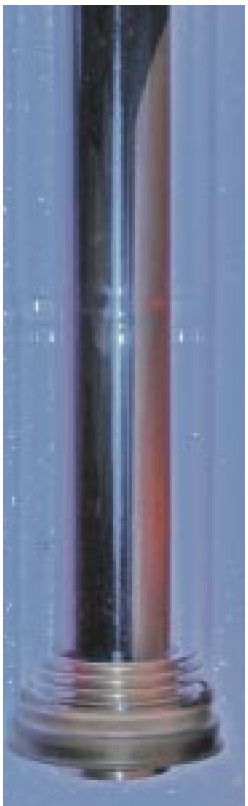
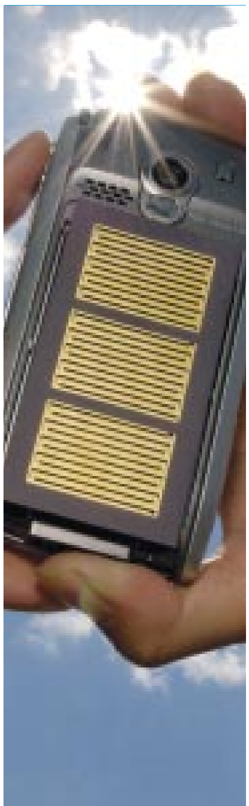
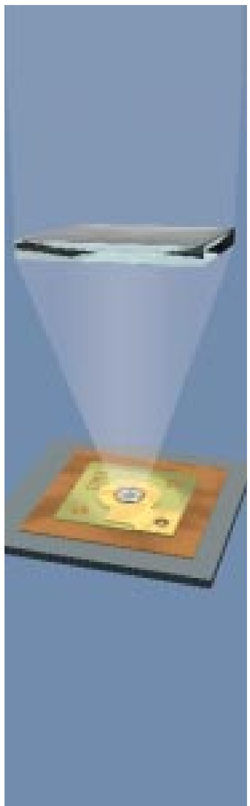
Fraunhofer Institut Solare Energiesysteme

Annual Report 2005

Achievements and Results

left
The absorber pipe is the core component of a solar-thermal, parabolic-trough power station, in which the thermal energy of the sun is used to generate electricity. The joint development with SCHOTT-Rohrglas GmbH will have its first application in a 64 MW power station in Nevada, USA, which will be connected to the grid in 2007. Fraunhofer ISE has many years of experience in the development of selective absorber coatings. For more information on solar-thermal power stations, see also the article on p. 81.

centre
Miniature fuel cells present a power-supply option for mobile electronic devices. The form of the planar fuel cell shown here allows it to be integrated well into the casing of adevice. In addition, the oxygen from the air needed for operation can enter the fuel cell purely by diffusion. Both hydrogen-based and methanol-based fuel cell systems are developed by Fraunhofer ISE (see article on p. 86).

right
The operating principle of FLATCON® technology: 4 x 4 cm^2 Fresnel lenses concentrate the solar radiation by a factor of 500 onto high-efficiency multiple-junction solar cells. An efficiency value of 35 % is currently achieved at Fraunhofer ISE with concentrator solar cells of III-V semiconductors. The technology is suitable for power stations from 100 kW to several MW in sunny regions. In March 2005, Concentrix Solar GmbH, the most recent spin-off company from Fraunhofer ISE, was founded with the aim of marketing the FLATCON® technology (see articles on pp. 52 and 80).

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 systems, components, materials 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.

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Facts and Figures

Research, technological development and industrial activity promoting the technical use of solar energy have been expanding rapidly for a number of years now. In this context, Fraunhofer ISE was able to grow again by about 10 percent in 2005. A natural consequence of our continuous growth is the permanent need to optimise our structures. As part of this process, in 2005 we divided the Department for "Thermal and Optical Systems" (TOS), which had been the largest department of Fraunhofer ISE, into two: The Department for "Thermal Systems and Buildings", led by Dr Hans-Martin Henning, and the Department for "Materials Research and Applied Optics", led by Dr Andreas Gombert. In this way, we created two new departments at Fraunhofer ISE, which each have a clear scientific focus and a manageable size.

Dr Volker Wittwer, the previous Head of the TOS Department and simultaneously Deputy Director of the Institute, took on responsibility for a much wider area of the Institute leadership than in the past. In particular, this included strategic planning and all matters concerning patents for Fraunhofer ISE.

In connection with this restructuring process, we defined a sixth business area for our Institute: "Optical Components and Systems". Here, we are aiming specifically to address and stimulate further development in newer sectors including "Lighting Technology" (solar control, glare protection, lamp development), "Solar Power Plants" (highly concentrating optics for photovoltaic and thermal power stations) and "Display Technology" (improvement of contrast, resolution and system efficiency). The examples cited indicate that we intend to make our expertise on solar energy conversion more accessible to other technological areas also.

In the field of photovoltaic energy conversion, the developments at Fraunhofer ISE were particularly tempestuous in 2005: At the beginning of the year, we co-founded the "Technology Centre for Semiconductor Materials THM, Freiberg" together with the Fraunhofer Institute for Integrated Systems and Device Technology IISB, and the spin-off company, Concentrix Solar GmbH, was also founded in spring. Setting up the "Photovoltaic Technology Evaluation Center PV-TEC" demanded great effort throughout the whole year. Dr Willeke and his team deserve my highest commendation for their achievements.

- THM was founded on the suggestion of the relevant industrial partners located in Freiberg. Fraunhofer IISB and Fraunhofer ISE foresee appreciable synergetic potential in their close co-operation and the possibility for strategic expansion of their previous R & D areas. Initially, R & D will focus on silicon materials research and the corresponding materials processing. I would particularly like to thank Prof. Schindler for his contribution toward establishing THM.
- Concentrix Solar will introduce our high-efficiency photovoltaic converter, combining optical concentration and GaAs solar cells, to the market. The first target markets are power plants in the 100 kW to 10 MW range for regions with a high proportion of direct solar radiation. Hansjörg Lerchenmüller has taken on the management of our newest spin-off company with the greatest enthusiasm and professionalism.
- PV-TEC became feasible due to significant financial support (11.7 million euros) by the German Federal Ministry for the Environment. During the report year, we set up a complete, very flexible production line for technological development of silicon wafer solar cells (optimisation of processes, materials and systems). PV-TEC will be officially opened in March 2006 in the presence of Federal Minister Gabriel. My special thanks are extended to Dr Ralf Preu and Dr Daniel Biro and their team for their perfect achievements within an extremely short period of time.

You will find further selected R & D highlights on page 10 of this report. However, I would particularly like to mention the field of "Micro-Energy Technology". This area, which combines small fuel cells, device-integrated solar cells or thermoelectric energy converters with suitable storage technology and optimised energy management, was identified as one of the twelve "Perspectives for Future Markets" by the Fraunhofer-Gesellschaft. Dr Christopher Hebling is co-ordinating this Fraunhofer Innovation Theme at our Institute and, with my support, for the entire Fraunhofer-Gesellschaft.

Two events in the personnel sector should be specifically reported here: Dr Andreas Gombert qualified as an academic lecturer in the "Faculty of Applied Science" in spring 2005. Once again, sincere congratulations in the name of Fraunhofer ISE! Together with Dr Wittwer and myself, three scientists now have a formal association with a Faculty at the University of Freiburg. To my regret, Dr Tim Meyer, the previous Head of the Department for "Electrical Energy Systems", left our Institute in October to accept a very responsible position in industry. Dr Wittwer deserves my sincere thanks for leading the department until the appointment of a successor. I also wish to heartily thank Dr Meyer, on behalf of the whole Institute, for his excellent work over many years at Fraunhofer ISE.

As every year, I wish to emphatically thank all members of the Institute staff here for their achievements. My gratitude also extends to our Trustees and our clients and supporters in industry, ministries and the European Union. This Annual Report from Fraunhofer ISE is the last one to be written under my directorship. It was always a great pleasure and source of satisfaction for me to work together with all of you to promote a sustainable energy supply and technological development for the future. Your trust and your highly motivated and creative work toward our common goals have not only commanded my undisguised admiration, but have also continually excited and inspired me.

With my sincere thanks

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 scientific and technical staff are based in the individual departments

Institute Director	Prof. Joachim Luther	
Deputy Director	Dr Volker Wittwer	
Departments	Electrical Energy Systems Dr Tim Meyer (until 31.10.2005) (from 1.11.2005) Dr Volker Wittwer	+49 (0) 7 61/45 88-51 40
	Energy Technology Dr. Christopher Hebling	+49 (0) 7 61/45 88-51 95
	Materials Research and Applied Optics (from 1.4.2005) Dr Andreas Gombert	+49 (0) 7 61/45 88-59 83
	Solar Cells - Materials and Technology Dr Gerhard Willeke	+49 (0) 7 61/45 88-52 66
	Thermal Systems and Buildings (from 1.4.2005) Dr Hans-Martin Henning	+49 (0) 7 61/45 88-51 34
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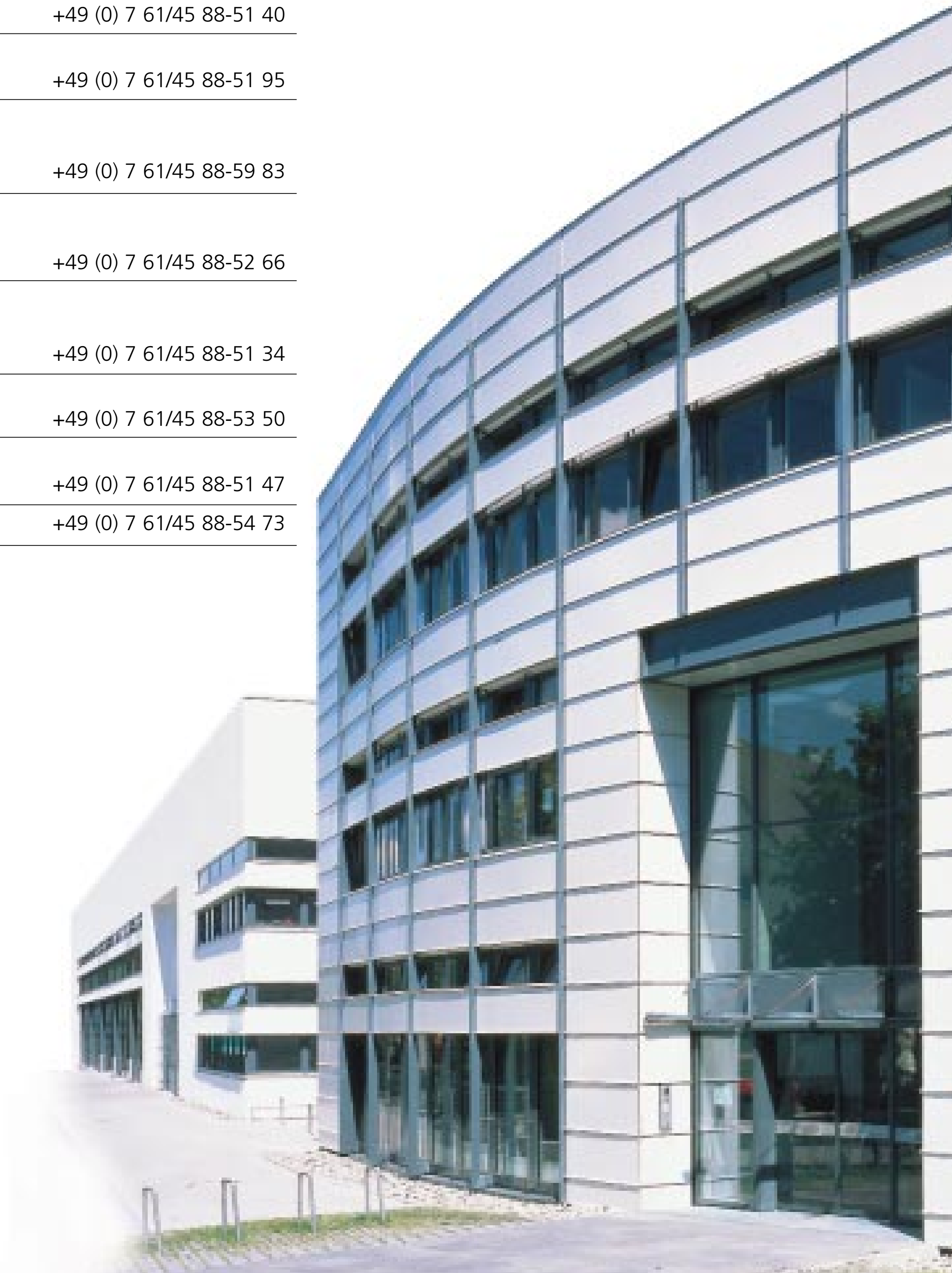
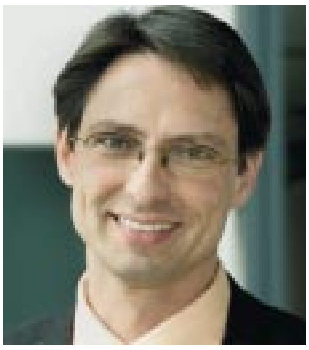




The photos show the Institute Director and the Deputy Director of Fraunhofer ISE, the Heads of the scientific departments, and the Business Manager of Fraunhofer ISE.

Joachim Luther, Volker Wittwer
Christopher Hebling, Hans-Martin Henning, Andreas Gombert
Gerhard Willeke, Tim Meyer (until 31.10.2005), 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 systems, components, materials 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 purification of drinking water.

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.

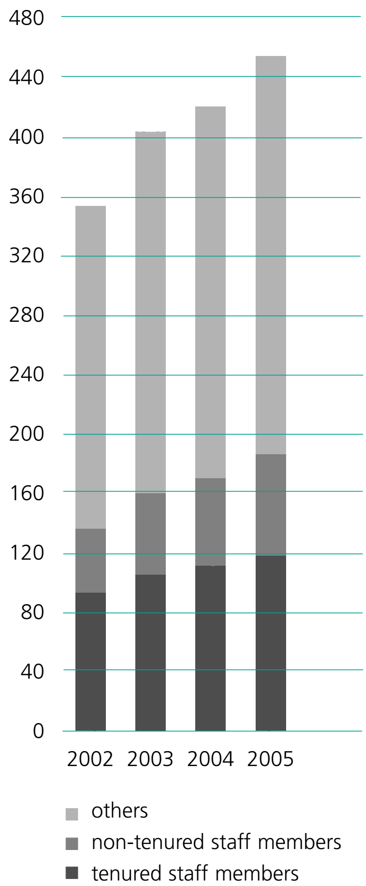
Networking within the Fraunhofer-Gesellschaft

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 has the following memberships:
- 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"

International Clients and Co-operation Partners

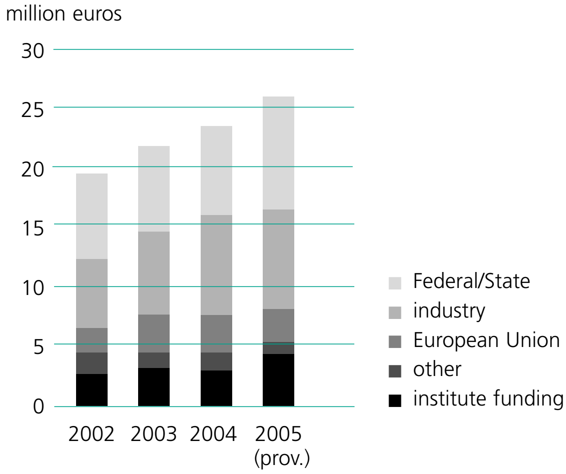
The Fraunhofer Institute for Solar Energy Systems has co-operated successfully for years with international co-operation partners and clients from a wide range of business sectors and company sizes. You can find a list of our partners at www.ise.fraunhofer.de/german/profile/index.html

Personnel development

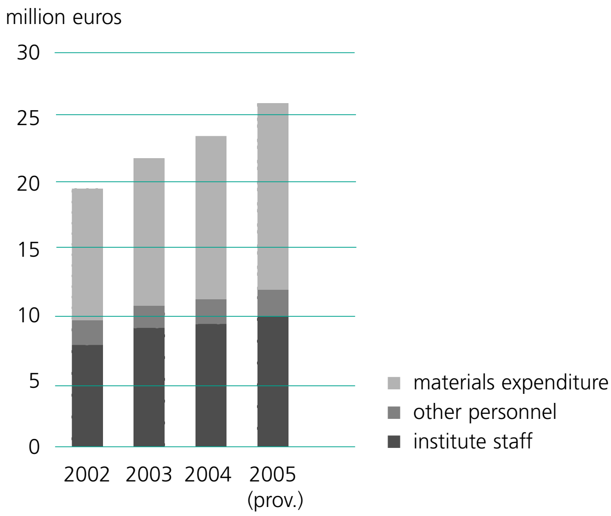


Finances

Income



Expenditure



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 2005, 55 doctoral candidates, 81 undergraduate students, 5 apprentices and 127 scientific assistants were employed at the Institute. In this way, Fraunhofer ISE makes an important contribution to the education system.

In addition to the expenditure documented in the graph, the Institute made investments of 4.5 million euros in 2005 (not including the investment of 10.7 million euros for the BMU-funded PV-TEC project).

