIM 2006 der deutschen Sektion der International Building Performance Simulation Association, Munich, Germany, 9.–11.10.2006.

Kuhn, T. E.
»Sun Protection: Shading Blinds«, ISES International Summer Workshop – Solar Low-Energy Housing in Europe, Freiburg, Germany, 14.8.2006

Kuhn, T. E.
»Sonnenschutz und Lichtlenksysteme – Praxisbericht«, Kompetenzseminar Handwerk+Energie, Heidelberg, Germany, 9.11.2006

Lehnert, W.[1]; Grünerbel, M.[1]; Hartnig, Ch.[1]; Gülzow, E.[2]; Schulze M.[2]; Wittstadt, U.; Smolinka, T.
»Aging Mechanisms in PEM Fuel Cells«, 10th Electrochemical Talks, Neu-Ulm, Germany, 27./28.6.2006
([1]: Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Ulm, Germany)
([2]: Institut für Technische Thermodynamik, ITT, Stuttgart, Germany)

Litterst, C.[1]; Eccarius, S.; Hebling, C.; Zengerle, R.[1]; Koltay, P.[1]
»Novel Structure for Passive CO_2 Degassing in µDMFC«, 19th IEEE Conference on Micro Electro Mechanical Systems; Istanbul, Turkey, 22.–26.1.2006
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Löckenhoff, R.; Dibowski, G.[1]; Dimroth, F.; Meusel, M.; van Riesen, S.; Bett, A. W.
»1000 Sun, Compact Receiver Based on Monolithic Interconnected Modules (MIMs)«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bonn, Germany)

Löckenhoff, R.; Wilde, J.; Dimroth, F.; Bett, A. W.
»Approaches to Large Area III-V Concentrator Receivers«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Lungenschmied, C.[1]; Dennler, G.[1]; Neugebauer, H.[1]; Sariciftci, S.[1]; Glatthaar, M.; Meyer, T.[2]; Meyer, A.[2]
»Flexible, Large Area, Encapsulated, Organic Solar Cells«, European Conference on Hybrid and Organic Solar Cells ECHOS, Paris, France, 28.–30.6.2006
([1]: Linz Institute for Organic Solar Cells, Johannes Kepler University, Linz, Austria)
([2]: Solaronix SA, Aubonne, Switzlerand)

Luther, J.
»Gedanken zu einer nachhaltigen globalen Energieversorgung«, Universitätsklinikum Freiburg, Freiburg, Germany, 25.1.2006

Luther, J.
»Hocheffiziente Photovoltaik – Stand und Potenziale«, Bayern Innovativ – Kooperationsforum, Munich, Germany, 22.2.2006

Luther, J.
»Forschung und Entwicklung für eine nachhaltige Energieversorgung«, Universitätsbeirat, Universität Freiburg, Germany, 8.3.2006

Luther, J.
»PV Activities and Strategies at the Fraunhofer ISE«, Commission for Sustainable Development (CSD), New York, USA, 1.–6.5.2006

Luther, J.
»Solar Energy Conversion – Solar Electricity Generation, Photovoltaic Energy Conversion«, Global Science Conference (OECD), Paris, France, 17.–18.5.2006

Luther, J.
»Strom aus Sonnenenergie – Photovoltaische Energiekonversion«, Kolloquium an der Universität Tübingen, Tübingen, Germany, 31.5.2006

Luther, J.
»Verteilte Stromerzeugung und ›intelligente‹ Netze: Energieeffizienz, Einbindung erneuerbarer Energiequellen, Sicherheit der Stromversorgung«, Parlamentarischer Abend der Fraunhofer-Gesellschaft, Berlin, Germany, 1.6.2006

Luther, J.
»Solare Energietechnologien – Ein nachhaltiger Wachstumsmarkt Beispiel: Photovoltaik«, Tagung ›20 Jahre BMU‹, Berlin, Germany, 6.6.2006

Luther, J.
»Photovoltaik – Strom aus Sonnenenergie, Neue Ergebnisse aus Forschung und Technologieentwicklung«, Samstagsuniversität, Universität Freiburg, Germany, 24.6.2006

Luther, J.; Bett, A. W.; Burger, B.; Dimroth, F.
»High Concentration Photovoltaics Based on III-V Multi-Junction Solar Cells«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Luther, J.
»Sustainable Electricity Generation – Solar Energy and Other Renewable Energy Sources«, Energy and Environment, Instituto Internacional Casa de Mateus, Vila Real, Portugal, 27.–30.9.2006

Luther, J.
»The Global Potential of Solar Systems – Solar Electricity«, XVI. Malenter Symposium, Lübeck, Germany, 8.–10.10.2006

Luther, J.
»Wege zu einer nachhaltigen Energieversorgung – die Bedeutung der Energiemeteorologie«, Wissenschaftsforum, Berlin, Germany, 2.11.2006

Luther, J.
»Photovoltaik – Strom aus Sonnenenergie«, Wissenschaftliche Gesellschaft, Universität Freiburg, Freiburg, Germany, 3.11.2006

Luther, J.
»Solarforschung – in der Mitte eines langen Weges«, Vortrag im Umweltministerium Baden-Württemberg, Stuttgart, Germany, 22.11.2006

Niggemann, M.; Glatthaar, M.; Riede, M.; Ziegler, T.; Zimmermann, B.; Gombert, A.
»Optical Near Field Phenomena in Planar and Structured Organic Solar Cells«, Photonics Europe, Strasbourg, France, 3.–7.4.2006

Oszcipok, M.
»Start- und Abschaltvorgänge in PEM-Brennstoffzellen unter 0 °C«, Elektrochemie Seminar am Paul-Scherrer Institut, Villigen PSI, Switzerland, 10.4.2006

Pearsall, N.[1]; Scholz, H.[2]; Zdanowicz, T.[3]; Reise, C.
»PV System Assessment in PERFORMANCE – towards Maximum System Output«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: University of Northumbria, Newcastle, United Kingdom)
([2]: European Commission, DG JRC, Ispra, Italy)
([3]: Wroclaw University of Technology, Poland)

Pfanner, N.
»Anwendungen – Photovoltaik in der Beleuchtungstechnik«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 27./28.9.2006

Reber, S.; Duerinckx, F.[1]; Alvarez, M.[2]; Garrard, B.[3]; Schulze, F. W.[4]
»EU Project SWEET on Epitaxial Wafer Equivalents: Results and Future Topics of Interest«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: IMEC Leuven, Belgium)
([2]: ATERSA, Catarroja, Spain)
([3]: Crystalox Ltd., Wantage, United Kingdom)
([4]: PV Silicon AG, Erfurt, Germany)

Rein, S.
»Lifetime Spectroscopy – Method of Defect Characterization«, Nordic Workshop on Crystalline Silicon Solar Cells IFE, Losby Gods, Norway, 23.1.2006

Reise, C.; Ebert, G.; Köhl, M.; Herrmann, W.[1]; Stellbogen, D.[2]; Gabler, H.[2]; Pearsall, N.[3]; Gottschalg, R.[4]; de Moor, H.[5]; Despotou, E.[6]; Dunlop, E.[7]
»PERFORMANCE – a Science Base on PV Performance for Increased Market Transparency and Customer Confidence«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: TÜV Immisionsschutz und Energiesysteme GmbH, Köln, Germany)
([2]: Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW) Baden-Württemberg, Stuttgart, Germany)
([3]: University of Northumbria, Newcastle, United Kingdom)
([4]: Loughborough University Leicester, United Kingdom)
([5]: Energy Research Center (ECN), Solar Energy, Petten, The Netherlands)
([6]: European PV Industry Association, Brussels, Belgium)
([7]: Institute for Environment and Sustainability, Ispra, Italy)

Riepe, S.; Schultz, O.; Warta, W.
»Redistribution of Recombination Active Defects and Trapping Effects in Multicrystalline Silicon After Wet Thermal Oxidation«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Rinio, M.; Käs, M[1].; Hahn, G[1].; Borchert D.
»Hydrogen Passivation of Extended Defects in Multicrystalline Silicon Solar Cells«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: University of Konstanz, Department of Physics, Germany)

Rochlitz, L.; Aicher, T.
»Micro Reformer Fuel Cell System of a few 100 Watts«, ACHEMA 2006, Frankfurt, Germany, 15.–19.5.2006

Rochlitz, L.; Aicher, T.
»Development of a Micro Reformer for PEM Fuel Cells with a Few Hundred Watts Power Output«, Fuel Cell Science & Technology, Turin, Italy, 13./14.9.2006