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

- silicon wafer solar cell with a silicon carbide passivation layer and laser-fired contacts achieved an efficiency value of 20.2 %
- monocrystalline silicon wafer solar cell (Cz) with an area of 12.5 x 12.5 cm^2, prepared with an industrial process using a hot-melt screen-printing paste, achieved an efficiency value of 18 % with a fill factor of 80 %
- crystalline silicon solar cell (4 cm^2) with a-Si back-surface passivation and laser-fired contacts achieved an efficiency value of 21.3 %
- crystalline Si solar cell with back-surface contacts and secondary concentrator achieves a total efficiency value of 21 %
- for the first time, silicon wafers were produced at Fraunhofer ISE with a kerf width of only 170 µm using an industrial multiple-wire saw
- epitaxial silicon films from the continuous CVD (chemical vapour deposition) system form the basis for solar cells with an efficiency value of 12.5 % over an area of 21 cm^2.
- module of six 92 x 92 mm^2 solar cells on recrystallised wafer equivalents achieves an open circuit voltage of 3.2 V
- triple-junction solar cell of GaInP/GaInAs/Ge achieves an efficiency value of 35.2 % under 600 x concentration
- Concentrix Solar GmbH was founded as a spin-off company from Fraunhofer ISE
- the first PV concentrator system (1 kW) based on FLATCON® modules supplied electricity to the public grid
- inverted configuration of an organic solar cell with an efficiency value of 3 % represents an essential step towards producible wrap-through solar cells applying a roll-to-roll process
- vacuum-tight sealing method based on solder glass developed for dye solar cells with an area of 60 x 100 cm^2
- optimised operation management system developed for low-voltage grid with distributed generators
- 3-phase, highly efficient inverter without a transformer developed for the low power range (5 kW)
- high-precision power measurement of Si PV modules (2 x 2 m^2) achieved with an accuracy of better than ± 2.5 %
- weather-resistant fuel cell system (30 W, incl. power electronics and electronic controls system) operated for 1000 hours with a dynamic load in a temperature range from -20 °C to +40 °C
- fully automatic kerosene reformer constructed to provide fuel for a solid-oxide fuel cell in the low power range (500 W to 1 kW) and operated in a long-term test for 300 hours
- production-relevant concept developed for a planar direct methanol fuel cell. This uses a purely diffusive air supply and carbon dioxide degassing optimised by microfluid design
- process developed for soot-free catalytic partial oxidation of diesel
- active phase stabilisation for interference lithography makes deeper structures feasible for a wider application spectrum of micro-structured surfaces
- heat transfer between inorganic adsorbents and metallic heat-transport systems significantly improved by new coating technology (application in thermal storage units and heat transformation)
- algorithm developed to optimise biomimetic structures in hydraulic circuits, particularly solar collectors
- standard measurement procedure developed for steam production power of thermal collectors under stagnation conditions

Prizes

The Institute Director, Prof. Joachim Luther, received a number of important national and international awards in 2005.

Environmental Prize 2005 of the German Federal Environmental Foundation DBU

The German Federal Environmental Foundation DBU awarded the Environmental Prize in 2005 to Prof. Joachim Luther as the Director of Fraunhofer ISE for his achievements in research and market introduction of solar energy systems. This prize, the most highly valued environmental award in Europe, was divided equally among Prof. Luther and the scientist, Prof. Berndt Heydemann. The prize was presented by the German President, Horst Köhler, in Lübeck.

"If Germany is one of the internationally leading countries in the use of solar energy today, this can be attributed significantly to his efforts", said the General Secretary of the German Federal Environmental Foundation DBU, Dr Fritz Brickwedde, in commending the work of the solar expert.

Becquerel Prize

On the occasion of the 20th European Photovoltaic Solar Energy Conference in Barcelona, the EU Commission presented Prof. Joachim Luther with the highest award of the EU in the solar energy field, the Becquerel Prize. The prize is named after the French scientist, Edmond Becquerel, who discovered the photovoltaic effect in 1839.

ISES Special Service Award

The International Solar Energy Society (ISES) honoured Prof. Luther with the ISES Special Service Award in recognition of his outstanding services to solar energy. The prize was awarded to him at the ISES Solar World Congress 2005 in Orlando, Florida.

Prof. Luther during the Awards Ceremony for the German Environmental Prize on 16th October, 2005 in Lübeck.
Photo: German Federal Environmental Foundation DBU

16th International Rhineland Prize for Environmental Conservation

"A scientist, who over the past years laid the foundations underpinning the economic success of solar energy" was the commendation of the Chief Executive of the TÜV Rheinland Group, Prof. Bruno O. Braun, in presenting the 16th International Rhineland Prize for Environmental Conservation to Prof. Joachim Luther. With his work focussed on applied aspects, Prof. Luther had made an important contribution to Germany's technological leadership in this area.

The Association of German Engineers VDI in Hamburg and Schleswig awarded the "Prof. Werner Petersen Prize for Excellent Undergraduate Theses" to **Jan Schöne** for his thesis entitled "GaInP/GaInAs/Ge heterostructures for triple-junction solar cells: Micro-structural investigations applying transmission electron microscopy and high-resolution X-ray diffraction".

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: 7th October, 2005

Buildings and Technical
Building Components

Optical Components
and Systems

Solar Cells

Off-Grid Power Supplies

Grid-Connected Renewable
Power Generation

Hydrogen Technology

Service Units

Building efficiently with the sun

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 planned "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 following statistic demonstrates the importance of this subject. Today, more than 40 % of the end energy consumption in Germany is used to operate buildings. It is used for heating, cooling, ventilation, illumination and many other purposes. The rational use of energy reduces the amount of energy consumed for these services and often improves the user comfort at the same time. A general principle applies in all cases: 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 building complexes with simulation tools which we can develop further if required. The topics are treated at all levels, ranging from fundamental development to market introduction of materials, components and systems.

These tasks rely on co-operation between many disciplines - from materials research and thin-film 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 support 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, and the application of solar energy. In addition to solar-heated domestic hot water and solar-assisted space heating, promising 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 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.

Our facilities and measurement procedures cover a broad spectrum to investigate and develop materials, components and systems for buildings and technical building components.

Buildings and Technical Building Components

A biomimetic approach optimises the energy efficiency of absorbers for solar collectors. The piping for conventional solar absorbers usually has a series or parallel configuration (meander or harp configuration). By contrast, natural vein structures - in leaves or blood vessels, for example - often consist of multiply branching structures. These structures optimise circulation and reduce the pressure losses. We have transferred this principle to technology as part of the work for a doctoral thesis. The results support the development of energy-efficient absorbers (see article on p. 26).

Contacts

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Hydrogen technology	Dr Christopher Hebling	Tel.: +49 (0) 7 61/45 88-51 95 E-mail: Christopher.Hebling@ise.fraunhofer.de

New Technology in Building Projects Optimises Energy Consumption and Comfort

High thermal, visual and acoustic comfort is just as important in building planning as the avoidance or reduction of cooling demand. New evaluation procedures for solar-control and glare-protection components, as well as validated building simulation programs, are being adopted in planning practice. We have applied our research results to building projects and demonstrated that economic viability, energy saving and comfort can be combined harmoniously.

Sebastian Herkel, Tilmann Kuhn,
Jens Pfafferott, Jan Wienold

In the selection of projects listed in the table, we supported the planning process in 2005 with contributions from building science, building technology and façade development.

	Building science	Building technology	Energy supply	Façade
Max Planck Institute for Breeding Biology, Cologne	•			•
Max Planck Institute for Immune Biology, Freiburg	•	•		•
Fraunhofer ICT, Pfinztal	•			•
Low-energy house with phase-change material, Rome	•			
Engelhardt & Bauer Druck GmbH, Karlsruhe	•	•	•	•
German Federal Ministry for Health and Social Security BMGS, Bonn	•			•
German Federal Ministry of Education and Research (Extensions A4-A6), Bonn	•			
Werner-von-Siemens Gymnasium, Regensburg	•			•
Prime Tower, Zurich				•
FrankfurtHochVier, Frankfurt/Main				•
Building for basic research in biochemistry, University of Ulm				•
Kreditanstalt für Wiederaufbau, Frankfurt/Main				•

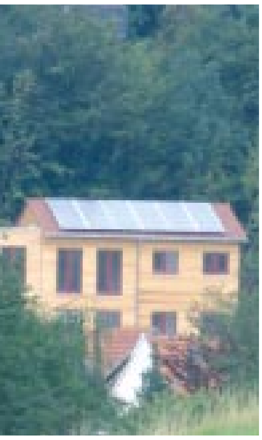


Fig: 1: Zero heating-energy house in Voggenthal.

Fig. 1: The "Voggenthal" zero heating-energy house by VARIOTEC GmbH is the first pre-constructed passive house with integrated vacuum insulation. Fraunhofer ISE supported the development of construction details and reduction of losses via thermal bridges. In summer, the building is pleasantly cool due to use of the cooling reservoir provided by the rainwater cistern. Architecture: Forstner. Photo: VARIOTEC.

Fig. 2: New BMGS premises in Bonn.

Fig. 2: New premises of the German Federal Ministry for Health and Social Security BMGS in Bonn. Cooling with thermally activated building components and the optimised building envelope concept ensure high thermal comfort in the naturally ventilated, high-rise building without the need for an air-conditioning system. Fraunhofer ISE provided simulation support in optimising the façade and developing the passive cooling concept. Commissioned by: Bundesamt für Bauwesen und Raumordnung BBR. Architecture and visualisation: Petzinka Pink Technologische Architektur. Technical building services: DS-Plan.

Fig. 3: "FrankfurtHochVier" building project.

Fig. 3: Again in 2005, Fraunhofer ISE was involved in the development of façades for several large buildings with advice and testing. The main emphasis of the work was on determining the solar-control effect of various façade variants. The "FrankfurtHochVier" building project is shown as an example in the illustration to the left. Architects: KSP Engel und Zimmermann, Frankfurt/Main Photo: KSP Engel und Zimmermann, Frankfurt/Main

Switching of Optical Properties by Colouring Liquids in Glazing Units

Technically and optically acceptable flow of a liquid through a sealed glazing unit offers the chance to integrate heating and cooling surfaces into an adaptable solar-control window. With this goal, we investigated different variants for the liquid flow circuit, the colouring and bleaching technology and suitable dyes, and developed a prototype. Its hydrostatic and dynamic performance were tested, with positive results.

Winfried Adelmann, Werner Hube*,
Werner Platzer

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Fig. 1: View of the institute roof area in winter through the coloured prototype of the liquid-filled double glazing unit. Tests of the hydrostatic and dynamic load performance with this prototype gave positive results. The goal is to achieve adaptable, colour-neutral solar-control glazing with integrated heating and cooling surfaces.

If the cavity between two flat glass panes is filled with a liquid, e.g. water, the glass bends significantly due to the hydrostatic pressure. In the hydraulic system that we developed for the liquid circuit, this is avoided by creating underpressure in the operating state, so that the panes only need to be kept apart by internal spacers. A 1 m^2 prototype of a liquid-filled glazing unit with connection openings and glass spheres as spacers withstood the pressure loads during operation and the filling process (testing by EPFL Lausanne).

We investigated different variants for the colouring and bleaching processes and for the flow circuit. Pigmentation was rejected due to the complex equipment and high energy consumption for the filtration system. A circuit with two immiscible fluids (water and oil) also had to be excluded due to the flammability of oils. The third variant is sequential filling with coloured and pure water, whereby the glazing unit is completely emptied between filling processes.

The technical properties of liquid-filled double glazing as the outer component of a thermally insulating glazing unit indicate an excellent switching range in the total solar energy transmittance g of better than 1:8 (coloured: g = 6%, empty: g = 50 %). The switching range can be adapted to specific requirements by changing the concentration. The dye stability is not yet adequate. Further development work is needed in this area.

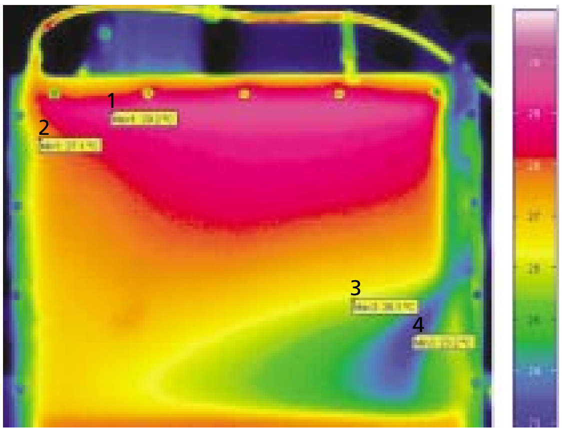
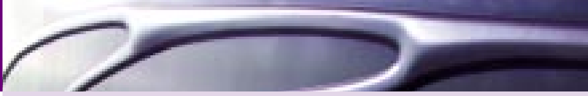


Fig. 2: Thermograph taken while the sealed glazing unit is filled with cold liquid (blue) and irradiated by a solar simulator. The coloured liquid is heated (yellow/red) and rises to the outlet, where it is removed by pumping.
(1: Min1: 27.1 °C; 2: Max1: 29.2 °C; 3: Max3: 26.1 °C; 4: Min3: 23.2 °C).



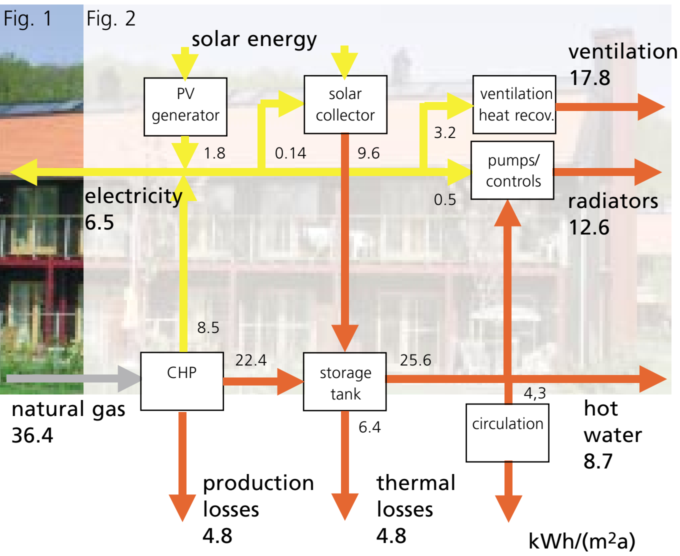
Factor 4 for Residential Buildings: Sustainable Solar Housing

Within the Task on "Sustainable Solar Housing" (Task 28/38) of the International Energy Agency IEA, Fraunhofer ISE led the subtask on "Monitoring and Evaluation" in investigating and analysing around 50 demonstration projects in ten countries with regard to their designs and energy consumption. The evaluated residential buildings include individual houses and medium-density housing with highly insulated building envelopes and heat-recovery ventilation systems.

Andreas Bühring, Sebastian Herkel,
Christel Russ

Fig. 1

Fig. 2



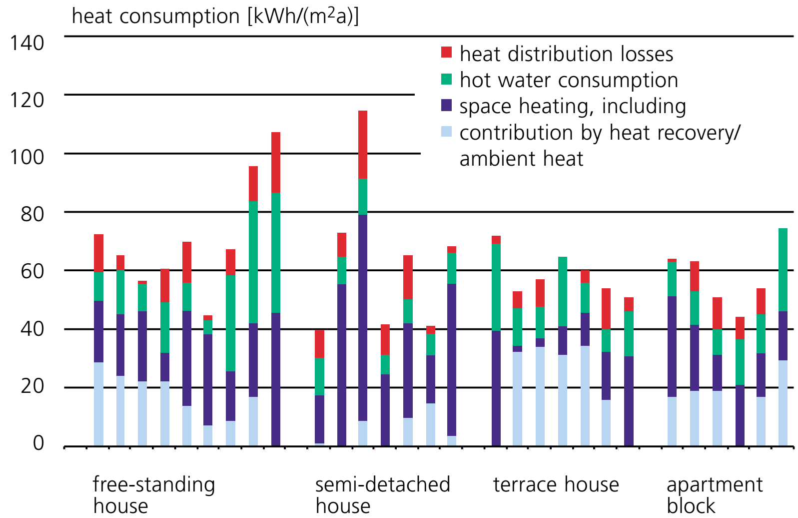


Fig. 3: The graph presents the heating consumption (space heating, hot water and heat from ventilation heat recovery), as well as heating distribution losses. Heat recovery from the return air and heat from earth-to-air heat exchangers contribute 19 kWh/(m²a) on average toward balancing the thermal losses. In passive residential buildings, this value is higher than the heating contribution based on external sources of energy.

Energy analysis of the projects evaluated in IEA Task 28/38 shows that highly efficient residential buildings with a low primary energy consumption for heating are feasible with an optimised building construction and the building materials and supply systems that are currently commercially available. Within IEA Task 28/38, we at Fraunhofer ISE developed a quantitative methodology for energy flow analysis, which allows a detailed and comparative analysis of the supply systems and their efficiency.

The final energy consumption for heating averaged over all the monitored buildings is around 25 kWh/(m²a) (referred to living area). For the passive buildings, the average is < 15 kWh/(m²a). The heating losses due to distribution, circulation, storage and transfer, amounting to 9 kWh/(m²a), are comparable to the consumption of heat for space heating or domestic hot water. There is potential for further optimisation in future here.

Fig. 1: Photo of a building in Göteborg, Sweden, which was investigated within the IEA Task 28/38 on "Sustainable Solar Housing". For the first time, a consistent analysis of the building construction features, the energy consumption values and their causes was prepared for 50 lowest-energy buildings in ten countries.

Fig. 2: Energy flow diagram analysing the heating supply for the "Wohnen und Arbeiten" housing complex in Freiburg. The figures indicate the specific final energy flows of gas, electricity and solar energy, and the losses and useful energy transferred to the building.

The essential criterion for assessing the efficiency of the supply systems in a building is the primary energy. The housing which was evaluated in this Task consumed an average of 48 kWh/(m²a) for heating, ventilation, domestic water and technical building services according to the German Energy-Saving Ordinance EnEV. The passive buildings needed less than 40 kWh/(m²a). The energy consumption of a third of the buildings is more than a factor 4 lower than the primary energy demand allowed by the EnEV.

The project was funded by the German Federal Ministry for Economics and Labour BMWA (and by the German Federal Ministry for Economics and Technology BMWi).

Thermally Activated Building Components Improve Thermal Comfort in Office Buildings

Future-oriented office buildings offer high-quality working conditions combined with low energy consumption. We evaluate the thermal comfort in low-energy office buildings and use the results as the basis for new concepts to improve thermal comfort and raise the air quality. Thermally activated building components present an economic type of technology to achieve thermal comfort. Measurements in buildings under typical operating conditions show that the thermal comfort in summer can be improved significantly with only a low consumption of primary energy.

Elke Gossauer, Sebastian Herkel, **Jens Pfafferott**, Jan Wienold

By analysing the measurement data from twelve low-energy office buildings with passive cooling, we have identified the factors which are responsible for thermal comfort. The results show that in addition to the building construction and solar-control measures in summer, activation of the available heat sinks determines the building temperature. For example, if the ground can be used via a borehole heat exchanger as a natural heat sink, building components activated with a liquid heat-transfer medium have the advantage, compared to night ventilation, that the heat extraction is almost independent of the outdoor temperature. Thus, the room temperature stays lower for longer (fig. 1).

As well as existing models to describe user comfort, we also apply new approaches which take the thermal adaptation of the user into account.

In the Fraunhofer Solar Building Innovation Center (Fraunhofer SOBIC), we compare passive cooling components for our clients: Night ventilation and a thermally activated building component in combination with a cooling tower. The thermally activated component is a special acoustic cooling ceiling (fig. 2) which is connected over large areas with the concrete ceiling. New planning tools and simulation models have benefited from operating experience with this project (fig. 3).

The work was financed by several medium-sized enterprises and the project funding body, VDI/VDE/IT. We are applying the results in current building projects.

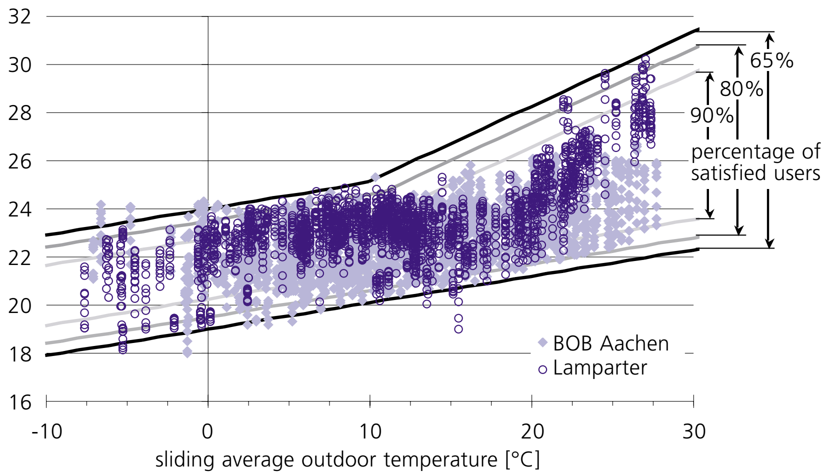


Fig. 1: The "Balanced Office Building Aachen" (thermally activated ceiling with a borehole heat exchanger) and the Lamparter office building (night ventilation and earth-to-air heat exchangers) were designed as passive buildings and achieve a primary energy consumption of around 82 and 53 kWh/(m²a) respectively for building operation. The building with a thermally activated ceiling (mauve diamonds = measured room temperature) is perceived to be thermally comfortable during hot summer periods by 90 % of the users, the building with ventilation-based cooling (purple circles) by 65 to 80 % of the users. Measurement: FH Köln and FHT Stuttgart.

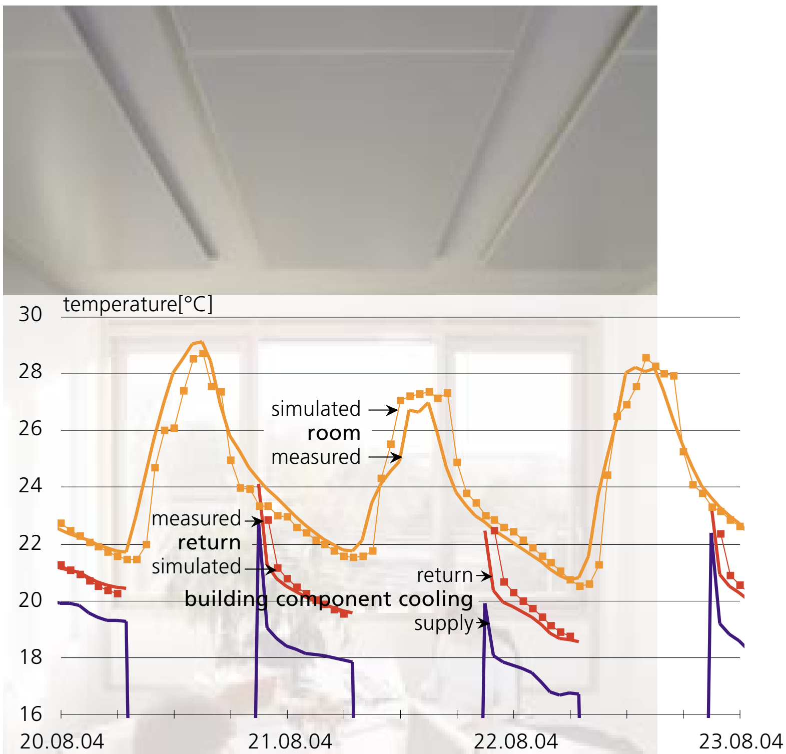
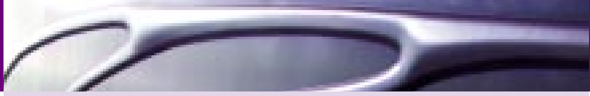


Fig. 2 (graph): Piping meanders in the cooling ceiling remove heat from the room at night. On a typical summer day, around 300 Wh/(m²d) of cooling energy is provided without use of a chiller. The measured room and return temperatures (solid orange and red lines) are described well by our simulation model (thin lines with squares). The boundary conditions (e.g. supply temperature, purple line) for the simulation were obtained from an experiment with high internal gains under real operating conditions.

Fig. 3 (background photo): At the Fraunhofer Solar Building Innovation Center SOBIC, a water-cooled acoustic ceiling is evaluated in a realistic situation. The only heat sink is a cooling tower which operates at night. This cooling ceiling can also be installed after the initial construction of a building, and thus offers an alternative to activated concrete core cooling in renovation projects.



Measurement of the Adsorption Kinetics of Water Vapour on Adsorbents

Sorption kinetics plays an important role in increasing the efficiency of adsorption chillers and heat pumps. Since 2004, we have been able to characterise different composite samples of adsorbents and heat transfer surfaces with respect to their adsorption rate. Analysis of the achievable water vapour loading and the adsorption kinetics indicates the potential for optimising the material properties and the material's contact to the heat transfer surface. At the same, it provides important information for controlling adsorption heat pumps.

Hans-Martin Henning, Lena Schnabel

Both canonical (constant particle number) and isobaric measurements are possible with the kinetics measurement stand. The dry sample is placed on a thermostatted plate and then is exposed to a defined quantity of water vapour. In a canonical measurement, the adsorbed amount of water is determined from the fall in pressure; in an isobaric measurement, the heat flow signal is analysed. Figures 1 and 2 show results from a measurement of the same material with different particle sizes. It is evident that reduction of the particle size and an increase in the contact area between particles leads to significantly shorter adsorption times.

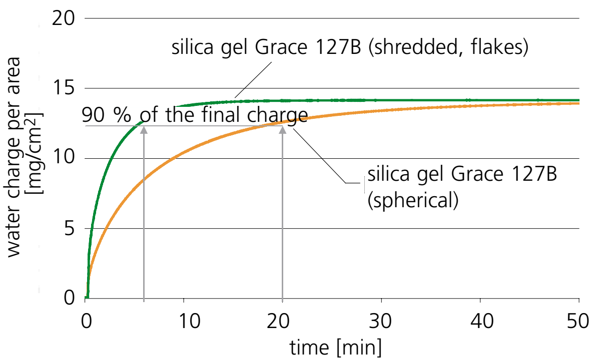


Fig. 1 shows two charging profiles for the same material (silica gel 127 B from the Grace company) with different particle sizes in a canonical measurement. The spherical particles have a diameter of 2.5 - 4 mm, the shredded particles measure 1 - 1.5 mm. The comparison shows that the smaller, flake-like particles have already reached 90% of their final charge after 6 minutes, whereas the large particles need 20 minutes.

"Solarthermie 2000plus": Research Support for Solar Air-Conditioning

In the "Solarthermie 2000plus" funding programme of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU, we at Fraunhofer ISE are providing the research support for solar air-conditioning. Optimisation of the funded systems with regard to their design and performance will pave the way to market introduction.

Hans-Martin Henning, Edo Wiemken

The essential elements of the research support are:

- Preparation of concepts for unified system evaluation with respect to energy and economics, and for monitoring
- Support to the programme administration in Jülich on the selection of projects to be funded; this also includes simulations to evaluate the submitted concepts
- Comparative analysis of the measurement results from the systems constructed
- Dissemination of experience in the form of documentation, planning guidelines and public information workshops
- Participation in new activities on solar cooling on an international basis (e.g. within a new IEA Task in the Solar Heating and Cooling Programme).

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

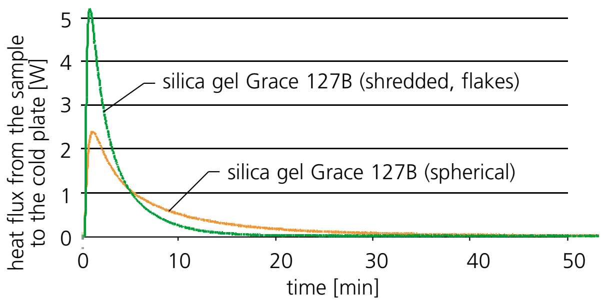


Fig. 2 shows the heat flux signal which is measured between the sample and the thermostatted plate. The same total amount of heat is transferred for the two samples. However, it is clear that the smaller particles reach a much higher peak value, which is attributed to better access for the water vapour and better heat transport.

Phase Change Materials in Heat Transfer Fluids and Building Components

As part of an international research project, we developed and investigated phase change slurries (PCS). These heat transfer fluids contain micro-encapsulated phase change materials (PCM) and are thus characterised by a very high specific heat capacity within the melting range. This allows more heat to be transported for less pumping energy, and low-volume heat storage with little change in temperature.

In a second research project, we are developing systems which allow controlled cooling of rooms and are based on the PCM building materials that have been commercially available since 2004.

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

The rheological behaviour of new heat transfer fluids is very important for their use in practice. Thus, in 2005 we set up a new laboratory to characterise flow behaviour with Fraunhofer investment funding. The central measurement instrument is a rotation rheometer to determine the viscosity of heat transfer slurries. As the rheological properties depend, among other factors, on the size of the suspended microcapsules, we have extended the facility with a device to measure particle size from nanometres to millimetres.

This new measurement equipment allows us to determine the applicability of new PCS (phase change slurries, e.g. emulsions) quickly and accurately during their development. This shortens the development time for new PCS. The viscosity value determined can then be used, e.g. as an additional parameter in simulations, to gain information on the pumping power required to circulate the PCS. In this way, we can identify the most appropriate applications even before the actual system planning has started.

Whereas the micro-encapsulated PCM is added to a liquid in the PCS mentioned above, we are also investigating building materials with an integrated heat-transfer circuit and PCM in another research project. These PCM building materials have been commercially available since 2004. In test constructions, we pump cooling fluid through piping within the PCM building materials, so that the room cooling can be controlled actively. Any type of heat sink can be accessed by connection to water piping systems, so that a narrow temperature range can be guaranteed. The high thermal capacity of the PCM allows the cooling processes to be shifted into the night and high peak loads to be avoided during the day.

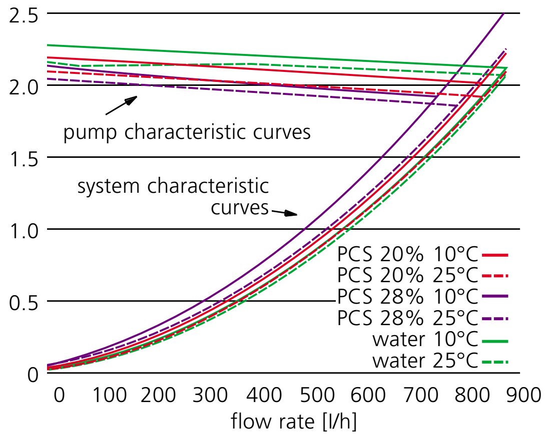


Fig. 1: The viscosity of the PCS directly affects the pumping behaviour of the heat transfer fluid. The curves show the pressure loss of pure water (green) and PCS (black - with a 20 % capsule content; purple - with a 28 % capsule content) in a test system. As can been seen, the temperature has a much stronger effect on the system pressure drop for the PCS than for pure water. While the pressure loss for 28 % PCS increases by about 20 % in comparison to water, the amount of heat transported increases by 400 %. The maximum pumping height which a pump can achieve (1 bar corresponds to 10 m) decreases with increasing viscosity. The pump characteristic curve shows a reduction by about 20 % for a PCS with a microcapsule content of 28 %.

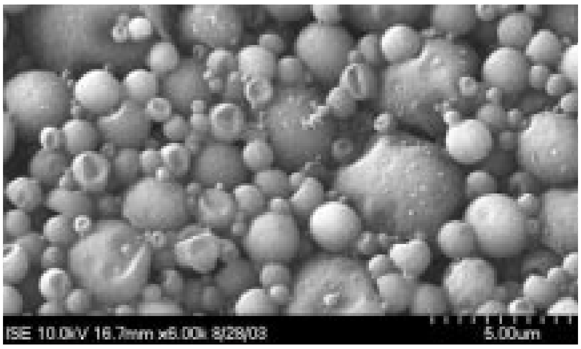
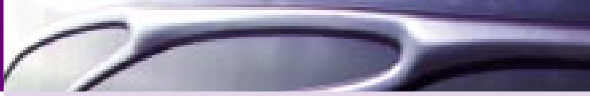


Fig. 2: The scanning electron micrograph gives a qualitative impression of the size distribution of the paraffin microcapsules. Large capsules (app. 5 µm) and many small capsules can be seen. Whereas the number of small capsules is much greater than that of large ones, their volume percentage is small.

This work is funded by the German Federal Ministry for Economics and Labour BMWA and is carried out in co-operation with Fraunhofer UMSICHT and industrial partners.



Heat Pumps for Energy-Efficient Housing

Over the past few years, we have been able to assist several industrial partners in successfully developing their heat pump systems further for applications in passive houses. The focus was on compact heating and ventilation units with exhaust-air heat pumps. On the basis of this experience, we are currently developing further systems, which are also suitable for supplying heat to good low-energy houses. One main aspect is gaining access to additional and cost-effective heat sources.

Andreas Bühring, Christian Bichler, Christel Russ, Jeannette Wapler*, Martina Jäschke**, Marek Miara*, Matthias Schubert, Daniel Kühn, Michael Schossow, Jan van Wersch

* PSE GmbH Forschung Entwicklung Marketing, Freiburg
** PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Fig. 1: In our test facility, we measure the energy efficiency of the complete units and their components. On the one hand, we can select from a wide range of stationary testing conditions. On the other hand, the automated controls allow us to apply dynamically changing conditions, e.g. according to the EN 255-3 standard. We derive recommendations for optimising the components and their interaction from the measurements.

In a compact heating and ventilation unit with an integrated exhaust-air heat pump, enough energy is extracted from the exhaust air with an air-to-air heat exchanger and a subsequent heat pump that the heating demand of a residential building can be met. These units are used for ventilation, space heating and domestic hot water heating in highly efficient residential buildings such as passive houses. Further technological development of the compact heating and ventilation units is central to our current work.

Together with our industrial partners, we are developing highly efficient heat pumps for very well insulated housing. We offer numerous R&D services for developing optimised equipment. These include thermal simulation studies and computational fluid dynamic simulations (e.g. with "Fluent"), as well as advice on the selection of components, the configuration of component groups and the design of prototypes. Beyond this, we provide support in developing controls. We measure prototypes in our test facility and in field tests. We pay particular attention to high energy efficiency, low production costs and the possibility to integrate solar technology.

The primary requirement for heat pump systems to be used in other building types, e.g. KfW 60 houses or 3-litre houses, is access to an additional, cost-effective heat source. For this purpose, we are developing new components such as a combination evaporator for simultaneous use of the exhaust-air heat and the heat in a flowing liquid. A glycol-water mixture, which has been heated in a solar system or an earth-to-liquid heat exchanger, is used as the fluid here. The Institute has applied for patents on the work presented here.

Fig. 2: Computational fluid dynamic simulations, e.g. with the "Fluent" program, are an important tool to improve ventilation equipment with integrated heat pumps. The simulation results are validated with spatially distributed temperature and velocity measurements, and also with the visualisation of air currents using smoke, as shown in the photo.

Pellet-Fuelled Stirling Engine to Supply Heat and Electricity

This year, Fraunhofer ISE has begun the development of very small combined heat and power units (micro-CHP) fuelled by wood as a regenerative resource. Combustion of wood pellets drives a small Stirling engine, which is coupled to a generator to generate electricity. At the same time, the exhaust heat is used for space heating and domestic hot water in a residential building. We are developing these miniature CHP units in a joint project with seven industrial companies and other research partners.

Andreas Bühring, Benoit Sicre, Jörg Dengler, Marek Miara**, Jeannette Wapler**, Martina Jäschke*

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** PSE GmbH Forschung Entwicklung Marketing, Freiburg

Wood is gaining in importance as a source of energy. We have thus begun a joint research project with several industrial partners, Fraunhofer ISC and FH Wolfenbüttel, in which a novel energy system is being developed on the basis of wood as a regenerative fuel. This was preceded by two studies for the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU, and the Badenova utility. These investigations led to the concept of a very small combined heat and power unit (micro CHP), which is fuelled with easily handled wood pellets (fig. 1). At the same time, we were able to analyse the operating principle of the unit with simulation studies.

According to these, the Stirling engine generates enough electricity to meet the annual demand of an average German household, balanced over the whole year. Development goals for the future include a high electricity yield and a high total efficiency, good heat transfer to a buffer storage tank, compactness and simple operation. Furthermore, an optimised combustion process and subsequent exhaust gas purification is intended to lead to very low emissions.

Apart from the development of individual components, the main aim of the project is to optimise the complete system and to produce prototypes for demonstration purposes.