Rommel, M.; Koschikowski, J.; Wieghaus, M.
»Solar Driven Desalination Systems Based on Membrane Distillation«, NATO Advanced Research Workshop, Solar Desalination for the 21st Century, 23.–25.2.2006, Hammamet, Tunisia

Rommel, M.
»Medium Temperature Collector Developments and Collector Testing«, SHC-IEA TASK 33/IV Industry Workshop Solar Heat for Industrial Processes, Lisbon, Portugal, 13.10.2006

Roth, T.; Rüdiger, M.; Diez, S.; Glunz, S.; Trupke,T.[1]; Bardos, R.[1]
»Temperature and Injection-Dependent Photoluminescence Lifetime Spectroscopy«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Centre of Excellence for Advanced Silicon Photovoltaics and Photonics, University of New South Wales, Sydney, Australia)

Roth, T.
»Analyse von elektrisch aktiven Defekten in Silicium für Solarzellen«, DBU Stipendiatenseminar, Mirow, Germany, 6.–10.11.2006

Roth, W.
»Unternehmenskooperationen als Einstieg in Projekte der internationalen Finanzierungsorganisationen – Erfolgsbeispiele und Zukunftsperspektiven der Themengruppe Energie«, Abschlusstreffen der Bayerischen Initiative zur Konsortialbildung für internationale Entwicklungsprojekte, Munich, Germany, 18.1.2006

Roth, W.
»Netzferne Stromversorgung mit Photovoltaik – Einführung«, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 26.9.2006

Roth, W.
»Nutzung der Sonnenenergie«, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 26.9.2006

Roth, W.
»Netzferne Stromversorgung mit Photovoltaik«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 27./28.9.2006

Roth, W.
»Photovoltaische Stromversorgung von Industrieprodukten und technischen Einrichtungen«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 27./28.9.2006

Schaadt, A.; Aicher, T.; Lenz, B.; Rochlitz, L.
»Herstellung von Wasserstoff aus flüssigen Kohlenwasserstoffen«, Brennstoffzellen-Kongress, f-cell-2006 Stuttgart, Stuttgart, Germany, 25./26.9.2006

Schmich, E.; Reber, S.; Hees, J.; Trenkle, F.; Schillinger, N.; Willeke, G.
»Emitter Epitaxy for Crystalline Silicon Thin-Film Solar Cells«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Schmidt, H.
»Welcher Wechselrichter für welche Dünnschichttechnologie?«, Fachseminar Dünnschicht-Photovoltaikmodule, OTTI Energie-Kolleg, Freiburg, Germany, 20.6.2006

Schmidt, H.
»Elektromagnetische Verträglichkeit«, Fachseminar Leistungselektronik für erneuerbare Energiesysteme, OTTI Energie-Kolleg, Regenstauf, Germany, 6./7.7.2006

Schmidt, H.
»Grundlagen zur Nutzung der Sonnenenergie - Messtechnik«, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 26.9.2006

Schmidt, H.
»Aufbau und Funktionsweise von Solarzelle, Modul und Solargenerator«, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 26.9.2006

Schmidt, H.
»Batterien in netzfernen Stromversorgsanlagen«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 27./28.9.2006

Schmidt, H.
»Laderegler und Überwachungseinrichtungen für Batterien in photovoltaischen Energieversorgungssystemen«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI Energie-Kolleg, Freiburg, Germany, 27./28.9.2006

Schmidt, H.
»EMV-Messverfahren für PV und EMV-gerechtes Schaltungsdesign«, Profiseminar EMV und Blitzschutz für Solaranlagen, OTTI Energie-Kolleg, Regensburg, Germany, 22./23.11.2006

Schmidt, H.
»Elektrische Wechselwirkungen Modul - Wechselrichter«, 3. Modulworkshop Photovoltaik-Modultechnik, TÜV Rheinland, Cologne, Germany, 29./30.11.2006

Schmidt, H.; Burger, B.; Kiefer, K.
»Welcher Wechselrichter für welche Modultechnologie?« in: OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006

Schmidt, F.; Henninger, S.[1]
»Neue Sorptionsmaterialien für die Wärmespeicherung«, Konferenz Innovative Solar-Speicherkonzepte, AEE Intec, Vienna, Austria, 17.3.2006
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Schnabel; L.
»Konzeption und Betrieb von offenen Kühlsystemen«, 7. Berliner Energietage Umweltschonende Gebäudekühlung, Berlin, Germany 2.–4.5.2006

Schöne, J.; Dimroth, F.; Bett, A. W.; Tauzin, A.[1]; Jaussaud, C.[1]; Roussin, J.-C.[1]
»III-V Solar Cell Growth on Wafer-Bonded GaAs/Si-Substrates«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Commissariat à l'Energie Atomique (CEA), Grenoble, France)

Schubert, M.; Riepe, S.; Warta, W.
»Spatially Resolved Trapping Detection and Correlation with Material Quality in Multicrystalline Silicon«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Schultz, O.; Glunz, S.; Riepe, S.; Willeke, G.
»Gettering of Multicrystalline Silicon for High-Efficiency Solar Cells«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Siefer, G.; Bett, A. W.
»Calibration of III-V Concentrator Cells and Modules«, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Siefer, G.; Bett, A. W.
»Accelerated Indoor Aging Test Procedure for Concentrator Modules«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Smolinka, T.; Grootjes, S.[1]; Mahlendorf, F.[2]; Hesselmann, J.; Makkus, R.[1]
»Prototype of a Reversible Fuel Cell System for Autonomous Power Supplies«, 3rd European PV-Hybrid and Mini Grid Conference, Aix-en-Provence, France, 11.–12.5.2006
([1]: Energy Research Centre of the Netherlands (ECN), The Netherlands)
([2]: Universität Duisburg–Essen, Germany)

Smolinka, T.
»Manufacturing and Characterisation of Membrane Electrode Assemblies for PEM Electrolysis and Fuel Cells«, 28th International Exhibition-Congress on Chemical Engineering, Environmental Protection and Biotechnology, Frankfurt am Main, Germany, 15.–19.5.2006

Steinhüser, A.
»Photovoltaik-Hybridsysteme«, Vorlesung an der Universität Karlsruhe, Germany, 30.5.2006

Steinhüser, A.
»Computerunterstützte Auslegung von Photovoltaik-Systemen«, Vorlesung an der Universität Karlsruhe, Germany, 30.5.2006

Steinhüser, A.
»Computerunterstützte Auslegung und Simulation von Photovoltaik-Systemen«, OTTI-Profiseminar – Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany 27./28.9.2006

Vetter, M.
»Photovoltaik-Hybridsysteme mit thermoelektrischen Generatoren«, Herbstschule Thermoelektrik der Deutschen Thermoelektrischen Gesellschaft, Tübingen, Germany, 9.–13.10.2006

Weber, E. R.
»Metalle in Si-Solarzellen – Gute Zellen aus schmutzigem Silicium«, Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany, 28.7.2006

Weber, E. R.
»Die Zukunft der siliciumbasierten Photovoltaik«, IHP Microelectronics, Frankfurt/Oder, Germany, 15.11.2006

Weber, E. R.
»Globaler Klimawandel und Erneuerbare Energien«, Kolloquium am Physikalischen Institut der Albert-Ludwigs-Universität Freiburg, Freiburg, Germany, 20.11.2006

Welser, E.; Dimroth, F.; Ohm, A.; Guter, W.; Siefer, G.; Schöne, J.; Polchroniadis, E. K.[1]; Bett, A. W.
»Lattice-Matched GaInAsSb on GaSb for TPV Cells«, 7th World Thermophotovoltaic Generation of Electricity (TPV) Conference, Madrid, Spain, 25.–27.9.2006
([1]: Aristotle University of Thessanoliki, Greece)

Went, J.
»Leistungsultraschall zur Verbesserung der Membranfiltration«, VDI-Gesellschaft Verfahrenstechnik und Chemieingenieurwesen GVC, Fachausschuss zur Mechanischen Flüssigkeitsabtrennung, Karlsruhe, Germany, 14.–17.3.2006.

Wilson, H. R.
»High-Performance Glazing«, ISES International Summer Workshop-Solar Low-Energy Housing in Europe, Freiburg, Germany, 14.8.2006

Wirth, H.
»Modulkonzepte für die nächste Solarzellen-Generation«, glasstec 2006, Düsseldorf, Germany, 23.10.2006

Wittwer, C.; Erge, T.; Thoma, M.
»Ausgleich fluktuierender Stromerzeugungsressourcen in Niederspannungsnetzen durch optimierte Netzbetriebsführung«, in: OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006

Wittwer, C.
»The Storage Capacity of Co-Generation«, EuroSolar 2006, Gelsenkirchen, Germany, 30./31.10.2006

Wittwer, C.; Becker, R.
»Modellbasierte Ertragskontrolle für PV Anlagen in vernetzten Gebäuden«, IKM 2006 17. Internationalen Kolloquium über Anwendungen der Informatik und Mathematik in Architektur und Bauwesen, Weimar, Germany, 12.–14.7.2006

Wittwer, C.
»POMS: Managementsystem for Distributed Generation and Loads in Low Voltage Grids«, 1. Internationales Symposium für Verteilte Stromerzeugung und intelligente Netze, Arsenal Research Techbase, Vienna, Austria, 18./19.10.2006

Wittwer, C.; Erge, T.; Becker, R.; Franzen, E.
»Modellbasierte Ertragskontrolle von netzintegrierten PV-Systemen durch Einsatz webfähiger Embedded Systems«, in: OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006

Wittwer, V.
»Solarthermie Vision 2030: Eine Herausforderung an die Forschung«, in: OTTI Energie-Kolleg, 16. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 17.–19.5.2006

Zacharias P.; Wittwer, C.
»Netzintegration der erneuerbaren Energien«, FVS Jahrestagung 2006, Berlin, Germany, 21./22.9.2006

Ziegler, C.
»Model Based Design of Fuel Cells and Fuel Cell Systems: PEM Design«, Workshop on Numerical, Mathematical and Modelling Analysis related to Fluid Dynamics in Hydrogen Fuel Cells, Ottawa, Canada, 10.–12.5.2006

Zimmermann, B.; Glatthaar, M.; Niggemann, M.; Riede, M.; Hinsch, A.; Gombert, A.
»Inversion of the Layer Sequence in Organic Solar Cells«, Technologies for Polymer Electronics – TPE 2006, Rudolfstadt, Germany, 16.–18.5.2006

Publications

Alemán, M.; Richter, L.; Filipovic, A.; Willeke, G.
»New Concepts for the Front Side Metallization of Silicon Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Alemán, M.; Streek, A.[1]; Regenfuß, P.[1]; Mette, A.; Ebert, R.[1]; Exner, H. [1]; Glunz, S.W.; Willeke, G.
»Laser Micro-Sintering as a New Metallization Technique for Silicon Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006
([1]: Laser Institut Mittelsachsen)

Balaras, C.[1]; Henning, H.-M.; Wiemken, E.; Grossman, G.[2]; Podesser, E.[3]; Ferreira, C.[4]
»Solar Cooling – an Overview of European Applications and Design Guidelines«, in: ASHRAE Journal, Vol. 48, No. 6, June 2006, pp. 14-22
([1]: Institute for Enviromental Research & Sustainable Development, NOA, Athens, Greece)
([2]: Technion Israel Institute of Technology, Haifa, Israel)
([3]: Joanneum Research, Institute of Energy Research, Graz, Austria)
([4]: University of Technology, Delft, The Netherlands)

Baumann, S.; Kray, D.; Mayer, K.; Eyer, A.; Willeke, G.
»Comparative Study of Laser Induced Damage in Silicon Wafers« in: Proceedings, 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Becker, R.; Rommel, M.; Wittwer, C.
»Regelungstechnische Untersuchungen zur Vermeidung von Stillstandssituationen bei großen solartechnischen Anlagen«, in: Proceedings, OTTI Energie-Kolleg, 16. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 17.–19.5.2006

Benick, J.; Rentsch, J.; Schetter, C.; Voyer, C.; Biro, D.; Preu, R.
»PECVD PSG as a Dopant Source for Industrial Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Beyer, H.[1]; Friesen, G.[2]; Gottschalg, R.[3]; Williams, S.[3]; Reise, C.; Guerin de Montgareuill, A.[4]; van de Borg, N.[5]; de Moor, H.[5]; Koloenny, W.[6]; Prorok, M.[6]; Tdanowicz, T.[6]; Herrmann, W.[7]; Huld, T.[8]; de Kaizer, C.[9]
»Vergleich von Verfahren zur Abschätzung der Jahreserträge unterschiedlicher PV-Technologien im Rahmen des Projektes Performance – Ergebnisse eines ersten, ›Round Robin‹ Tests«, in: Proceedings, OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006
([1]: Institut für Elektrotechnik, Hochschule Magdeburg-Stendal, Germany)
([2]: Scuola Universitaria Professionale Svizzera Italiana, SUPSI, Lugano, Switzerland)
([3]: Loughborough University Leicester, United Kingdom)
([4]: Commissariat à l'Energie Atomique, CEA, Cadarache, France)
([5]: Energy Research Center (ECN), Solar Energy, Petten, The Netherlands)
([6]: University of Technology, Wroclaw, Poland)
([7]: TÜV Rheinland, Köln, Germany)
([8]: European Commission, DG JRC, Ispra, Italy)
([9]: University Utrecht, The Netherlands)

Biro, D.; Preu, R.; Glunz, S.; Rein, S.; Rentsch, J.; Emanuel, G.; Brucker, I.; Faasch, T.; Faller, C.; Willeke, G.; Luther, J.
»PV-Tech: Photovoltaic Technology Evaluation Center – Design and Implementation of a Production Research Unit«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Bopp, G.; Gabler, H.[1]; Haugwitz, F. [2]; Liu Hong[3]; Li Zhiming[3]; Müller, H.[2]; Steinhüser, A.
»PV Village Power Supply Systems in China – Results from a Technical Monitoring Campaign« in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Zentrum für Sonnenenergie- und Wasserstoff-Forschung ZSW, Stuttgart, Germany)
([2]: Deutsche Gesellschaft für Technische Zusammenarbeit, Beijing, China)
([3]: Qinghai Provincial New Energy Research Institute, Xining, China)

Borchert, D.[1]; Hanke, M.[1]; Ban, Q.[1]; Schmidt, K.[1]; Rinio, M.[1]
»Microcrystalline Silicon Films as Active Layers in Crystalline Silicon Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Fraunhofer ISE Labor- und Servicecenter Gelsenkirchen, Germany)

Borchert, D.; Riepe, S.; Kübler, R.[1]; Beinert, J.[1]; Kraft, T.[1]; Kleer, G.[1]; Petri, S.[2]
»Influence of the Thermal Treatment During the Saw Damage Etching Process on the Mechanical Stability of Multicrystalline Silicon Wafers«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Fraunhofer Institute für Werkstoffmechanik IWM, Freiburg, Germany)
([2]: Shell Solar Deutschland GmbH, Gelsenkirchen, Germany)

Bryniok, D.[1]; Dobers, K.[2]; Eiband, A.[2]; Fuchs, D.[3]; Hauser, H.[2]; Roth, W.; Sellmeier, C.[3]; Vielreicher, H.[3]; Wang, W.[4]
»BIKE Bayerische Initiative zur Konsortialbildung für internationale Entwicklungsprojekte«, in: Tagungsband zur Abschlussveranstaltung zur Initiative BIKE, Munich, Germany, 18.1.2006
([1]: Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik IGB, Stuttgart, Germany)
([2]: Fraunhofer-Institut für Materialfluss und Logistik IML, Dortmund und Priem am Chiemsee, Germany)
([3]: Fraunhofer-Gesellschaft, European and International Business Development, Munich, Germany)
([4]: Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK, Berlin, Germany)

Burger, B.; Dimroth, F.; Siefer, G.; Lerchenmüller, H.
»High-Concentration PV Using III-V Cells«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Diez, S.; Rein, S.; Roth, T.; Glunz, S.
»Analyzing Defects by Temperature- and Injection-Dependent Lifetime Measurements«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Diez, S.; Rein, S.; Glunz, S. W.
»Analyzing Multiple Defect Levels in Silicon by Temperature- and Injection-Dependent Lifetime Spectroscopy (T-IDLS)«, in: Proceedings, 16th Workshop on Crystalline Silicon Solar Cells & Modules: Materials and Processes, Denver, Colorado, USA, 6.–9.8.2006, pp. 181–184

Dimroth, F.; Baur, C.; Bett, A. W.; Köstler, W.[1]; Meusel, M.[1]; Strobl, G.[1]
»Thin 5 Junction Solar Cells with Improved Radiation Hardness«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: RWE Schott Solar GmbH, Alzenau, Germany)

Ebert, G.
»Integrated Energy Systems« in: Proceedings of CAE-Fraunhofer Workshop on Energy Efficient Technology, Chinese Academy of Engineering, Beijing, China, 29.6.2006

Ebert, G.
»Energy Efficiency in Photovoltaics« in: Proceedings of CAE-Fraunhofer Workshop on Energy Efficient Technology, Chinese Academy of Engineering, Beijing, China, 29.6.2006