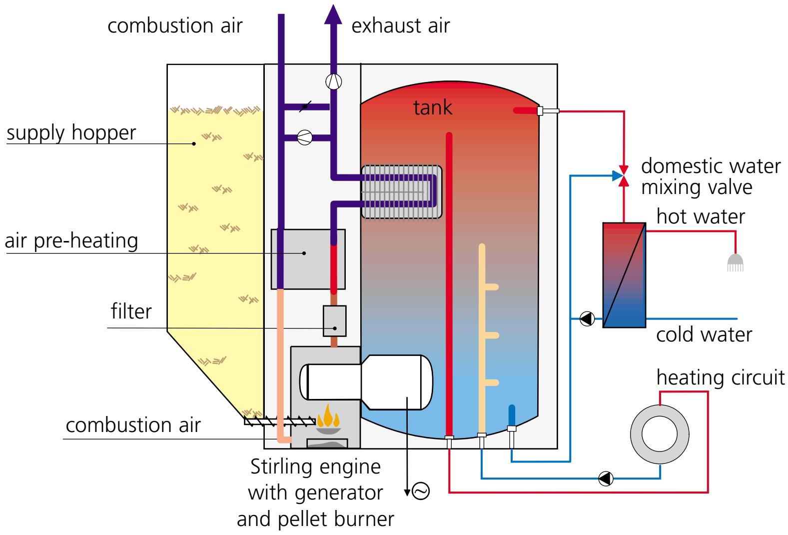
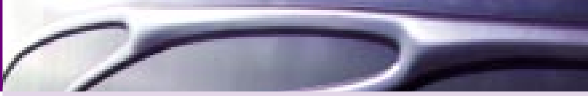


Fig. 1: The specific possibilities of a Stirling engine for generating electricity are provided by the external combustion. Biomass, in this case wood pellets, can be used to drive the engine. The fact that all components are largely integrated leads to a high utilisation factor for the released heat. The largest possible amount of combustion heat is extracted from the exhaust gas and stored in the buffer tank. Initial simulation results show that the annual electricity demand of an average German household can be met by a Stirling engine with an electric power rating of 1.5 kW and a high electricity-to-heat ratio in the partial load range.

Fig. 2: Wood pellets are small cylindrical rods with a diameter of 6 to 8 mm and a length of 20 to 40 mm. They are made by pressing sawdust and other wood remnants. In contrast to fossil fuels, wood pellets are CO_2 neutral, because combustion only releases the amount of carbon dioxide which had previously been absorbed by the tree during its growth.

The work is funded as an InnoNet project by the German Federal Ministry for Economics and Technology BMWi and is co-financed by the seven industrial partners.



FracTherm – Bionic Approach to Development of a Solar Absorber

Conventional solar absorbers usually have a series or parallel configuration of the piping (meander or harp absorbers). However, these configurations can lead to large pressure drops or inhomogeneous flow over the absorber, which can affect the efficiency negatively. By contrast, natural vein structures, for example in leaves or blood vessels, often consist of multiply branching networks. Following a bionic approach, we have transferred this principle to technology, with the aim of developing energy-efficient absorbers.

Markus Arntzen, Wolfgang Graf, **Michael Hermann**, Matthias Rommel, Arim Schäfer, Kurt Schüle, Thorsten Siems*, Christoph Thoma

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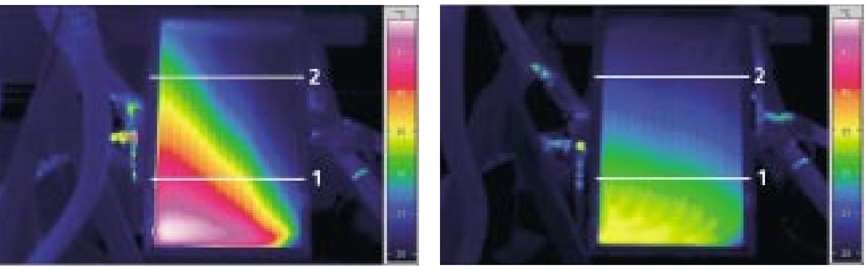

Fig. 1: Thermographic images of absorbers with piping in the harp configuration (left) and a *FracTherm* absorber (right) while hot water enters the initially cold absorber. Analysis of the thermographic sequences demonstrated that flow through the *FracTherm* absorber is much more homogeneous (temperature scale: 19 - 49 °C).

As part of the work for a doctoral thesis, we have developed and filed a patent application for an algorithm, with which a given area can be covered with a suitable, quasi-fractal hydraulic structure once the positions of the inlet and outlet points have been specified.

This so-called *FracTherm* algorithm is extremely flexible with regard to the perimeter contour of the area to be covered. The hydraulic structure adapts very well to the specified geometry; for example, narrow sections within the area are taken into account when the branching points are allocated.

With the aid of the *FracTherm* computer program, which is based on the algorithm of the same name, both hydraulic and thermal simulations can be carried out to evaluate the individual variants. The generated structures can be exported easily as DXF files, and are thus available for further use by the common CAD and CAM programs. In this way, prototypes and mass products can be manufactured by milling, casting, embossing, roll-bonding or similar processes.

Experiments with a solar absorber which had been produced by roll-bonding showed high thermal efficiency, homogeneous flow and for high flow rates, significantly reduced pressure losses compared to piping configurations conforming to the state of the art.

Individual design solutions for heat exchanger structures can be tailored to clients' wishes with *FracTherm*.

Work for the doctoral thesis was funded by the scholarship programme of the German Federal Environmental Foundation (DBU).

Fig. 2: Section of a solar absorber, with flow channels designed according to bionic principles with the *FracTherm* algorithm we have developed. The absorber is of aluminium and was made by the Alcan Rollbond company using the roll-bonding process.

Investigations of Stagnation Behaviour in Thermal Solar Systems

Management of the stagnation situation is an important pre-condition to ensure operational safety and reliability of thermal solar systems. When stagnation occurs, there is a danger that fluid evaporates in the collector field and that steam penetrates into the piping of the solar loop. How far it penetrates depends on the one hand on the steam production power of the collector field, and on the other hand on the dissipative power of the solar loop components. We have developed a standardised procedure to determine the steam production power of collectors.

Matthias Rommel, Thorsten Siems*, Kurt Schüle, Jan Steinmetz, Korbinian Kramer, Christof Thoma, Stefan Mehnert

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The steam production power of collectors is the power which is transferred under stagnation conditions in the form of steam to the solar loop piping, i.e. the external piping of the collector field. Stagnation occurs when the heat generated in the collector field cannot be removed because the storage tank is fully charged and neither a load nor a heat sink is connected. We carry out measurements to determine the steam production power of collectors using our solar simulator, with a closed solar loop and the water-glycol mixture used in practice as the fluid. The measurement procedure is illustrated in fig. 1. Figure 2 shows an example of the measured steam production power as a function of the system pressure. Collector manufacturers and system providers can use the results to determine how far the steam penetrates, whether temperature-sensitive components could be damaged and how the expansion vessel should be dimensioned.

If there is a risk of damage, measures must be taken to deliberately condense the steam in already existing or additionally introduced solar loop components and dissipate the energy. Such components could be vessels which are sometimes additionally installed before the expansion vessel to protect it against high temperatures. New components, similar to heat exchangers, are also conceivable, which are specially developed to dissipate steam. To investigate this issue, we have constructed a special test stand to measure the steam dissipation power of solar loop components, and will offer these investigations as a service in future.

Fig. 1: Solar collector under the solar simulator of our indoor test stand during the stagnation measurement according to the procedure we have developed. To the left and right are the test pipes of the solar loop, with which the steam penetration distance can be measured. Temperature sensors, which are mounted along the test pipes at intervals of one metre, are used to measure whether the steam has reached a given position. From the known heat loss of the test pipes, it is possible to determine the thermal power which enters the solar loop piping in the form of steam and which must be dissipated by the piping to the surroundings.

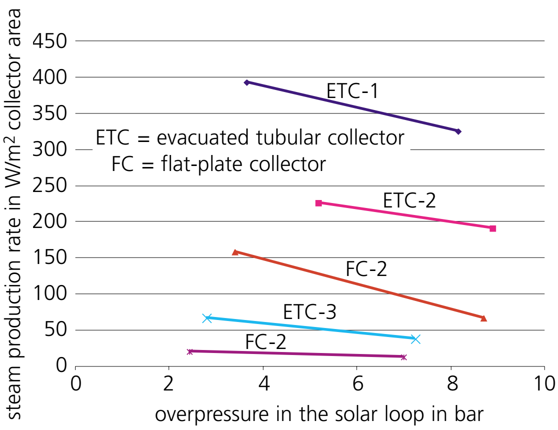
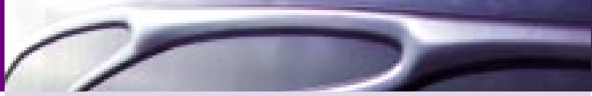


Fig. 2: The steam production power of collectors can be quantified with the standardised measurement procedure that we have developed. The graph shows the results for five different collectors. The radiation intensity during each experiment was 1000 Wm^{-2}. The results show a large bandwidth in the steam production power. This depends essentially on the internal configuration of the absorber piping. It is not significant whether it is a flat-plate or an evacuated tubular collector. Collector fields with higher steam production power displace more fluid and thus require larger expansion vessels.

This work was funded as part of a joint project within the "Solarthermie 2000plus" programme by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU. In the project, we co-operate with other research institutes and several industrial partners.

Further information:
www.solarkombianlagen-xl.info



Durability Analysis of PV Modules and Façade Components

Durability analysis is a key competence for the development of new products and the improvement of existing ones, not only in the rapidly expanding solar market but also in the building sector. The innovation rate today is high for photovoltaic systems, thermal solar systems and solar building. We apply durability analysis to test the quality - or the reliability - of new components and products.

Tilmann Kuhn, Michael Köhl, Odon Angeles, Markus Heck, Stefan Brachmann

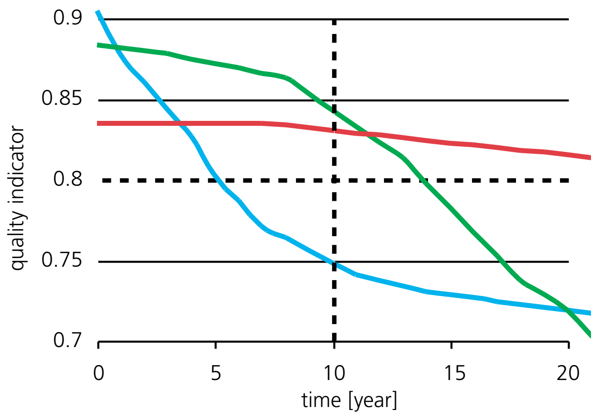


Fig. 1: Hypothetical degradation profiles of three products (red, green, blue). The quality indicator can be the absorptance of a façade collector, for example. The lower limit for the quality indicator is 0.81. The resulting lifetimes for red/green/blue are >20/14/5 years. Only the "blue" product does not achieve the specified service lifetime of 10 years.

In addition to the cost-performance ratio, durability is a central criterion for the quality of new products. From the manufacturer's perspective, it is an important basis for providing guarantees and for identifying weaknesses. A complete economic analysis can only be made once the service lifetime is known. Due to the significance of the topic, we have begun to expand our activities strongly in this field.

Durability is the ability of a product or a system to maintain its performance over a certain period of time. In order to give information on durability, initially a quality indicator must be defined (e.g. the absorptance of a façade collector. The demands on the durability are defined by specifying a lower limit for the quality indicator and the required lifetime. Figure 1 illustrates that in assessing the quality of a product, not only the performance of the new product but also its service lifetime and the total yield over the product lifetime are important.

The graph also helps to explain the dilemma which confronts many investors when they have to choose an investment object: The lifetime of high-quality products significantly exceeds the guarantee period. This is often not the case for cheap products. However, a longer lifetime can only affect the decision-making process if it can

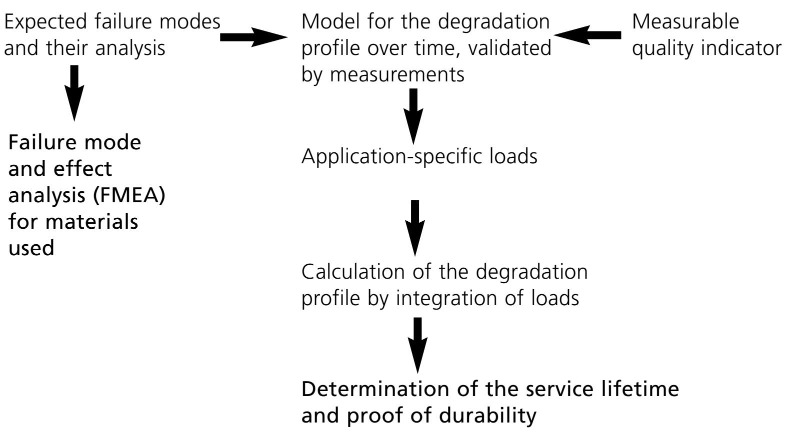


Fig. 2: Basic principles of durability analysis. The goal is to determine the service lifetime for each application case. The failure mode and risk analysis already indicates potential for optimisation.

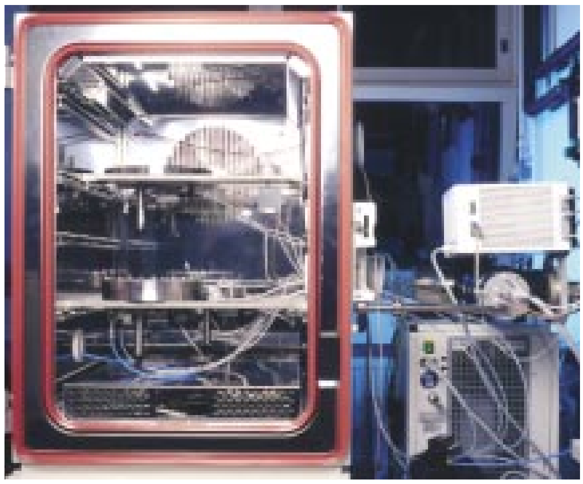


Fig. 3: Permeation measurement of high-barrier films using mass spectrometry. These films are used, for example, as the backing films for photovoltaic modules or for the envelope of vacuum insulation panels.

be quantified. Our goal is to be able to predict the service lifetime of certain products individually according to the intended application environment (desert, maritime climate, mountains).

Figure 2 illustrates the basic approach to durability analysis. The starting point is an analysis of the expected failure/degradation mechanisms. Laboratory measurements, in which stress factors can be varied in a controlled fashion, allow the kinetics of the degradation processes to be determined. By applying a model for the performance degradation profile with time, the service lifetime for each particular application case is obtained from knowledge of the loads specific to that application and environment.

Parallel to developing test methods, we expose identical samples to weathering for at least a year under conditions similar to real applications. Time-resolved measurements are made of the sample properties, the meteorological data and further stress factors such as the sample temperatures. Comparison of the degradation observed during outdoor exposure with the laboratory results allows the lifetime estimation models to be validated.

At present, our work is concentrating on lifetime prediction for PV modules (see p. 57), coloured coatings for facade collectors and vacuum insulation panels (VIP). Within a VIP development project, we have set up a rapid but highly sensitive measurement facility for temperature-dependent permeation of gases through high-barrier films (fig. 3) and have measured the temperature-dependent permeation of water vapour through a laminate that was developed by one of our project partners (fig. 4). The effectivity of the barrier film over the required lifetime can then be derived for given environmental conditions. The pressure sensor developed within the project by the Fraunhofer Institute for Microelectronic Circuits and Systems IMS allows us to monitor changes in the internal pressure in the VIP's (fig. 5).

The work is funded by the German Federal Ministry for Economics and Labour BMWA.

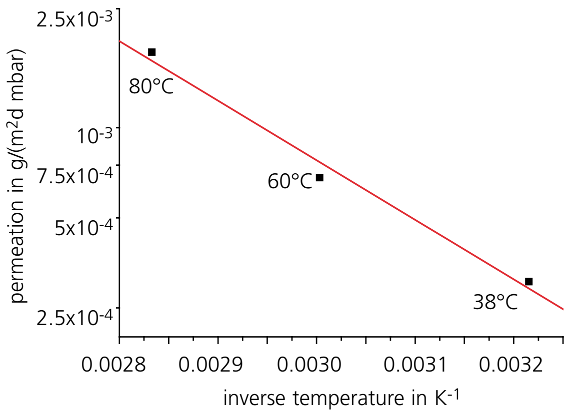
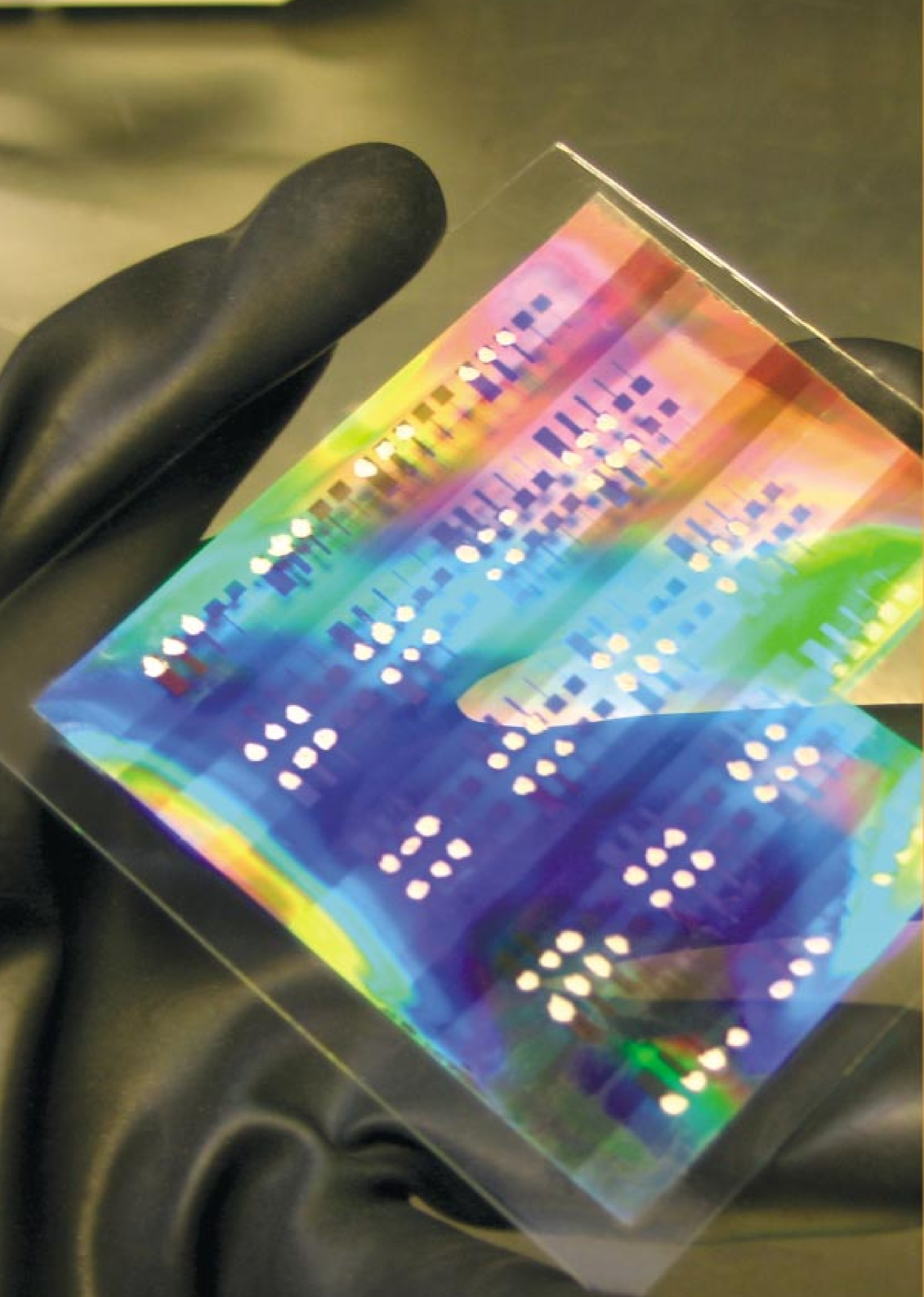


Fig. 4: Temperature-dependent water vapour permeation through a high-barrier laminate for vacuum insulation panels. The laminate consists of PE / PET / Al / ormocer / Al / PE and was produced by the project partners, Fraunhofer FEP, ISC and IVV. The measured values for the permeation, indicated by the black squares, show the linear dependence of the logarithm of the permeation on the inverse temperature which is typical for an Arrhenius function.