Eccarius, S.; Garcia, B.; Manurung, T.; Weidner, J.; Hebling, C.
»Crossover Phenomena in Direct Methanol Fuel Cells«, in: Proceedings Grove Fuel Cells, Fuel Cell Science & Technology, Turin, Italy, 13.–14.9.2006

Ell, J.[1]; Georg, A.
»Reasons for the Specific Kinetics of Switchable Mirrors of Magnesium Nickel Films« in: Proceedings, Photonics Europe, Strasbourg, France, 3.–7.4.2006, Vol. 6197, pp. 61970
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Ell, J.[1]; Georg, A.; Arntzen, M.[2]; Gombert, A.; Graf, W.; Wittwer, V.
»Optical Investigation of the Hydrogenation and Dehydrogenation Mechanism of Evaporated MgNi Films«, in: Solar Energy Materials and Solar Cells, to be published
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
([2]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)

Enge, O.[1]; Clauss, C.[1]; Schneider, P.[1]; Schwarz, P.[1]; Vetter, M.; Schwunk, S.
»Quasi-stationary AC Analysis Using Phasor Description With Modelica« in: Proceedings, 5th International Modelica Conference, Vienna, Austria, 3.–4.9.2006
([1]: Fraunhofer Institut für Integrierte Schaltungen IIS, Erlangen, Germany)

Erath, D.; Mette, A.; Hübner, G.[1]
»Neue Siebdrucktechnologie erhöht den Wirkungsgrad von Solarzellen«, in: Horizonte, Nr. 29, Dezember 2006, pp. 24–26
([1]: Hochschule der Medien HdM Stuttgart, Germany)

Erge, T.; Thoma, M.; Buchholz, B.
»Management von dezentralen Erzeugungsanlagen in Verteilnetzen – eine Lösung für die Praxis«, in: etz – Elektrotechnik und Automation, Heft Nr.11, pp. 64–69

Gerteisen, D.; Walter, M.
»Charakterisierung von porösen Gasdiffusionselektroden in Polymer-Elektrolyt-Brennstoffzellen mit Hilfe der Impedanzspektroskopie in einer Referenzelektrodenanordnung«, in: Technische Mitteilungen 99, 2006 Heft 1/2, pp.112–117, ISSN 0040-1439

Glunz, S.; Janz, S.; Hofmann, M.; Roth, T.; Willeke, G.
»Surface Passivation of Silicon Solar Cells Using Amorphous Silicon Carbide Layers«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Gölz, S.; Bopp, G.; Buchholz, B.[1]; Pickhan, R.[1]
»Waschen mit der Sonne – Direkter Verbrauch von lokal erzeugtem PV-Strom durch gezielte Lastverschiebung in Privathaushalten«, in: Proceedings, OTTI Energie-Kolleg 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006, pp. 99–104
([1]: MVV Energie Mannheim, Germany)

Gölz, S.; Vogt, G.; Maigne, Y.[1]; Mozas, K.[1]
» Success Factors for Sustainable Private Business Operation of Decentralised Rural Electrification with PV – Results from the Project ›Delta PRO RES‹ In the Lower Delta Mekong Countries«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Fondation Energies pour le Monde (FONDEM), Paris, France)

Gölz, S.; Maigne, Y; Mozas, K.
»Bankabel Rural Electrification with Renewable Energy Sources in Lower Delta Mekong Countries«, in: Projektbroschüre des Projekts DELTA PRO RES, June 2006

Goldschmidt, J.; Glunz, S.; Gombert A.; Willeke, G.
»Advanced Fluorescent Concentrators«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Gombert, A.
»Optically Functional Surfaces for Solar Applications«, in: Proceedings, Eurosun 2006, Glasgow, Scotland, 27.–30.6.2006, to be published

Granek, F.; Hermle, M.; Fleischhauer, B.; Grohe, A.; Schultz, O.; Glunz, S.; Willeke, G.
»Optimisation of Laser-Fired Aluminium Emitters for High Efficiency N-Type Si Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Grohe, A.; Harmel, C.; Knorz, A.; Glunz, S.; Preu, R.; Willeke, G.
»Selective Laser Ablation of Anti-Reflection Coatings for Novel Metallization Techniques«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Grohe, A.; Fleischhauer, B.; Preu, R.; Glunz, S. W.; Willeke, G. P.
»Boundary Conditions for Industrial Production of LFC Cells«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Grohe, A.; Knorz, A.; Alemán, M.; Harmel, C.; Glunz, S. W.; Willeke, G. P.
»Novel Low Temperature Front Side Metallization Scheme Using Selective Laser Ablation of Anti Reflection Coatings and Electroless Nickel Plating«, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Grohe, A.; Catoir, J.; Fleischhauer, B.; Preu, R.; Glunz, S. W.; Willeke, G. P., Schneiderlöchner, E.[1]; Lüdemann, R.[1]; Liu, J.[2]; Schramm, S.[2]; Trassl, R.[2]; Wieder, S.[2]
»Boundary Conditions for the Industrial Production of LFC Cells – Results from the Joint Project INKA«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Deutsche Cell GmbH, Freiberg/Sachsen, Germany)
([2]: Applied Materials GmbH & Co. KG, Alzenau, Germany)

Grohe, A.; Preu, R.; Glunz, S. W.; Willeke, G.
»Laser Applications in Crystalline Silicon Solar Cell Production«, in: Proceedings, 21st Photonics Europe, Strasbourg, France, 3.–7.4.2006

Gschwander, S.; Schossig, P.
»Phase Change Slurries as Heat Storage Material for Cooling Applications«, in: Proceedings, Eurosun 2006, Glasgow, Scotland, 27.–30.6.06

Gschwander, S.; Schossig, P.
»Paraffin Phase Change Slurries«, 7th Conference on Phase Change Materials, Dinan, France, 13.–15.9.2006

Guter, W.;
»IV-Characterization of Devices Consisting of Solar Cells and Tunnel Diodes«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Häberle, A.[1]; Berger, M.[1]; Luginsland, F.[1]; Zahler, C.[1]; Baitsch, M.; Henning, H. M.; Rommel, M.
»Linear Concentrating Fresnel Collector for Process Heat Applications«, in: Proceedings, 13th Solar Paces International Symposium, Sevilla, Spain, 20.–23.6.2006, CD-ROM
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)

Haussmann, T.[1]; Schossig, P.
»PCM-aktiv: A project for activ driven construction materials with latent heat storage«, in: Proceedings, 7th Conference on Phase Change Materials and Slurries for Refrigeration and Air Conditioning, Dinan, France, 15.9.2006, pp. 167–174
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)

Haussmann, T.[1]; Schossig, P.
»Baustoffe mit Phasenwechselmaterialien als Kältespeicher für energieeffiziente Gebäude«, in: Proceedings, Statusseminar – Thermische Energiespeicherung, Freiburg, Germany, 2./3.11.2006
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)

Hebling, C.
»Off-Grid Fuel Cell Systems for Outdoor Use«, in: Proceedings Small Fuel Cells Conference, Washington D.C., USA, 2.–4.4.2006

Hebling, C.
»Fuel Cells for Portable Electronics: A Survey«, in: Proceedings Lucerne Fuel Cell Forum, Lucerne, Switzerland, 3.–6.7.2006

Hebling, C.
»Brennstoffzellen in der Servicerobotik«, in: Tagungsunterlagen, f-cell 2006, Stuttgart, Germany, 25./26.9.2006

Henning, H.-M.
»Solar Cooling and Air-Conditioning – Thermodynamic Analysis and Overview about Technical Solutions«, in: Proceedings, Eurosun 2006, Glasgow, Scotland, UK, 27.-30.6.2006 to be published

Henning, H.-M.; Häberle, A.[1]; Guerra, M.[2]; Motta, M.[3]
»Solar Cooling and Refrigeration with High Temperature Lifts – Thermodynamic Background and Technical Solution«, in: Proceedings, The Sustainable Mobility Challenge at the National Congress of the Italian Thermotechnical Association (ATI), University of Perugia, Perugia, Italy, 14.9.2006
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)
([2]: ROBOUR SpA, Verdillino/Zingonia, Italy)
([3]: Politecnico di Milano, Italy)

Henning, H.-M.
»Components and Systems – Overview and Thermodynamic Analysis«, in: Proceedings, Intersolar 2006, Freiburg, Germany, 22.6.2006, pp. 11–16

Henning, H.-M.
»Solares Kühlen und Klimatisieren«, in: Tagungsband, 8. Internationales Symposium für Sonnenenergienutzung, Gleisdorf, Österreich, 6.–8.9.2006, pp. 195–207

Henning, H.-M.
»Übersicht zum Einsatz von Adsorptionsmaterialien in der thermischen Energietechnik«, in: Proceedings, PTJ-Workshop zur Wärmespeicherung und -transformation mit mikro- und mesoporösen Adsorbentien, Technische Fachhochschule Wildau, Wildau, Germany, 19./20.9.2006; CD-ROM

Henning, H.-M.
»Grundlegende Überlegungen zur Speicherung von Solarenergie zur Beheizung von Gebäuden«, in: Proceedings, PTJ-Workshop zur Wärmespeicherung und -transformation mit mikro- und mesoporösen Adsorbentien, Technische Fachhochschule Wildau, Wildau, Germany, 19./20.9.2006; CD-ROM

Henning, H.-M.
»Neuer hoch-effizienter Sorptionsentfeuchter«, in: Proceedings, PTJ-Workshop zur Wärmespeicherung und -transformation mit mikro- und mesoporösen Adsorbentien, Technische Fachhochschule Wildau, Wildau, Germany, 19./20.9.2006; CD-ROM

Henning, H.-M.
»Kälteanlagen für den Betrieb mit (Ab-)Wärme: Funktionsweise, Anlagen und Stand der Technik«, in: Proceedings, RENEXPO, Fachforum Solare Kühlung und Klimatisierung, Augsburg, Germany, 28.9.–1.10.2006; CD-ROM

Henning, H.-M.
»Thermodynamische Grundlagen der solaren Kühlung – ein Weg zur Systemauswahl«, in: Proceedings, RENEXPO, Fachforum Solare Kühlung und Klimatisierung, Augsburg, Germany, 28.9.–1.10.2006

Henning, H.-M.
»Solar Assisted Air-Conditioning of Buildings – an Overview«, Applied Thermal Engineering, www.sciencedirect.com, available online 27.9.2006

Henning, H.-M.; Schossig, P.; Lambrecht, K.; Mertz, G.
»Wellness-Feeling – Was tun gegen die Hitze?«, in: Das Haus, Ausgabe EV – E 3516, Nr. 7/2006, pp. 50–58

Henning, H.-M.; Braun, R.; Lokurlu, A.; Noeres, P.
»Solare Kühlung und Klimatisierung – Belüftung und Wärmerückgewinnung – Einführung«, in: KI Luft- und Kältetechnik, Vol. 6, Issue 2006, pp. 241–247

Herkel, S.; Pfafferott, J.; Löhnert, G.; Voss, K.; Wagner, A.
»Energy Efficient Office Buildings – Result and Experiences from a Research and Demonstration Program in Germany», in: Proceedings, Buildings Performance Congress, Messe Frankfurt, Germany, 27.4.2006

Hofmann, M.; Glunz, S.; Preu, R.; Willeke, G.
»21%-Efficient Silicon Solar Cells Using Amorphous Silicon Rear Side Passivation«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Janz, S.; Reber, S.; Habenicht, H.; Lautenschlager, H.; Schetter, C.
»Processing of C-Si Thin-Film Solar Cell on Ceramic Substrate with Conductive Sic Diffusion Barrier Layer«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Janz, S.; Reber, S.; Habenicht, H.; Lindekugel, S., Lautenschlager, H.; Schetter, C., Lutz, F.
»Solar Cell Processing of Recrystallized Wafer Equivalents on Low-Cost Ceramics«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Janz, S.; Reber, S.; Glunz, S.
»Amorphous Sic: Applications for Silicon Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Jaus, J.; Fleischfresser, U.; Peharz, G.; Dimroth, F.; Lerchenmüller, H.; Bett, A. W.
»Heat Sink Substrates for Automated Assembly of Concentrator Modules«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Kaiser, R.
»Lifetime, Test Procedures and Recommendations for Optimal Operating Strategies for Lead-Acid-Batteries in Renewable Energy Systems – a Survey on Results From European Projects from the 5th Framework Programme«, in: Proceedings, 3rd European Conference PV-HYBRID and MINI-GRID, Aix-en-Provence, France, 11.–12.5.2006, pp. 125–130

Kaiser, R.
»Geschlossene Bleibatterien«, in: Seminarband Wiederaufladbare Batteriesysteme, OTTI-Energie-Kolleg, Ulm, Germany, 3./4.5.2006, pp. 25–48

Kaiser, R.
»Optimised battery management system to improve the storage lifetime in renewable energy systems«, in: Proceedings, 10th European Lead Battery Conference, Athens, Greece, 27.–29.9.2006

Kaiser, R; Schiffer, J.[1]; Sauer, D. U.[1]; Bindner, H.[2]; Cronin, T.[2]; Lundsager, P.[2]
»Model Prediction for Ranking Lead-Acid Battery According to their Expected Lifetime in Renewable Energy Systems and Autonomous Power Supply Systems«, in: Proceedings, 10th European Lead Battery Conference, Athens, Greece, 27.–29.9.2006
([1]: RWTH Aachen University, Electrochemical Energy Conversion and Storage Systems Group, Aachen, Germany)
([2]: RISOE National Laboratory, Roskilde, Denmark)

Kaiser, R.; Sauer, D. U.[1]; Karden, E.[2]; Fricke, B.[2]; Blanke, H.[1]; Thele, M.[1]; Bohlen, O.[1]; Schiffer, J.[1]; Gerschler, J. B.[1]
»Charging Performance of Automotive Batteries – an Underestimated Factor Influencing Lifetime and Reliable Battery Operation«, in: Proceedings, 10th European Lead Battery Conference, Athens, Greece, 27.–29.9.2006
([1]: RWTH Aachen University, Electrochemical Energy Conversion and Storage Systems Group, Aachen, Germany)
([2]: Ford Reserach Center Aachen, Germany)

Kalz, D.; Pfafferott, J.; Schossig, P.; Herkel, S.
»Thermally Activated Building Systems Using Phase-Change Materials«, in: Proceedings, EuroSun 2006, Glasgow Caledonian University, Scotland, UK, 27.–30.6.2006

Kalz, D.; Pfafferott, J.; Schossig, P.; Herkel, S.
»Flächenkühlsysteme mit integrierten Phasenwechselmaterialien – Eine Simulationsstudie«, in: Proceedings, BauSIM 2006 – Erste Deutsch-Österreichische IBPSA Konferenz, Technische Universität München, Munich, Germany, 9.–11.10.2006, pp. 81–83

Kalz, D.; Pfafferott, J.; Herkel, S.
»Monitoring and Data Analysis of two Low Energy Office Buildings with a Thermo-active Building System (TABS)«, in: Proceedings, EPIC 2006 AIVC, 4th European Conference on Energy Performance and Indoor Climate in Buildings, Palais des Congrès, Lyon, France, 20.–22.11.2006

Kiefer, K.; Warta, W.; Hohl-Ebinger, J.; Herrmann, W.; Heisterkamp, N.
»Optimisation of the Power Measurement of Silicon Photovoltaic Modules« in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Klamouris, C.[1]; Böttger, G.[1]; Hübner, M.[1]; Dreschmann, M.[1]; Paulsson, K.[1]; Bett, A. W.; Kueng, T.[1]; Becker, J.[1]; Freude, W.[1]; Leuthold, J.[1]
»Optically Powered Platform with Mb/s Transmission over a Single Fiber«, in: Proceedings, 32nd European Conference on Optical Communication, Cannes, France, 24.–28.9.2006, pp. 461–462
([1]: Universität Karlsruhe, Germany)

Köber, M.; Hermle, M.; Isenberg, J.; Kasemann, M.[1]; Cárdenes, H.; Warta, W.
»Analysis of the Effects Caused by Parameter Inhomogenity with a 2D Modelling Tool Based on Circuit Simulation«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Kontermann, S.; Emanuel, G.; Benick, J.; Preu, R.; Willeke, G.
»Characterisation of Silver Thick-Film Contact Formation on Textured Monocrystalline Silicon Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Koschikowski, J.; Rommel, M.; Wieghaus, M.; Rebmann, H.; Ebermeyer, M.; Hermle, M.
»Solar Thermally Driven Membrane Distillation for Small-Scale Desalination Plants«, in: Proceedings, Global Conference on Renewable Energy Approaches for Desert Regions, Amman, Jordan, 18.–22.9.2006

Kramer, K.; Schüle, K.; Siems, T.; Schäfer, A.; Rommel, M.
»Wirkungsgradmessungen von Prozesswärmekollektoren bei Temperaturen bis 200 °C«, Tagungsband, 16. Symposium Thermische Solarenergie, Bad Staffelstein, 17.–19.5.2006, pp. 191–196