Fig. 5: Measurement of the pressure inside vacuum insulation panels with microelectronic pressure sensors. A sensor consists of a chip, an antenna coil and several passive electronic components. A sensor-transponder ASIC (ASIC = application-specific integrated circuit) produced by the Fraunhofer Institute for Microelectronic Circuits and Systems IMS is used as the chip. It has lateral dimensions of 17 x 17 mm^2.



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, comprising 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 often 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 plants. 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 very 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 re-direction 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.

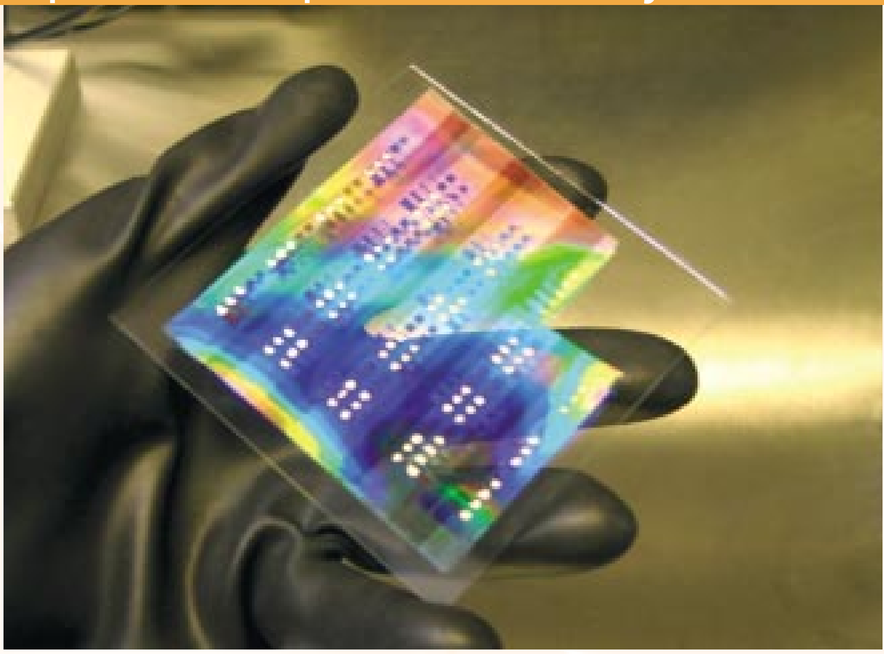
We have developed selective absorber coatings for solar thermal collectors (temperatures of up to 230 °C) and transferred them to industrial production for many years now. However, coatings for absorber pipes in solar-thermal power plants must permanently withstand much higher temperatures of more than 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 large-area (140 cm x 180 cm), complex coating systems
- 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



Novel opto-electronic components such as organic light-emitting diodes (OLED) or organic photodiodes (OPD) have become feasible due to the use of semiconducting organic materials. In order to optimise the configuration of these components, we are developing vertically orientated, interdigitated nano-electrodes. The photo shows a nano-structured test substrate for organic photodetectors with interdigitated titanium and gold electrodes. The separation between the electrodes is 400 nm. The organic semiconductor is deposited in a subsequent processing step (see article on p. 38).

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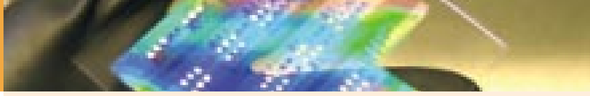

Production of Refractive-Diffractive Microstructures

By structuring surfaces, we are able to influence their optical properties in specific ways. The production process used, based on interference lithography, can be applied to areas of more than a square metre, but was limited in the past to structure dimensions in the range from 0.2 to 10 micrometres. We investigated new photosensitive materials which now allow us to produce three-dimensional microstructures with dimensions of up to 100 micrometres.

Benedikt Bläsi, Andreas Gombert, Jörg Mick*

* Institute for Microsystems Technology IMTEK, University of Freiburg

Interference lithography is a method to produce microstructured surfaces. Two main features distinguish interference lithography from other structuring procedures: On the one hand, areas of up to 1.2 x 1.2 m^2 can be structured in a single exposure of a photosensitive material (photoresist). On the other hand, these periodic grating structures can be prepared with dimensions which are significantly smaller than a micrometre.

When such large areas are processed, the available exposure intensity is very low. Thus, the structure depths which can be achieved with conventional photoresist materials are limited to a few micrometres. As a result, typical applications of these grating structures are based on diffractive optical effects.

Usage of novel photoresist materials gave us the opportunity to produce significantly deeper microstructures. These photoresists are characterised by extremely low absorption in the material itself and great sensitivity to light with the wavelength selected for exposure. Optimal use is thus made of the limited amount of energy available for exposure. With the new

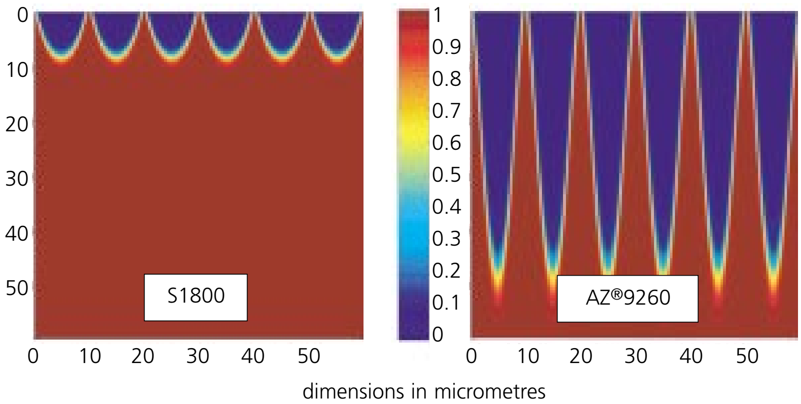

Fig. 1: Photoresist simulation to compare conventional with novel materials. The model demonstrates that in conventional materials, structure depths of 10 µm cannot be exceeded, even with the very high exposure intensity of 1 000 mJ/cm^2. By contrast, new materials such as AZ®9260 allow large structures to be produced with dimensions between 10 and 100 µm.

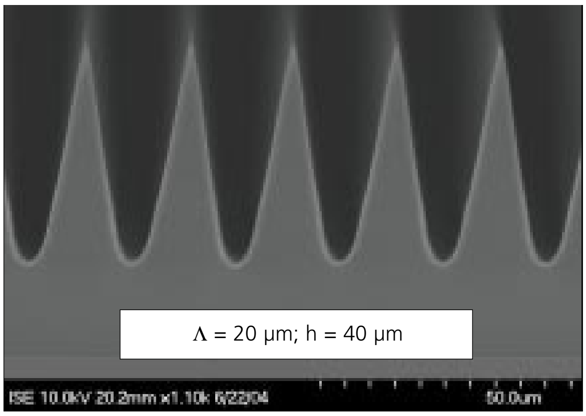

Fig. 2: Symmetric microstructure produced by interference lithography in the positive photoresist, AZ®9260. The grating period is 20 µm for a structure depth of 40 µm.

types of resist, we have succeeded in producing three-dimensional microstructures with dimensions between 10 and 100 µm for the first time by interference lithography.

We investigated a diazonaphtochinone positive resist and a chemically amplified negative resist, which differ both in the chemistry employed and in their response functions to the incident radiation by light. This opens up a wide spectrum of structure profiles which can be produced. In addition to the rounded microstructures which are known from interference lithography, binary structural forms with large aspect ratios (ratio of structure depth to structure period) are possible using the negative resist NANO™SU-8.

The extension of classical interference lithography into new structure dimensions and forms opens up additional application areas. In addition to diffractive effects, now refractive optical properties can also be applied to tailor the function of a surface. Light-redirecting structures play a central role here. The microstructures shown in fig. 3, which we developed within the MIKROFUN II project that is funded by the German Federal Ministry for Economics and Labour BMWA (and the German Federal Ministry for Economics and Technology BMWi), can be used for solar control and energy-efficient use of daylight in buildings. When the photoresist structures are replicated as metallic tools, which then serve as embossing dies, they provide a cost-effective means for mass production of microstructures in film materials or polymer sheets.

In addition to solar applications, light-redirecting structures can also be used to optimise lighting systems. Particularly in the display industry, such structures play a major role both for efficient light-guiding within the display unit and also for coupling the light out of the system. With the new structure forms that are now possible, interference lithography presents a suitable production procedure, especially considering that seamless, large-area but low-weight components are required.

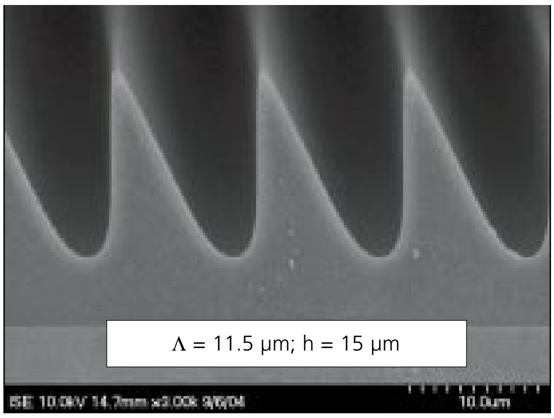

Fig. 3: Tilted parabolic microstructure produced by interference lithography in AZ®9260. Such structures can be used e.g. as angle-selective reflectors consisting of compound parabolic concentrators with selective reflection. A further application is the collection and redirection of light which is incident at large angles on projection screens.

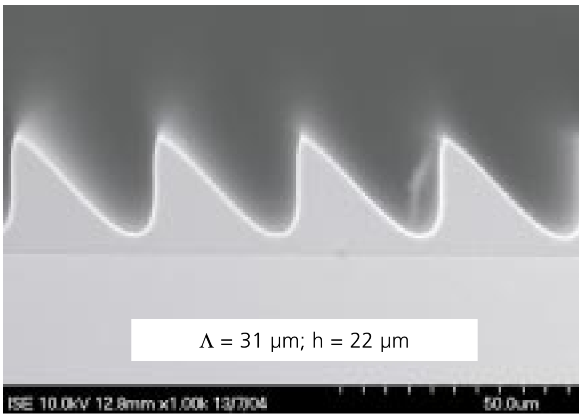

Fig. 4: Prismatic microstructure produced by interference lithography in AZ®9260. The use of daylight can be optimised by integrating structures with such profiles into glazing units. Further applications can be found in lighting systems or displays.

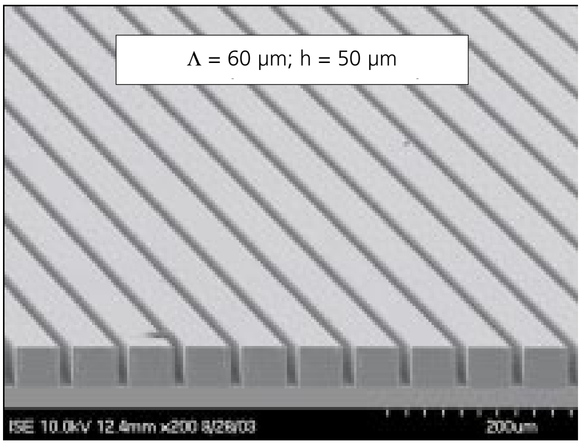

Fig. 5: Microstructures in the chemically amplified photoresist, NANO™SU–8. The chemical reactions within this resist require much less exposure energy to create the structures, allowing structure depths exceeding 100 µm to be achieved. In addition, it is a photomaterial with very high contrast, so that binary structures can be produced.

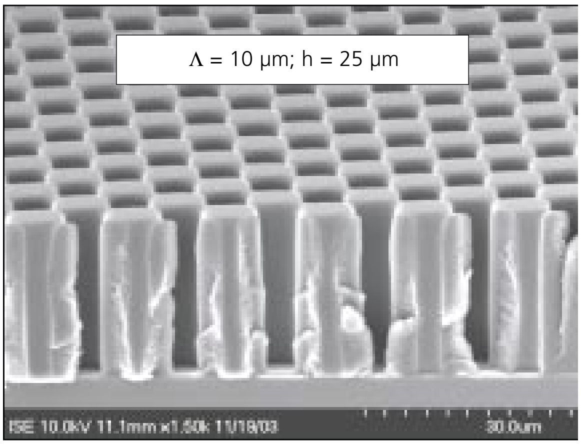

Fig. 6: By combining two exposures with linear interference patterns, three-dimensional microstructures with large aspect ratios can be produced in NANO™SU–8. As in the linear case, the high contrast of the photoresist allows the structure flanks to be almost perpendicular.

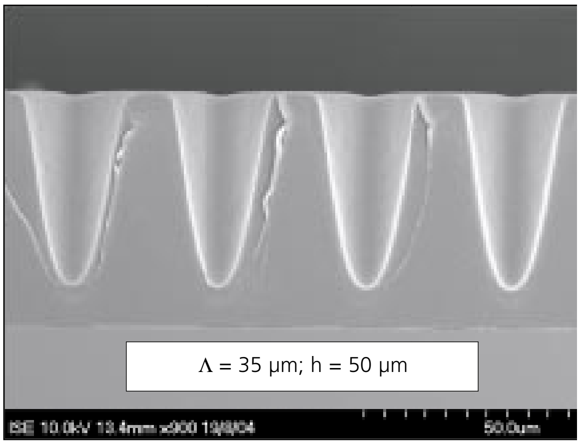

Fig. 7: Extension of the process technology and a modification of the photoresist, NANO™SU–8, allow us to produce rounded structure features as an option. A cross-section through a two-dimensional series of micro-cavities is shown as an example. It was produced, as for fig. 6, by double-exposure interference lithography.

Evaluation and Quality Control for the Optics of Photovoltaic Concentrator Systems

The reproduction quality achieved during embossing of Fresnel lenses and the optical losses caused by the lens system have a decisive influence on the efficiency of concentrator photovoltaic modules. We have designed and constructed an optical measurement stand to provide quality control for the production of Fresnel lenses and evaluate future alternatives for producing Fresnel lenses.

Johannes Herzog*, Hansjörg Lerchenmüller, **Werner Platzer**, Günter Walze, Stefan Wendlandt

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In the FLATCON® concentrator photovoltaic modules developed at Fraunhofer ISE, Fresnel lenses concentrate direct sunlight onto a focus with a diameter of 2 mm. The concentration factor of 500 allows the active solar cell area in concentrator modules to be reduced to a fraction of that in conventional photovoltaic modules.

At present, we are producing the Fresnel lenses in co-operation with the most recent spin-off company from Fraunhofer ISE, Concentrix Solar GmbH, in a manual embossing process. In the process of transferring the FLATCON® technology to series production, we are setting up an industrial production procedure to manufacture the lenses.

A lens plate as used in a FLATCON® module consists of 48 Fresnel lenses, each measuring 40 x 40 mm^2. In our laboratory measurement stand, we position the Fresnel lens to be measured with a drive unit under a source of parallel light. A CMOS sensor is used to digitalise the radiation distribution of the Fresnel lens and is evaluated with analysis software.

With the help of this laboratory measurement equipment, we can evaluate different, optional manufacturing procedures. In the production process, the measurement system will be used for quality control to detect changes in processing parameters. This quality control procedure allows us both to develop a technologically and economically optimised manufacturing process and to ensure high-quality production of the Fresnel lenses.