Kray, D.; Schumann, M.; Eyer, A.; Willeke, G.; Kübler, R.[1]; Beinert, J.[1]; Kleer, G.[1]
»Solar Wafer Slicing with Loose and Fixed Grains«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany)

Kray, D.; Schumann, M.; Schultz, O.; Bergmann, M.; Ettle, P.; Rentsch, J.; Eyer, A.; Willeke, G.
»Experimental Investigation of Wire Sawing Thin Multicrystalline Wafers«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Kuhn, T.
»Solar control: Two New Systems and a General Evaluation Method for Facades with Venetian Blinds or other Solar Control Systems«, in: Tagungsband, Konferenz Bausim 2006 der deutschen Sektion der International Building Performance Simulation Association, Munich, Germany, 9.–11.10.2006, p. 108

Kuhn, T.
»Thermischer und visueller Komfort – Leistungsmerkmale und Klassifizierung: Inhalt und Hintergründe zu den Normentwürfen prEN14500 und prEN14501«, in: Architektur und Sonnenschutz 9/2006, pp. 22–28

Létay, G.[1]; Hermle, M.; Bett, A. W.
»Simulating Single-Junction GaAs Solar Cells Including Photon Recycling«, in: Progress Photovoltaic: Research Application 2006, to be published
([1]: Synopsys LLC, Zürich, Switzerland)
Litterst, C.[1]; Eccarius, S.; Hebling, C.; Zengerle, R.[1]; Koltay, P.[1]
»Novel Structure for Passive CO_2 Degassing in µDMFC«, in: Proceedings of 19th IEEE Conference on Micro Electro Mechanical Systems (IEEE-MEMS); Istanbul, Turkey, 22.–26.1.2006, pp. 102–105
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Löckenhoff, R.; Dibowski, G.[1]; Dimroth, F.; Meusel, M.[2]; van Riesen, S.; Bett, A. W.
»1000 Sun, Compact Receiver Based on Monolithic Interconnected Modules (MIMS)«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bonn, Germany)
([2]: RWE Space Solar Power GmbH, Heilbronn, Germany)

Löckenhoff, R.; Wilde, J.; Dimroth, F.;
»Approaches to Large Area III-V Concentrator Receivers«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Lokurlu, A.; Buck, R.; Henning, H.-M.; Dötsch, C.
»Solarunterstützte Kraft-Wärme-Kälte-Kopplung – Hybridsysteme im Trend«, in: KI Luft- und Kältetechnik, Vol. 9, Issue 2006, pp. 365–368

Mack, B.; Hermle, M.; Philipps, S.
»Simulation of the Tunneling Current in Heavily Doped Pn-Junctions«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Mette, A.; Schetter, C.; Wissen, D.[1]; Lust, S.[1]; Glunz, S.; Willeke, G.
»Increasing the Efficiency of Screen-Printed Solar Cells by Light-Induced Silver Plating«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Q-Cells AG, Thalheim, Germany)

Mette, A.; Emanuel, G.; Erath, D.; Preu, R.; Willeke, G.
»High Efficiency on Large Area Screen Printed Silicon Solar Cells and Contacting High Sheet Resistance Emitters Using Hotmelt Ink«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Mette, A.; Richter, P.; Glunz, S.; Willeke, G.
»Novel Metal Technique for the front Side Metallization of Highly Efficient Industrial Silicon Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Morin, G.; Platzer, W.; Eck, M.[1]; Uhlig, R.[1]; Häberle, A.[2]; Berger, M.[2]; Zarza, E.[3]
»Road Map Towards the Demonstration of a Linear Fresnel Collector Using a Single Tube Receiver«, in: Proceedings-CD, 13th Solar Paces International Symposium, Seville, Spain, 20.–23.6.2006, CD-ROM
([1]: Deutsche Zentrum für Luft- und Raumfahrt (DLR), Stuttgart, Germany)
([2]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)
([3]: Plataforma Solar de Almertía, PSA, Tabernas, Spain)

Motta, M.[1]; Aprile, M.[1]; Henning, H.-M.
»Highly Efficient Solar Assisted Sorption System for Airconditioning of Buildings«, in: Tagungsband 8. Internationales Symposium für Sonnenenergienutzung, Gleisdorf, Österreich, 6.–8.9.2006; pp. 209–218
([1]: Departimento di Energetica, Politecnico di Milano,Italy)

Nytsch-Geusen, C.[1]; Ernst, T.[1]; Nordwig, A.[1]; Schwarz, P.[2]; Schneider, P.[2]; Vetter, M.; Wittwer, C.; Holm, A.[3]; Nouidui, T.[3]; Leopold, J.[4]; Schmidt, G.[4]; Mattes, A.[5]
»Advanced Modeling and Simulation Techniques in MOSILAB: A System Development Case Study«, in: Proceedings, 5th International Modelica Conference Wien, 3./4.10.2006
([1]: Fraunhofer-Institut für Rechnerarchitektur und Softwaretechnik FIRST, Berlin, Germany)
([2]: Fraunhofer-Institut für Integrierte Schaltungen IIS, Erlangen, Germany)
([3]: Fraunhofer-Institut für Bauphysik IBP, Stuttgart, Germany)
([4]: Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik IWU, Chemnitz, Germany)
([5]: Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK, Berlin, Germany)

Nytsch-Geusen, C.[1]; Nordwig, A.[1]; Vetter, M.; Wittwer, C.; Nouidui, T.[2]; Schneider, P.[3]
»MOSILAB: Ein Modelica-Simulationswerkzeug zur energetischen Gebäude- und Anlagen-simulation«, in: Proceedings, OTTI Energie-Kolleg, 16. Symposium Thermische Solar-energie, Bad Staffelstein, Germany, 17.–19.5.2006
([1]: Fraunhofer-Institut für Rechnerarchitektur und Softwaretechnik FIRST, Berlin, Germany)
([2]: Fraunhofer-Institut für Bauphysik IBP, Stuttgart, Germany)
([3]: Fraunhofer-Institut für Integrierte Schaltungen IIS, Erlangen, Germany)

Ortiz, B.
»Can Carbon Credits Contribute to Finance Projects for Rural Development«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, pp. 3061–3066

Ortiz, B.
»Can Carbon Credits Contribute to Finance Projects for Rural Development«, in: Proceedings, 3rd European Conference PV-HYBRID and MINI-GRID, Aix-en-Provence, France, 11.–12.5.2006, pp. 230–236

Pearsall, N.[1]; Scholz, H.[2]; Zdanowicz, T.[3]; Reise, C.
»PV System Assessment in PERFORMANCE – towards Maximum System Output«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006
([1]: University of Northumbria, Newcastle, United Kingdom)
([2]: Institute for Environment and Sustainability, Ispra, Italy)
([3]: University of Technology, Wroclaw, Poland)

Pfafferott, J.; Herkel, S.; Kalz, D.; Zeuschner, A.
»Comparison of Low-Energy Office Buildings in Summer Using Different Thermal Comfort Criteria«, in: Proceedings, NCEUB Network for Comfort and Energy Use in Buildings, Windsor, United Kingdom, 27.–30.4.2006

Pfafferott, J.; Herkel, S.; Kalz, D.; Zeuschner, A.
»Comparison of Low-Energy Office Buildings in Summer Using Different Thermal Comfort Criteria«, in: Proceedings, Healthy Buildings 2006, Lisbon, Portugal, 4.–8.6.2006

Pfanner, N.; Roth, W.
»Anwendungen – Photovoltaik in der Beleuchtungstechnik«, in: Tagungsband, OTTI Energie-Kolleg, Fachseminar Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 27./28.9.2006, pp. 317–386

Platzer, W.; Pitz-Paal, R.[1]
»Solarthermische Kraftwerke – Europäische Potenziale kostengünstig erschließen«, in: Tagungsband, Jahrestagung 2006 des Forschungsverbunds Sonnenenergie, Forschung und Innovation für eine nachhaltige Energieversorgung, Berlin, Germany 21./22.9.2006
([1]: Deutsches Zentrum für Luft- und Raumfahrt e.V. DLR)

Preu, R.; Biro, D.; Rentsch, J.; Emanuel, G.; Grohe, A.; Hofmann, M.
»The Status of Silicon Solar Cell Production Technology Development at Fraunhofer ISE«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Reber, S.; Duerinckx, F.[1]; Alvarez, M.[2]; Garrard, B.[3]; Schulze, F. W.[4]
»EU Project SWEET on Epitaxial Wafer Equivalents: Results and Future Topics of Interest«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, , CD-ROM
([1]: IMEC Leuven, Belgium)
([2]: Aplicaciones Técnicas de la Energía, SL (ATERSA), Spain)
([3]: Crystalox Ltd., Wantage, United Kingdom)
([4]: PV Silicon AG, Erfurt, Germany)

Reise, C.; Ebert, G.; Köhl, M.; Herrmann, W.[1]; Stellbogen, D.[2]; Gabler, H.[2]; Pearsall, N.[3]; Gottschalg, R.[4]; de Moor, H.[5]; Despotou, E.[6]; Dunlop, E.[7]
»PERFORMANCE – a Science Base on PV Performance for Increased Market Transparency and Customer Confidence« in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: TÜV Immisionsschutz und Energiesysteme GmbH, Cologne, Germany)
([2]: Zentrum für Sonnenenergie- und Wasser-stoff-Forschung (ZSW) Baden-Württemberg, Stuttgart, Germany)
([3]: University of Northumbria, Newcastle, United Kingdom)
([4]: Loughborough University, United Kingdom)
([5]: Energy Research Center (ECN), Solar Energy, Petten, The Netherlands)
([6]: European PV Industry Association, Brussels, Belgium)
([7]: European Commission, DG JRC, Ispra, Italy)

Rentsch, J.; Schultz, O.; Grohe, A.; Biro, D.; Preu, R.; Willeke, G.
»Technology Route Towards Industrial Application of Rear Passivated Silicon Solar Cells«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Riede, M.[1]; Liehr, A.[1]; Glatthaar, M.[1]; Niggemann, M.[1]; Zimmermann, B.[1]; Ziegler, T.; Gombert, A.; Willeke, G.
»Datamining and Analysis of the Key Parameters in Organic Solar Cells«, in: Proceedings, Photonics Europe, Strasbourg, France, 3.–7.4.2006
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Roth, W.; Bryniok, D.[1]; Dobers, K.[2]; Eiband, A.[2]; Fuchs, D.[3]; Hauser, H.[2]; Sellmeier, C.[3]; Vielreicher, H.[3]; Wang, W.[4]
»BIKE - Bayerische Initiative zur Konsortialbildung für internationale Entwicklungsprojekte«, in: Tagungsunterlagen zur Abschlussveranstaltung der Bayerischen Initiative zur Konsortialbildung für internationale Entwicklungsprojekte, Munich, Germany, 18.1.2006
([1]: Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik IGB, Stuttgart, Germany)
([2]:Fraunhofer-Institut für Materialfluss und Logistik IML, Dortmund und Priem am Chiemsee, Germany)
([3]:Fraunhofer-Gesellschaft, European and International Business Development, Munich, Germany)
([4]: Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK, Berlin, Germany)

Roth, W.
»Netzferne Stromversorgung mit Photovoltaik – Einführung«, in: Tagungsband, OTTI Energie-Kolleg, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 26.9.2006, pp. 9–54

Roth, W.; Reise, Ch.
»Grundlagen zur Nutzung der Sonnenenergie«, in: Tagungsband, OTTI Energie-Kolleg, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 26.9.2006, pp. 55–83

Roth, W.
»Anwendungen – Industrieprodukte und technische Einrichtungen«, in: Tagungsband, OTTI Energie-Kolleg, Fachseminar Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 27./28.9.2006, pp. 387–438

Schöne, J.; Dimroth, F.; Bett, A.; Tauzin, A.[1]; Jaussaud, C.[1]; Roussin, J.-C.[1]
»III-V Solar Cell Growth on Wafer-Bonded GaAs/Si-Substrates«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM
([1]: Commissariat à l'Energie Atomique (CEA), Grenoble, France)

Schmidt, H.; Burger, B.; Kiefer, K.
»Welcher Wechselrichter für welche Modultechnologie?«, in: Tagungsband, OTTI Energie-Kolleg, 21. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 8.–10.3.2006, pp. 220–225

Schmidt, H.; Roth, W.
»Aufbau und Funktionsweise von Solarzelle, Modul und Solargenerator«, in: Tagungsband, OTTI Energie-Kolleg, Grundlagenworkshop Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 26.9.2006, pp. 85–137

Schmidt, H.; Burger, B.; Kiefer, K.
»Welcher Wechselrichter für welche Dünnschichttechnologie?«, in: Tagungsband, OTTI Energie-Kolleg, Fachseminar Dünnschicht-Photovoltaikmodule, Freiburg, Germany, 20.6.2006, pp. 57–84

Schmidt, H.
»Elektromagnetische Verträglichkeit«, in: Tagungsband, OTTI Energie-Kolleg, Fachseminar Leistungselektronik für erneuerbare Energiesysteme, Regenstauf, Germany, 6./7.7.2006, pp. 199–228

Schmidt, H.; Kaiser, R.; Sauer, D.-U.[1]
»Batterien in netzfernen Stromversorgsanlagen«, in: Tagungsband, OTTI Energie-Kolleg, Fachseminar Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 27./28.9.2006, pp. 59–116
([1]: RWTH Aachen, ISEA)

Schmidt, H.
»Laderegler und Überwachungseinrichtungen für Batterien in photovoltaischen Energieversorgungssystemen«, in: Tagungsband, OTTI Energie-Kolleg, Fachseminar Netzferne Stromversorgung mit Photovoltaik, Freiburg, Germany, 27./28.9.2006, pp. 117–138

Schmidt, H.
»EMV-Messverfahren für PV und EMV-gerechtes Schaltungsdesign«, in: Tagungsband, OTTI Energie-Kolleg, Profiseminar EMV und Blitzschutz für Solaranlagen, Regensburg, Germany, 22./23.11.2006, pp. 35–64

Schönfelder, S.[1]; Bagdahn, J.[1]; Baumann, S.; Kray, D.; Mayer, K.; Willeke, G.; Becker, M.[2]; Christiansen, S.[2]
»Strength Characterization of Laser Diced Silicon for Application in Solar Industry«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Fraunhofer-Institut für Werkstoffmechanik IWM, Halle, Germany)
([2]: Martin-Luther Universität Halle-Wittenberg, Germany)

Schubert, M.; Riepe, S.; Warta, W.
»Spatially Resolved Trapping Detection and Correlation with Material Quality in Multicrystalline Silicon«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Schultz, O.; Rentsch, J.; Grohe, A.; Glunz, S.; Willeke, G.
»Dielectric Rear Surface Passivation for Industrial Multicrystalline Silicon Solar Cells«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Schultz, O.; Glunz, S.; Warta, W.; Preu, R.; Grohe, A.; Hermle, M.; Willeke, G.; Russel, R.[1]; Fernandey, J.[1]; Morilla; C.[1]; Bueno, R.[1]; Vincuería, I.[1]
»High-Efficiency Solar Cells with Laser-Grooved Buried Contact Front and Laser-Fired Rear for Industrial Production«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: BP Solar España, Poligono Industrial Tres Cantos, Madrid, Spain)

Schultz, O.; Glunz, S.; Riepe, S.; Willeke, G.
»Gettering of Multicrystalline Silicon for High-Efficiency Solar Cells«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Sicre, B.
»La Micro-Cogénération Bois: État de la Technique et Perspectives«, in: Proceedings, Capteur 2006, Bourges, France, 18./19.10.2006

Sicre, B.; Reynier, B.; Bühring, A.
»La Maison Solaire Énergétiquement Autarcique de Fribourg-en-Brisgau: Retour d'Expérience et Conséquences sur les Systèmes Énergétiques Actuels«, in: Proceedings, Capteur 2006, Bourges, France, 18./19.10.2006

Siefer, G.; Bett, A. W.
»Calibration of III-V Concentrator Cells and Modules«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006, CD-ROM

Siefer, G.; Bett, A. W.
»Accelerated Indoor Aging Test Procedure for Concentrator Modules«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Smolinka, T.; Grootjes, S.[1]; Mahlendorf, F.[2]; Hesselmann, J.; Makkus, R.[1]
»Prototype of a Reversible Fuel Cell System for Autonomous Power Supplies«, in: Proceedings, 3rd European PV-Hybrid and Mini-Grid Conference, OTTI Energie-Kolleg, Aix-en-Provence, France, 11.–12.5.2006, pp. 131–136
([1]: Energy Research Center of the Netherlands (ECN), The Netherlands)
([2]: Universität Duisburg-Essen, Germany)

Strobl, G.[1]; Bergunde, T.[1]; Köstler, W.[1]; Kern, R.[1]; Meusel, M.[1]; LaRoche, G.[1]; Zimmermann, W.[1]; Dimroth, F.; Geens, W.[2]; Taylor, S.[3] ; Fernandez, E.[3]; Gerlach, L.[3]; Signorini, C.[3]; Hey, G.[4]
»European Roadmap of Multijunction Solar Cells and Qualification Status«, in: Proceedings, IEEE 4th World Conference on Photovoltaic Energy Conversion, Waikoloa, Hawaii, USA, 7.–12.5.2006
([1]: RWE Space Solar Power GmbH, Heilbronn, Germany)
([2]: Umicore, Olen, Belgium)
([3]: European Space Agency, ESA, Noordwijk, The Netherlands)
([4]: Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bonn, Germany)