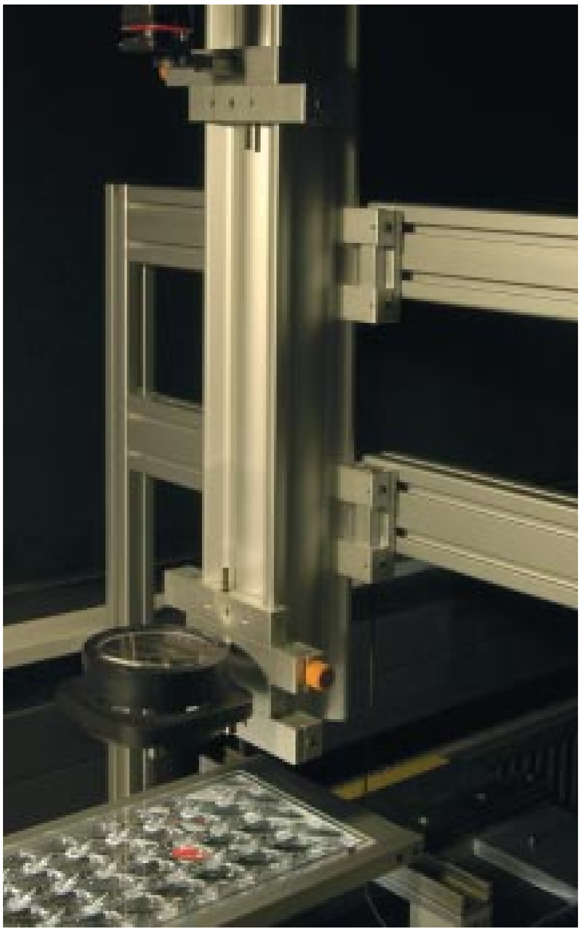


Fig. 1: Laboratory measurement stand to determine the radiation distribution in the focus of a Fresnel lens. The Fresnel lenses are moved with a drive unit and exposed sequentially to a parallel beam of light. The CMOS camera located under the lens plate digitalises the resulting focus spot from the lens and allows the intensity distribution to be analysed.

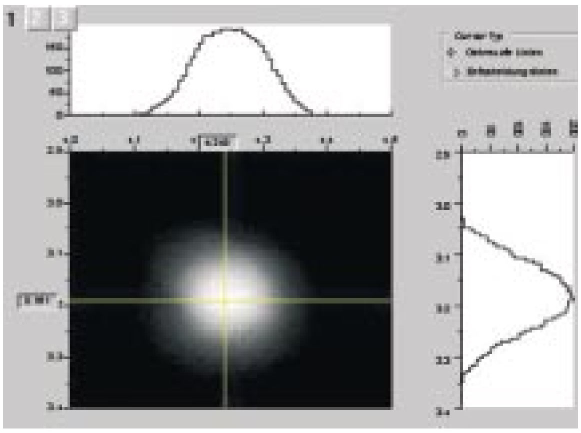
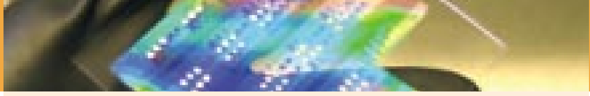


Fig. 2: Representation of the radiation distribution in the focus of a measured Fresnel lens. The quality of a lens is determined by the so-called intercept factor. This indicates which cumulative fraction of the incident radiation is concentrated by the Fresnel lens within a specified radius.



Organic, Opto-Electronic Component with Interdigitated Nano-Electrodes

The use of semiconductor organic materials enables the development of novel opto-electronic components such as organic light-emitting diodes (OLED) or organic photodiodes (OPD). We are developing vertically orientated, interdigitated nano-electrodes, which open up diverse possibilities for novel configurations of these components. For example, partly transparent components with metallic electrodes can be produced, as can combined organic-electronic components. The combination of OLED and OPD allows highly integrated components to be implemented, e.g. for sensor applications.

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* Institute for Microsystems Technology IMTEK, University of Freiburg

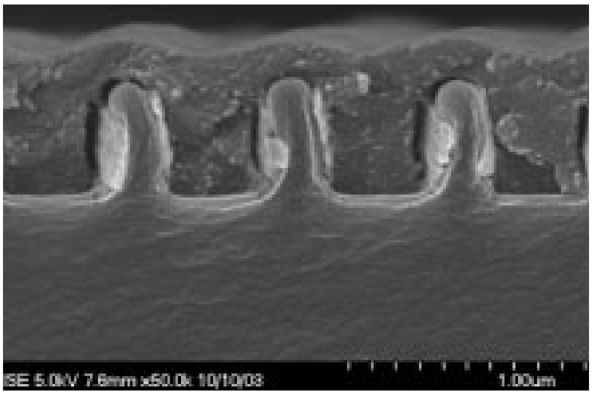

Fig. 1: Cross-section through an organic photodiode with interdigitated nano-electrodes of titanium and gold. The structured substrate consists of a polymer which is transparent to light, the absorber is a mixture of organic semiconductors. The distance between electrodes is about 400 nm (scanning electron micrograph).

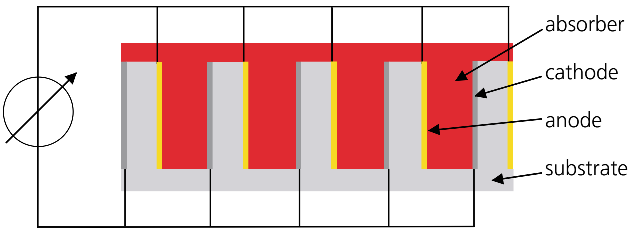

Fig. 2: Cross-sectional drawing of an organic, opto-electronic component (photodiode) with interdigitated nano-electrodes. The electrodes are deposited on the flanks of the nano-structured polymer substrate (grey). Subsequently, the organic semiconductor mixture is applied (red).

Interdigitated electrodes are common in sensors. Typical distances between the electrodes in one plane are between one and several micrometres. The smallest dimensions are produced by photo-lithographic procedures.

We have developed interdigitated nano-electrodes with a comb configuration and vertical orientation (fig. 1). This geometrical configuration allows very small distances between the electrodes, which are necessary due to the relatively low mobility of the charge carriers in organic semiconductors.

The nano-electrodes are built up on a pre-structured polymer substrate by a self-aligning coating process. We apply interference lithography and microreplication techniques to produce the substrate. Different metal electrodes can be deposited, depending on the type of organic, opto-electronic component.

Based on this architecture, we have prepared an organic photodiode with an electrode separation of 400 nm (fig. 2). We chose gold and titanium as the electrode materials. The electrodes are embedded in the photoactive layer of the photodiode. This enables efficient transport of the charge carriers. The current density/voltage characteristic under exposure to light is shown in fig. 3.

The versatile concept of interdigitated vertical nano-electrodes has high potential for application in many other components, such as organic light-emitting diodes, organic transistors and sensors.

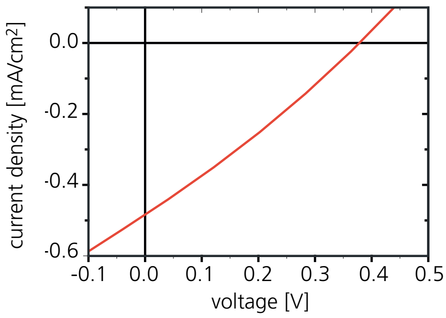

Fig. 3: Current density/voltage characteristic curve of an organic photodiode based on interdigitated nano-electrodes under illumination of one sun.

Tunable Organic Lasers based on Photonic Crystals (PC Lasers)

In co-operation with working groups at the Universities of Karlsruhe and Kassel, we are developing tunable PC lasers based on polymers. At Fraunhofer ISE, we model the optical properties of the lasers and apply interference lithography to produce microstructured polymer substrates, which serve as the basis for the organic lasers.

Karen Forberich, **Andreas Gombert**

Organic PC lasers are produced by depositing an organic semiconductor onto a microstructured polymer substrate. If the dye is optically pumped, the microstructures scatter back part of the light emitted by the semiconductor in phase. This results in the feedback and amplification needed for laser operation (fig. 1). We can determine the modes of such a laser by band structure calculations. Calculation of the effective amplification, i.e. the overlap between the active laser material and the intensity, and the active losses, allow us to identify the mode with the lowest losses as the laser mode.

The laser wavelength is determined by the period of the microstructure, the refractive index of the semiconductor and the thickness of the deposited dye layer. Thus, different laser wavelengths and thus tunable lasers can be generated by local variation of the period on a microstructured substrate. We produce the microstructured substrates by interference lithography and microreplication. Among other activities, an automated exposure unit was designed and constructed, with which individual fields with continuously varying periods can be generated on one substrate (fig. 2). This automated exposure unit allows rapid optimisation of grating structures produced by interference lithography.

The work on tunable PC lasers was funded by the German Federal Ministry for Education and Research BMBF.

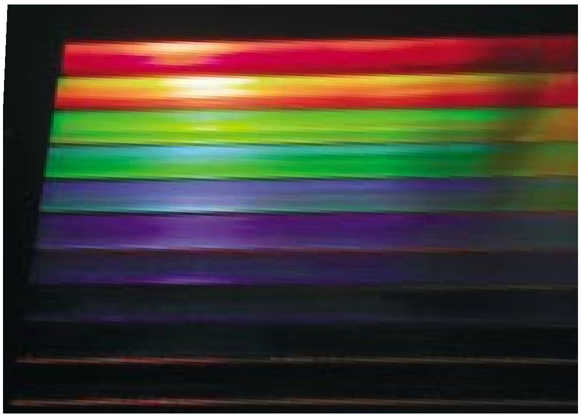

Fig. 2: Grating fields with continuously varying periods produced by an automated exposure unit. Tunable lasers can be prepared using substrates that are replicated from these gratings.

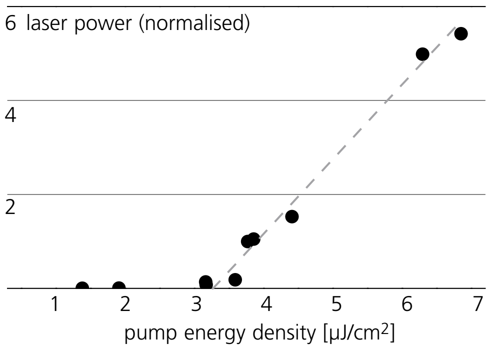

Fig. 3: Laser threshold of an organic PC laser, produced by coating a microreplicated, two-dimensional surface grating with the laser dye, Alq_3:DCM.

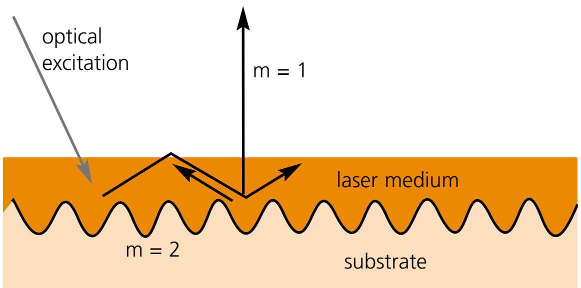

Fig. 1: Operational principle of an organic laser based on photonic crystals. An organic laser dye is depositied onto a replicated microstructured substrate. Diffraction by the substrate causes distributed feedback to become established, with the substrate taking on the role of a laser resonator.

Solar Cells

Photovoltaics has experienced a boom over the past ten years that was stimulated 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 almost 4 GW.

More than 90 % of the solar cells manufactured 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.

Supported by 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), we are currently establishing the Photovoltaic Technology Evaluation Center PV-TEC. Research, development and service will be offered to the photovoltaic industry in a new dimension, namely on 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.

In order to reduce consumption of the relatively expensive raw material, which will also be in short supply for the next two years (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 these thin films directly from crystals.

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 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 raising the quality and reducing costs. We are working on new module concepts, processing sequences 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.

Photovoltaic Technology Evaluation Center PV-TEC. The evaluation centre for solar cell production, which was financially supported with 11.7 million euros from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU, will be officially opened in March, 2006. In addition to the federal funding, Fraunhofer ISE is contributing a further two million euros with the support of the Fraunhofer-Gesellschaft. Solar cell producers and system manufacturers will be able to test new production technology for silicon solar cells with high statistical reliability in this service facility, without having to interrupt their own production lines. Thus, PV-TEC will facilitate very rapid technological transfer to the solar cell industry and underpin the leading position of German industry and research in this important area (see article on p. 46).

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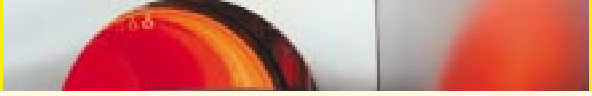


Dielectric Coatings for Back-Surface Passivation of High-Efficiency Solar Cells

Silicon solar cells with a dielectrically passivated back surface offer the potential for very high efficiency values. Our goal is to optimise these insulating layers with respect to their electrical and optical quality, but also concerning their compatibility with an industrial manufacturing process and lower material quality. We were able to achieve the best values internationally with film materials such as amorphous silicon, silicon nitride and silicon carbide.

Stefan Glunz, Andreas Grohe, Marc Hofmann, Stefan Janz, Franz-Josef Kamerewerd, Antonio Leimenstoll, Ralf Preu, Thomas Roth, Oliver Schultz, Sonja Seitz, Siwita Wassie, Gerhard Willeke

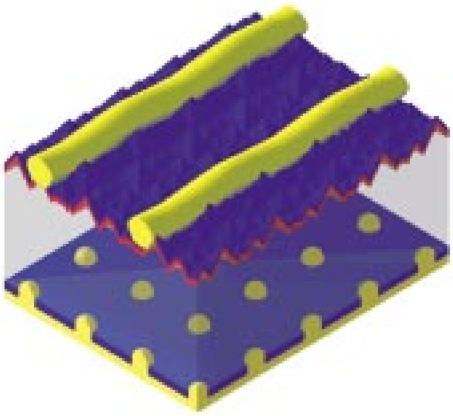


Fig. 1: Structure of a silicon solar cell with a passivated back surface. The point contacts on the back surface were fired with a laser through the newly developed passivation layers (LFC process).

Back-surface coating	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
silicon nitride	672	38.8	79.0	20.6
amorphous silicon	675	39.2	80.6	21.3[1]
silicon carbide	665	37.5	80.3	20.2[1]

Table 1: Results for LFC contacted solar cells with different types of back-surface passivation ([1]= independently confirmed results).

In industrial mass production, the entire back surface of a silicon solar cell is contacted with metal. Research results have shown that the potential efficiency value increases if only point contacts are made to the back surface of the cell, while the remaining area is electrically passivated with an insulating layer. This type of back surface reduces the recombination of charge carriers and simultaneously acts as a very good optical mirror, so that light which has penetrated deep into the cell is reflected back into it.

One of our main research topics is optimisation of the dielectric coatings needed. Thermally grown silicon dioxide is used in the best, record-breaking cells of monocrystalline silicon. However, with processing temperatures exceeding 1000 °C, this can strongly degrade the material quality of multicrystalline silicon. We thus aimed to reduce the processing temperatures. By applying plasma-enhanced chemical vapour deposition (PECVD) in the temperature range between 200 °C and 400 °C, we deposited different coating materials such as silicon nitride, silicon carbide or amorphous silicon onto the back surface of cells. Then, the point contacts to the back surface were produced with the laser-fired contact (LFC) process that was developed and patented by Fraunhofer ISE. With this approach, we achieved an efficiency value of 20.6 % with silicon nitride layers, which are already used in industrial mass production for the front surface. Although the quality of this back surface is already much higher than that of an industrially produced solar cell, there is still potential for optimisation when it is compared to the reference value of 21.9 % for cells with a passivation layer of thermally grown silicon dioxide. If we reduced the nitrogen content to the extent that an amorphous silicon film resulted, the efficiency value increased to values up to 21.3 %, a record value for "cold" passivated solar cells. Another interesting coating material, with which we achieved an efficiency value exceeding 20 % for the first time in the world, is silicon carbide. These coatings are characterised by higher thermal stability, which should simplify their integration into an industrial processing sequence.

High-Efficiency Silicon Concentrator Solar Cells with an Adapted Optical Concentrator Element

In photovoltaic concentrator systems, inexpensive optical components such as reflectors and lenses focus the sunlight onto the solar cells, so that the solar cell area can be greatly reduced. If high concentration factors are to be achieved in single-axis tracking systems, a second concentrator stage must be introduced. At Fraunhofer ISE, we are developing funnel-shaped optical elements as secondary concentrators, together with the optically contacted, high-efficiency silicon solar cells.

Armin Bösch, **Stefan Glunz**, Antonio Leimenstoll, Franz-Josef Kamerewerd, **Andreas Mohr**, Thomas Roth, Gerald Siefer, Gerhard Willeke

In photovoltaic concentrator systems, direct sunlight is focussed onto the solar cell by optical components. These systems must track the sun. To achieve a high concentration factor, double-axis tracking is usually applied. An alternative is offered by systems with primary and secondary concentrators. With these optical systems, high concentration factors of 300 can be achieved with single-axis tracking. However, the secondary concentration stage must have an acceptance angle of ±23.5°, so that the difference in solar altitude between summer and winter can be compensated.

At Fraunhofer ISE, we are developing funnel-shaped optical elements as the secondary concentrator stage, together with the corresponding silicon solar cells. The optical elements - so-called compound parabolic concentrators (CPC's) - are designed to increase the light concentration of the primary concentrator by a factor of 7.7.

Positioned at the base of the CPC's are the 4.5 x 4.5 mm^2 RLCC silicon concentrator solar cells (rear line contacted concentrator cells), which were specially developed for high concentration factors of 300 and achieve a peak efficiency value of 25 % for 100-fold concentration. As the solar cells are mounted directly under the base of the CPC's, it is useful to position both electric contacts on the back surface of the cell. This has the advantage that the contacts do not cause any shading and the CPC's can be mounted simply on the cells. In combination with the secondary concentrator stage, the RLCC cells that we have developed are characterised by efficiency values of 21 %. The development was funded by the European Union.

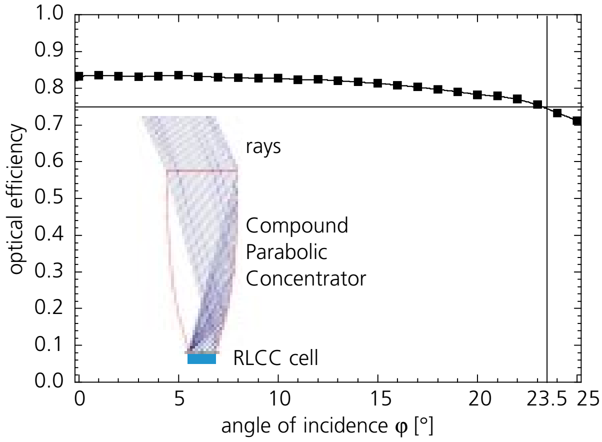


Fig. 1: The secondary concentrator stage - the compound parabolic concentrator (CPC) - is mounted directly onto the silicon concentrator cell with an optically transparent adhesive and concentrates the sunlight onto the solar cell via total internal reflection. The CPC's have an optical acceptance angle of ±23.5° to adapt the single-axis tracking system to the solar ecliptic. Angle-dependent optical measurements proved that the CPC's meet the specification for an acceptance angle of ±23.5°.