Trassl, R.[1]; Ratschat, H.[1]; Daube, C.[1]; Wieder, S.[1]; Wolke, W.; Preu, R.
»Successful Market Entry of Applied Materials´ ATON (TM) System for sputtered SiN:H«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Applied Materials GmbH & Co. KG, Alzenau, Germany)

Vogt, A.; Peharz, G.; Jaus, J.; Bösch, A.;
»Degradation Studies on Flatcon Modules and Assemblies«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Volz, K.[1]; Lackner, D.[1]; Rubel, O.[1]; Stolz, W.[1]; Baur, C.; Dimroth, F.; Müller, S.; Bett, A.
»Improving the Material Quality of MOVPE Grown (GaIn) (NAs)«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM
([1]: Materialforschungzentrum und Physikalische Fakultät, Phillips Universität, Marburg, Germany)

Voyer, C.; Biro, D.; Wagner, K.; Benick, J.; Preu, R.
»Fabrication of Textured Solar Cells Using Sprayed Phosporic Acid as the Dopant Source for the In-Line Emitter Diffusion«, in: Proceedings, 21st European Photovoltaic Solar Energy Conference & Exhibition, Dresden, Germany, 4.–8.9.2006, CD-ROM

Walze, G.; Gombert, A.; Nitz, P.; Blaesi, B.
»Rigorous Validation of the Lateral Goos-Hänchen Shift in Microstructured Sun Shading Systems«, in: Proceedings, Photonics Europe, Strasbourg, France, 3.–7.4.2006

Welser, E.; Dimroth, F.; Ohm, A.; Guter, W.; Siefer, G.; Schöne, J.; Polchroniadis, E.K.[1]
»Lattice-Matched GaInAsSb on GaSb for TPV Cells«, in: Proceedings, 7th World Thermophotovoltaic Generation of Electricity (TPV) Conference, Madrid, Spain, 25.–27.9.2006
([1]: Aristotle University of Thessanoliki, Greece)

Wiemken, E.; Henning, H.-M.
»Solar Assisted Air-Conditioning in the Frame of the German Solarthermie 2000Plus Programme«, in: Proceedings, The Sustainable Mobility Challenge at the National Congress of the Italian Thermotechnical Association (ATI), University of Perugia, Italy, 14.9.2006

Wilson, H. R.
»High-Performance Glazing«, in: Proceedings, ISES International Summer Workshop Solar-Low-Energy Housing in Europe, Freiburg, Germany, 11.–19.8.2006

Wittwer, C.; Becker, R.
»Modellbasierte Ertragskontrolle von PV-Anlagen in Gebäuden«, in: Tagungs-CD, Internationales Kolloquium über Anwendungen in der Informatik und Mathematik in der Architektur, Universität Weimar, Germany, 12.–14.7.2006

Yu, H.[1]; Ziegler, C.
»Transcient Behaviour of a Proton Exchange Membrane Fuel Cell under Dry Operation«, in: Journal of the Electrochemical Society JES
([1]: Dalian Institute of Chemical Physics, Chinese Academy of Sciences, Dalian, China)

Zacharias, P.; Schmid, J.[1]; Schweizer-Ries, P.[2]; Ortiz, B.; Vetter, M.
»Export erneuerbare Energietechniken – Ländliche Elektrifizierung«, in: Tagungsband zur Jahrestagung des ForschungsVerbunds Sonnenenergie Forschung und Innovation für eine nachhaltige Energieversorgung, 21.–22.09.2006
([1]: Institut für Solare Energietechnik ISET, Kassel, Germany)
([2]: Universität Magdeburg, Germany)

Zastrow, A.
»The Evaluation of Photocatalytic Activity: Measurement Techniques and Standardisation Tools for a New Range of Products and Rapidly Growing Industry«, in: Tagungsband, DECHEMA, Frankfurt, Germany, 15.–19.5.2005

Zimmermann, B.[1]; Glatthaar, M.[1]; Niggemann, M.[1]; Riede, M.[1]; Hinsch, A.; Gombert, A.
»ITO-Free Anode Wrap Through Organic Solar Cells – a Module Concept for Cost Efficient Reel to Reel Production«, in: Solar Energy: Materials and Solar Cells
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Books and Contributions to Books

Hebling, C.
»Brennstoffzellen für Portable Anwendungen«, in: Brennstoffzellen, Hrsg. Heinzel, A.; Roes, J.; Mahlendorff, F., Huethig Verlag (2006), pp. 105-119
ISBN 3-7880-7741-7

Kaiser, R.; Henning, H.-M; Schossig, P.
»Energiespeicher« in: Technologieführer – Grundlagen, Anwendungen, Trends, Bullinger, H.-J. (ed.), Springer Verlag, 2006
ISBN 3-540-33788-1

Ortiz, B.
»Energiebedarf in ländlichen Gebieten Mexikos und die Verminderung von CO_2-Emissionen« in: Ökologische Transformation der Energiewirtschaft, Erfolgsbedingungen und Restriktionen, Hrsg: Dipl.-Pol. Mischa Bechberger, Dr. phil. Danyel Reiche, Erich Schmidt Verlag, 2006, Berlin, pp. 139-158,
ISBN-13: 978 3 503 09303 7,
ISBN-10: 3 503 09313 3, ISSN: 1438-5023

Reber, S.; Kieliba, T.; Bau, S.
»Crystalline Silicon Thin-Film Solar Cells on Foreign Substrates by High-Temperature Deposition and Recrystallization« in: Thin-Film Solar Cells: Fabrication, Characterization and Applications, Arkhipov, V.; Poortmans, J. (ed.), published by John Wiley and Sons, 2006, pp. 39-95.
ISBN 0-470-09126-6

The Fraunhofer-Gesellschaft

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organisation undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration. The organisation also accepts commissions from German Federal and State ministries and government departments to participate in future-oriented research projects with the aim of finding innovative solutions to issues concerning the industrial economy and society in general.

Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, accelerating technological progress, improving the acceptance of new technologies, and not least by disseminating their knowledge and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, in other scientific domains, in industry and in society. Students working at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units, including 56 Fraunhofer Institutes, at 40 different locations in Germany. The majority of the 12,500 staff are qualified scientists and engineers, who work with an annual research budget of € 1.2 billion. Of this sum, more than € 1 billion is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German Federal and State governments in the form of institutional funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

Affiliated research centres and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to present and future scientific progress and economic development.

The Fraunhofer-Gesellschaft is a recognised non-profit organisation which takes its name from Joseph von Fraunhofer (1787-1826), the illustrious Munich researcher, inventor and entrepreneur.

Editors
Rosemarie Becker
Karin Schneider (Head)
Press and Public Relations

External photographers
Michael Eckmann, Freiburg
Sebastian Ehret, Freiburg
Sigrid Gombert, Freiburg
Eisenhart Keimeyer, Freiburg
Guido Kirsch, Freiburg
Jens Meier, Bremen
Joscha Rammelberg, Freiburg
Sabine Schnell, Freiburg
Volker Steger, München

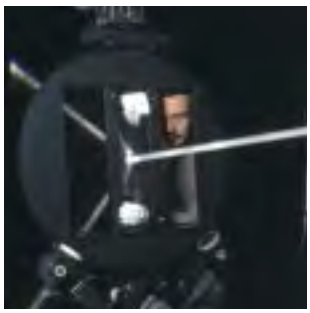
Translation from the German
Dr Helen Rose Wilson, Freiburg

Layout and Printing
www.netsyn.de
Joachim Würger, Freiburg

Editorial Address
Fraunhofer Institute for
Energy Systems ISE
Press and Public Relations
Heidenhofstr. 2
79110 Freiburg
Germany
Tel. +49 (0) 761/45 88-51 50
Fax. +49 (0) 761/45 88-93 42
info@ise.fraunhofer.de
www.ise.fraunhofer.de

Publications Orders
Please send an e-mail or a fax.

In addition to this annual report,
more information can be found at
our web site www.ise.fraunhofer.de



Fraunhofer Institute for
Solar Energy Systems ISE
Heidenhofstr. 2
79110 Freiburg
Germany

Tel. +49 (0) 7 61/45 88-0
Fax. +49 (0) 7 61/45 88-90 00
info@ise.fraunhofer.de
www.ise.fraunhofer.de