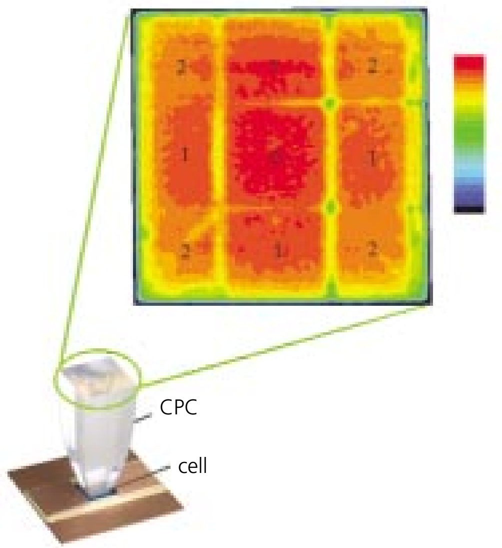
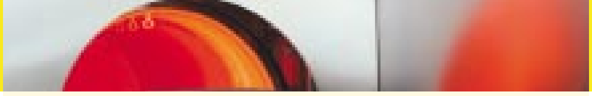


Fig. 2: A scanning laser system allows all the optical losses of the funnel-shaped polymer element to be imaged. The losses include reflections from the front surface of the compound parabolic concentrator (CPC), absorption losses in the CPC, reflection losses in the CPC and coupling losses between the cell and the CPC. It is particularly important to differentiate between the zones with direct ray transmission (0), single (1) and double (2) internal reflection. The yellow lines between these zones show the greatest optical losses due to light being coupled out of the element. This occurs around the edges of the transition zone from the CPC to the solar cell.



Production Technology for Crystalline Silicon Solar Cells

We develop production technology for crystalline silicon solar cells. We are focussing on treatment methods for silicon wafers which minimise stress on the materials, the implementation of highly efficient solar cell structures and the application of highly productive and cost-effective procedures. Our developments lead to high efficiency values with industrially applicable processes and can be transferred to production within the short or medium term.

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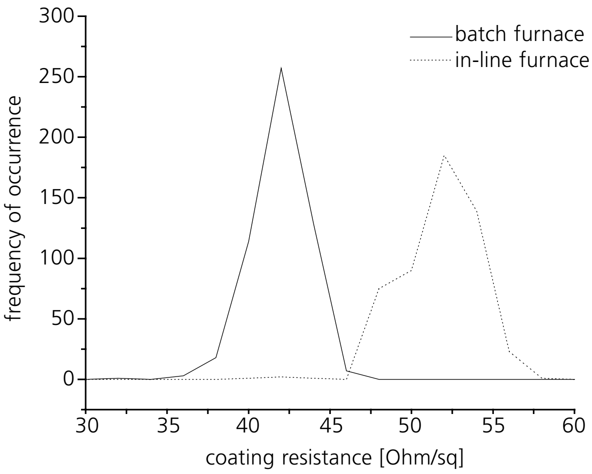
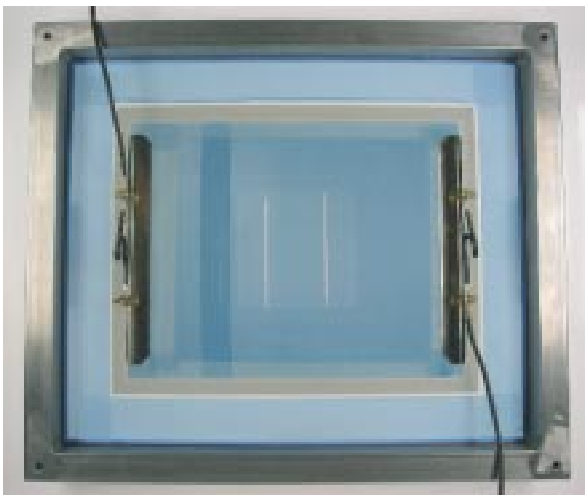


Fig. 1: Comparison of the film resistance distribution of a wafer after diffusion in an in-line furnace (dotted line) and a batch furnace (solid line). Sufficiently homogeneous film resistance values can also be achieved with the in-line spraying process.



In developing technology for solar cells of crystalline silicon wafers, we are concentrating on handling and processing methods to reduce breakage, the implementation of highly efficient structures and the application of high-yield and cost-effective procedures. Two examples:

Phosphorus diffusion to create the emitter is the central processing step for the initially boron-doped silicon material which is primarily used in photovoltaics. The most widespread process is batch furnace diffusion, in which several hundred silicon wafers are processed simultaneously in a quartz tube. Introduction of a processing gas containing phosphorus causes a phosphorus-rich glass to form, from which phosphorus diffuses into the surface layers (about 1 µm thick) of the silicon wafers. The handling to load the furnace is very complicated due to the simultaneous processing and the special arrangement of the wafers to achieve high packing densities. As an alternative, we have developed an in-line process in which the wafers are initially sprayed with an inexpensive doping material. We have succeeded in modifying phosphoric acid with small amounts of additive such that a very homogeneous phosphorus glass can be formed. The transport unit for the in-line furnace is also based on one of our developments. Instead of the usual metallic chain belt, we use ceramic fibre cords which are suspended along the whole length of the furnace. The cord pair which is uppermost at any time always moves in the direction of transport. With this furnace system, we not only avoid metallic contamination, but also significantly reduce the amount of energy needed for heating and cooling. Applied to the production of solar cells from textured Cz silicon, we achieved a very good efficiency value of 17.5 %, corresponding to the high level of conventional batch diffusion.

Fig. 2: If screen-printing pastes with a high melting point are to be used, the printing environment must be adapted to printing at higher temperatures in the range from 50 °C to 80 °C. A heatable trampoline screen is shown here.

An important approach to increase the efficiency value is to reduce shading by the front contacts and to lower the resistance of the contact structure. The main method used in industry to contact the front of the solar cell is selective screen-printing with a highly viscous, conductive silver paste. In a subsequent sintering step, the specific conductivity of the paste is increased and a good electrical contact to the silicon is created. This process results in contact structures which are usually 120 - 140 µm wide and 8 - 10 µm high. At Fraunhofer ISE, we have developed a procedure to increase the contact finger height and conductivity by a factor of four. This development is based on the use of pastes with a high melting point, accompanied by the corresponding modifications to the printing environment. On applying the process we had developed to solar cells, we achieved peak efficiency values of 18.0 % for typical industrial solar cells of textured Cz silicon and 15.8 % for untextured multicrystalline silicon. This value is 2 % relatively higher than that for the conventional screen-printing process. The process should be implemented in production on a short to medium-term basis. To do this, in future we will be able to use PV-TEC, our new large laboratory with an area of 1200 m^2, which we are currently establishing near Fraunhofer ISE with financial support from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU and funding from the Fraunhofer-Gesellschaft.

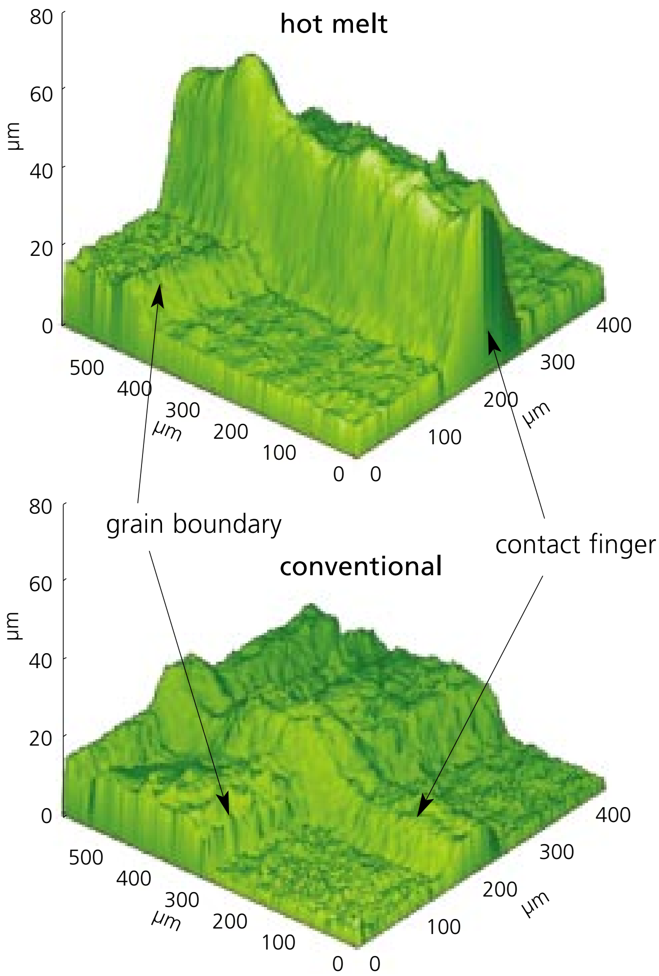


Fig. 3: Significantly larger amounts of paste can be deposited by using those with higher melting points. The figure shows the topography of contact fingers on multicrystalline silicon that have been screen-printed using silver pastes with high and lower melting points.

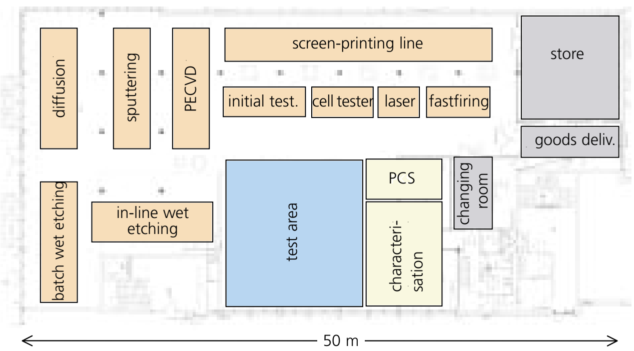
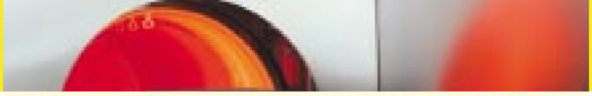


Fig. 4: The layout of the new Photovoltaic Evaluation Centre PV-TEC. It offers 1200 m^2 of well-equipped laboratory area. All processing systems have a capacity of at least 200 wafers per hour. New technology can be evaluated in the test area located adjacent to the standard processing equipment.



Behaviour of Recombination Centres during Solar Cell Processing

The efficiency value of multicrystalline silicon solar cells is limited by recombination. Both impurities in the material and extended defects act as recombination centres. We have developed a new investigation method, with which the behaviour of these recombination centres can be monitored during processing.

Dietmar Borchert, Markus Rinio, Stefan Müller, Elmar Zippel, Mark Scholz

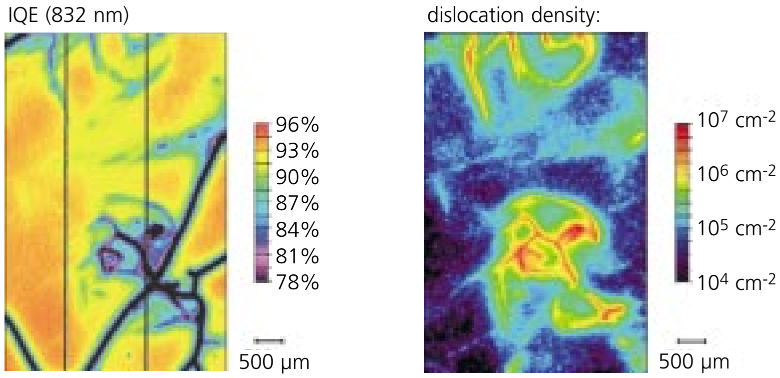


Fig. 1: LBIC and dislocation density topograms of the same sample section. The LBIC topogram shows the proportion of photons converted in the bulk (internal quantum efficiency, IQE) for a wavelength of 832 nm. The IQE is limited over large areas by the dislocation density. High dislocation densities reduce the IQE and thus the solar cell quality. Correlation of the two topograms allows the negative effect of individual dislocation clusters to be measured. In the IQE topogram, grain boundaries (broad black lines) and contact fingers (thin straight lines) can also be seen.

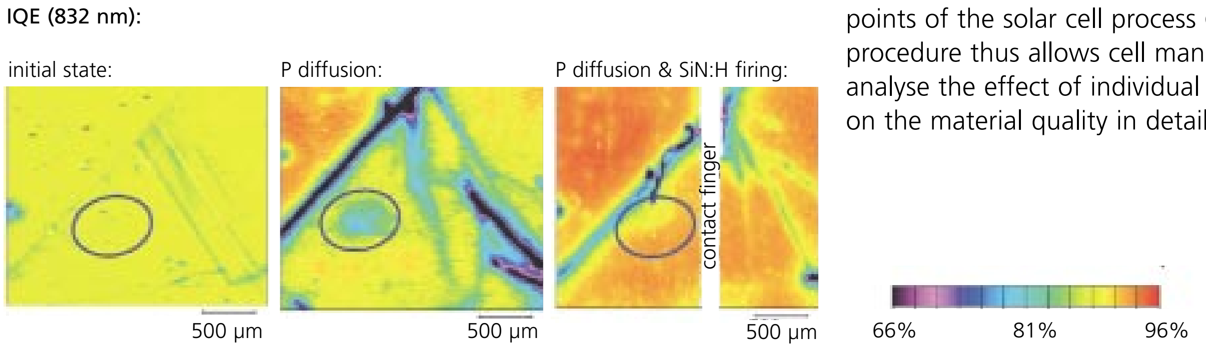


Fig. 2: LBIC topograms of three silicon wafers, which were cut from adjacent positions of the same block. Each wafer has the same distribution of extended defects (grain boundaries and dislocations). Left: Specially prepared sample in the initial state. Centre: Conventional, phosphorus-diffused solar cell with MgF anti-reflection coating. Right: Conventional, phosphorus-diffused solar cell with silicon nitride (SiN:H) coating after high-temperature treatment (firing). Comparison shows clearly that grain boundaries (dark lines in the centre image) and dislocation clusters (within blue oval) are not made worse until during the phosphorus diffusion process (accumulation of impurities). However, the material quality is improved in the remaining areas. Impurities wander toward the sample surface, if no extended defects are nearby. Firing the SiN:H layer partly reverses the degradation of extended defects (hydrogen passivation).

Multicrystalline silicon is the dominant semiconductor material in the photovoltaic industry. The efficiency values of multicrystalline solar cells are essentially limited by bulk recombination of charge carriers within the cell. In the material, both localised impurities and extended defects such as dislocations or grain boundaries act as recombination centres. The behaviour of these recombination centres changes during the manufacturing process.

We apply the light beam induced current (LBIC) method to the finished cell to investigate the effect of defects on the efficiency value. The method allows high spatial resolution and thus targeted observation of the individual defect types.

For example, dislocation clusters can easily be identified in the LBIC images by comparing them with images obtained after etching, and their effect on the solar cell quality can be determined (fig. 1).

Nevertheless, application of the LBIC procedure is possible only if a finished solar cell is available. It cannot be used, for example, to characterise the material in its initial state. We have overcome this disadvantage by developing a special preparation procedure, which allows us to make solar cells without modifying the material. As a result, we can now use our high-resolution LBIC instrument to make measurements at different points of the solar cell process (fig. 2). Our procedure thus allows cell manufacturers to analyse the effect of individual processing steps on the material quality in detail.

Sputtering for Mass-Production Coating of Solar Cells

One method to improve the efficiency value of industrial solar cells is to deposit silicon nitride (SiN) onto the surface of the solar cells. The development of sputtering as a new process for SiN deposition resulted in chemical engineering advantages such as a high deposition rate and excellent potential for upscaling the throughput. A further decisive result is that the quality of the coatings is equal in all respects to those from the industrial deposition processes that have been used up to now.

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Up to now, the most widespread technology to deposit silicon nitride (SiN:H) as an anti-reflective and passivation coating has been plasma-enhanced chemical vapour deposition (PECVD) in a tube furnace. The well-known difficulties in handling the silicon wafers, the low deposition rates, the use of potentially explosive gases and the inconsistent uniformity of the SiN:H coating thickness at times called for alternative methods. We decided on sputtering, which has already been applied successfully in other industrial sectors for many years.

Using a prototype of a sputter coater that is suitable for mass production and is installed at Fraunhofer ISE, we investigated the suitability of these coatings for the sensitive surfaces of solar cells. We were able to disprove the assumption that sputtering would damage the surface. On the contrary, the number of defects on the surface and in the bulk silicon was reduced to the same extent as by PECVD. The electrical quality of thin wafers or less pure material can thus be improved significantly. Together with the good optical properties, this leads to excellent efficiency values for the solar cells produced.

We have thus developed a process, which retains the quality of the deposited coatings and offers clear advantages compared to the standard PECVD process due to its high deposition rates, the excellent coating thickness homogeneity and good potential for up-scaling.

The joint development with an industrial partner was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU.

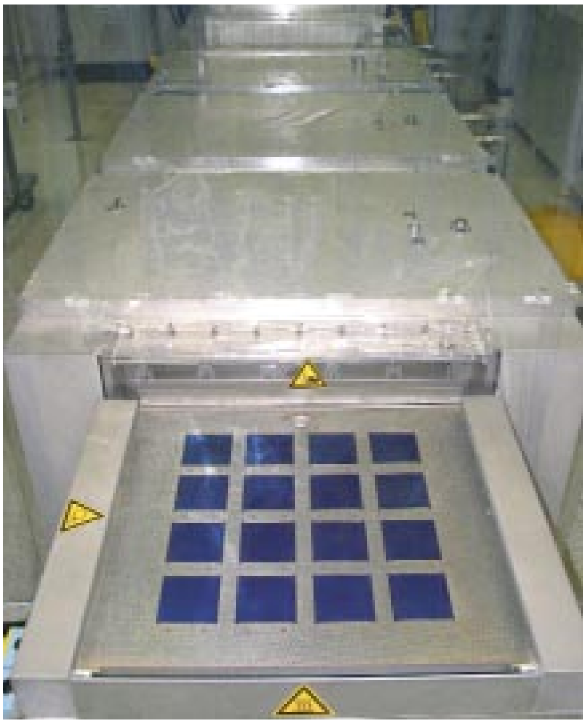
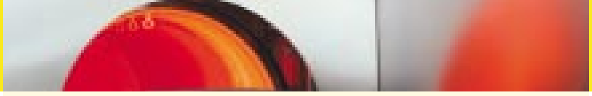


Fig. 1: Loading station of the prototype sputtering system for SiN coating of crystalline silicon solar cells. Up to 16 solar cells on one tray can be processed simultaneously.

Silicon material	Solar cell type	Coating on	Area [mm²]	V_{oc} [mV]	J_{sc} [mA/cm²]	FF [%]	η [%]
mc	sp, planar	front	125^2	616.8	31.6	80.0	15.6
Cz	sp, textured	front	125^2	624.8	36.0	80.2	18.0
FZ	LFC	back	20^2	669.4	38.6	80.0	20.6

Fig. 2: Characteristics of cells which were processed completely at Fraunhofer ISE, and coated with SiN by sputtering (mc: multicrystalline, Cz: Czochralski, FZ: float zone, screen-printed: near-industrial screen-printed solar cell, LFC: high-efficiency solar cell with passivated back surface and laser-alloyed point contacts). The good passivation effect and optical properties lead to very good results, comparable to those with PECVD. These are achieved even on the back surface of high-efficiency cells, which are usually difficult to passivate.



Low-Defect Micro-Structuring of Crystalline Silicon

Micro-structuring of crystalline silicon, e.g. for edge insulation or wafer dicing, without introducing crystal defects has only been possible up to now with complex, multiple-step processes. A process to remove the introduced defects had to follow any micro-structuring step. Our LCE process (laser chemical etching) avoids this and thus opens up a large potential for process simplification. The process is so flexible that not only silicon but many other materials (metals, other semi-conductors, etc.) can be treated.

Sybille Baumann, Achim Eyer, Fridolin Haas, **Daniel Kray**, Kuno Mayer, Mark Schumann, Gerhard Willeke

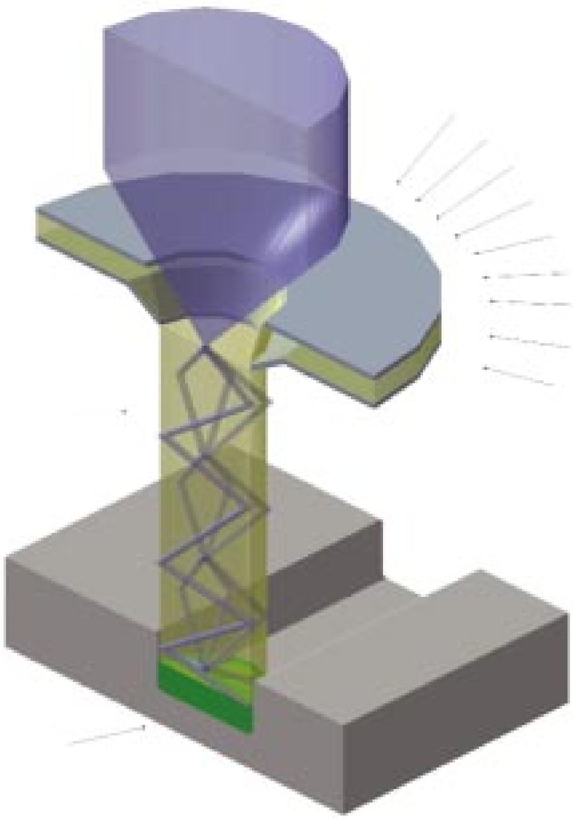


Fig. 1: Principle of the laser chemical etching (LCE) process. An etching solution flows radially under high pressure into a nozzle, so that a laminar jet results. A laser beam is coupled into the liquid jet via a window at the top of the nozzle. This makes localised and laser-assisted wet chemical etching feasible. The laser parameters and chemical systems can be adapted to many materials.

The LCE process, which operates according to the principle shown in fig. 1, is currently being thoroughly investigated and developed at Fraunhofer ISE. The first goal is defect-free micro-structuring of silicon, e.g. for edge insulation or separation of crystalline silicon solar cells (dicing). In initial experiments, we compared the crystal damage from a standard dry laser, from a water-jet guided laser and LCE with potassium hydroxide as the medium. The results in fig. 2 of X-ray diffraction measurements show that LCE introduced the lowest amount of damage to the material. By using chemical systems with even more favourable etching performance, we aim to micro-structure silicon very rapidly without causing any electrically active damage to the crystalline structure. In the long term, the LCE process could replace wire-sawing technology for cutting wafers. It offers the perspective for cutting very thin wafers (< 50 µm) with very little kerf loss (kerf < 100 µm), which do not require any subsequent etching step to remove the sawing damage. In addition to the treatment of silicon for photovoltaics and microelectronics, applications for other materials are foreseen. The only pre-condition for LCE treatment is the existence of wet-chemical etching systems for these materials. Some of the work to date has been funded by the European Union.

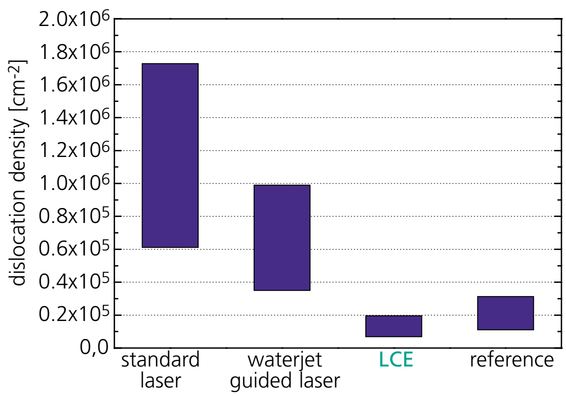


Fig. 2: X-ray diffraction measurements of silicon for three different micro-structuring processes. Although the trace width is about 50 % narrower than for other processes, standard lasers generate the highest dislocation density. The use of KOH as the medium for LCE reduces the dislocation density significantly compared to the water-jet guided laser and results in values similar to those measured on unstructured reference wafers.

Influence of Trapping on Minority Charge Carrier Lifetime Measurements in Crystalline Silicon

The decisive parameter characterising the quality of silicon material for solar cells is the lifetime of the excess charge carriers. The most important measurement methods for this parameter have been affected up to now by a measurement artefact, which is caused e.g. by the capture of excess charge carriers in traps, and distorts the measurement significantly, particularly in critical areas. We have succeeded in eliminating the trapping effect by additional illumination with light of lower energy than the energy band gap.

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The lifetime of excess charge carriers is an essential quality indicator for silicon material. Measurements of the minority charge carrier lifetime play a central role in optimising solar cell efficiency values, above all for multicrystalline silicon. Knowledge of the behaviour under operating conditions, i.e. particularly for low injection, is important for analysing the effect of the material quality on the solar cell result. For this reason, but also for fundamental investigations on the lifetime of excess charge carriers, measurements must be carried out with correspondingly low values of the excess charge carrier density. However, all measurement methods which use the conductivity of the excess charge carriers are marred by a measurement artefact, an apparent increase in the lifetime, to very high values at times. Assessment of the material quality can be completely false, particularly for the critical zones with low lifetimes.

In co-operation with the Freiburger Materialforschungszentrum FMF, we have succeeded in decisively improving the theoretical understanding of these trapping effects. Representations of the distribution of the trap parameters were gained with the carrier density imaging (CDI) method from injection-dependent measurements. By additional illumination with sub-bandgap light, we have developed a procedure which either completely suppresses or at least greatly reduces the effect of traps, and thus greatly extends the accessible measurement range.

The work was funded within the "Diagnostics" network by the German Federal Ministry for Education and Research BMBF.

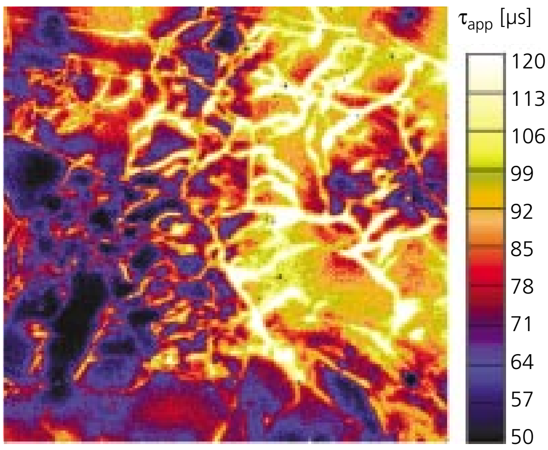

Fig. 1: Measurement of the (apparent) charge carrier lifetime of a multicrystalline silicon wafer (area shown: 13 x 13 mm^2) with the CDI method at a low density of the optically generated carriers. The light areas indicate long apparent lifetimes. However, these are caused by charges captured in trap states and distort the analysis of the material quality.

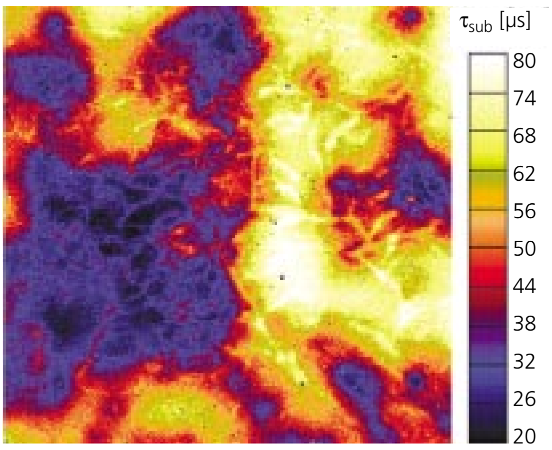

Fig. 2: The same silicon wafer as in the adjacent image, measured under the same generation conditions, but with additional illumination with sub-bandgap light: The areas with apparently very long lifetimes have disappeared almost completely; the true, much shorter lifetime of the free excess charge carriers can be determined.

FLATCON® Concentrator Technology Approaching the Market

Fraunhofer ISE has extensive expertise on highly concentrating photovoltaics, a technological branch which is attracting increasing attention. In summer 2005, we implemented the first highly concentrating, grid-connected FLATCON® concentrator system. All components, from the III-V based multi-junction solar cell, through the concentrator optics and module construction, to the controls for the tracking unit, were developed at Fraunhofer ISE and optimally tuned to each other in the concentrator system.

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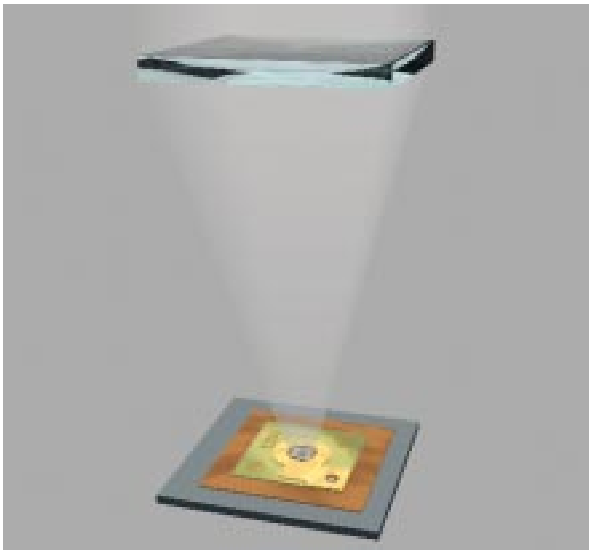


Fig. 1: The sunlight is concentrated 500-fold by a lens onto a small cells with a diameter of 2 mm. This allows expensive semiconductor material to be saved. However, as only direct sunlight can be concentrated, the PV system must track the sun.

Increased demand for concentrator technology can be observed in the booming photovoltaic market. The recent strong growth in the photovoltaic market was not confined to individual systems on household roofs. Numerous large arrays in the MW range were also installed. In regions with high direct solar radiation, we see a target market in these applications for the FLATCON® concentrator technology that we have developed.

The special aspect of developing a concentrator system is that several components must initially be optimised individually, and then modified such that they produce an optimal system result. The component development for our FLATCON® system included III-V multi-junction solar cells, point focus Fresnel lenses, module construction, design and control of a tracker and finally connection to the grid via an inverter.

Our decision for a highly concentrating photovoltaic system was based on a thorough technological analysis. With the FLATCON® technology, we use a 4 x 4 cm^2 Fresnel lens to concentrate the sunlight by a factor of 500 and focus it onto a round cell with a diameter of 2 mm (see fig. 1).

In this way, the amount of expensive semiconductor material is reduced and very efficient solar cells can be used. These high-efficiency cells are mounted onto copper plates, which act as heat sinks. In the next step, we position the solar cell units very exactly on a glass pane, which serves as the base plate for our FLATCON® concentrator module (see fig. 2).

For several years, we have been testing the long-term reliability of modules equipped with $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ tandem solar cells in our outdoor test stand. At the same time, we have conducted accelerated ageing tests in the laboratory. We are co-operating with international partners to prepare an IEC standard for concentrator systems.

In 2005, we achieved a major success in our cell development: Our concentrator triple-junction cell of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As/Ge$ achieved a European record efficiency value exceeding 35 % for 600-fold concentration of sunlight (see fig. 3). Following that, we produced the first FLATCON® test module with concentrator triple-junction cells, which attained an efficiency value of 25.9 % in the measurement stand on the Institute roof.

To bring the economically attractive FLATCON® technology into production and onto the photovoltaic market, we founded the company, Concentrix Solar GmbH, as the most recent spin-off of Fraunhofer ISE in March 2005 (cf. p. 80). Three months later, Concentrix Solar GmbH and we jointly implemented the first fully functional, grid-connected concentrator system based on the FLATCON® module technology described above.

Our projects on all aspects of the FLATCON® concentrator system are supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU, the European Union and the State of Baden-Württemberg.

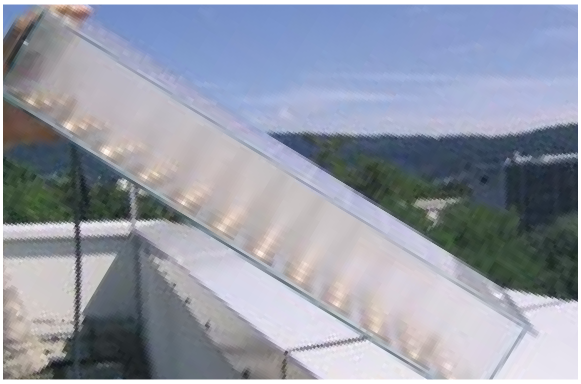


Fig. 2: Photo of a FLATCON® module. The light rays have been made visible here by injecting smoke into the module. The aperture area of a module is 768 cm^2 and is covered with 48 Fresnel lenses, each with an area of 16 cm^2. A concentrator solar cell of III-V semiconductor material is located at the focus of each lens.

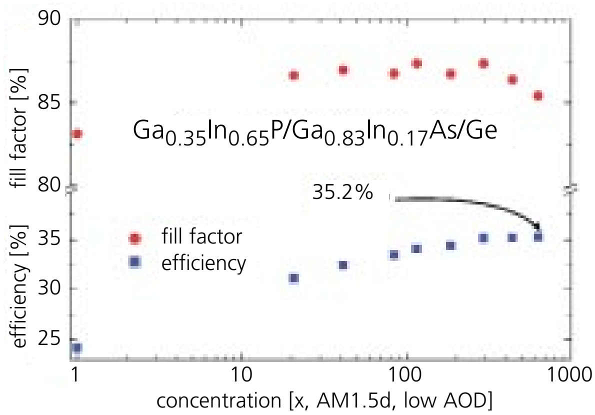
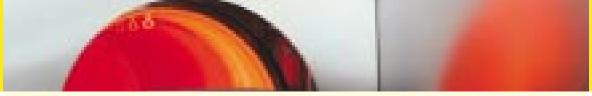


Fig. 3: The fill factor (red) and the efficiency value (blue) are plotted as a function of the concentration factor for the sunlight. With concentration factors between about 400 and 600, this triple-junction cell of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As/Ge$ achieved an efficiency value of 35.2 %.



Recrystallised Wafer Equivalents – Resource-Conserving Photovoltaics

Our concept of the "recrystallised wafer equivalent" presents an approach to solve the general problem of consumption of extremely pure raw material in photovoltaics. By using a cheap ceramic plate as the substrate and coating it only with the layer of high-quality silicon needed for the solar cell, valuable material and thus also costs can be saved. We demonstrated that such coatings can be produced over large areas, and that the substrate and coating can replace a conventional wafer in principle.

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A "recrystallised wafer equivalent" (RexWE) consists of an inexpensive substrate wafer, onto which coatings of electrically conductive silicon carbide (SiC) and silicon are deposited sequentially. The quality of the silicon layer is further improved after deposition by "zone-melting recrystallisation", to ensure the best possible efficiency value for the resulting solar cell.

Our first task was to produce a RexWE of industrially relevant area on an innovative and inexpensive ceramic substrate. To this purpose, we coated ceramic plates of dimensions up to 210 x 210 x 0.8 mm^3 with SiC films of only 1 µm thickness, and then deposited app. 10 µm silicon onto these with a high-throughput process. The result, after the subsequent zone melting in the high-throughput reactor, is shown in fig. 1.

The designation, "wafer equivalent", implies that such coated substrates can replace conventional wafers. We tested this for the RexWE with the help of ideal, SiO_2-coated silicon wafers as the substrate. The deposition of the silicon layer proceeded naturally more easily than for the RexWE on ceramic. It was equally simple to process the 100 x 100 mm^2 RexWE to form solar cells with efficiency values of up to 8.4 %. Even encapsulation to produce a mini-module, shown in fig. 2, was possible without difficulty. The initial experience with RexWE on large areas has demonstrated that there is still great potential for this concept in future.

The work is funded within two projects by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU, and the European Commission.

Fig. 1: Recrystallised wafer equivalent on a reaction-bonded silicon carbide ceramic substrate. The vertical, high-quality crystallites of the silicon layer, which are more than 10 cm long and up to 5 mm wide, are visible. The wafer equivalent in the photograph has an area of 180 x 180 mm^2. The result shows that recrystallised wafer equivalents with excellent properties can be produced using production-relevant materials and processes.

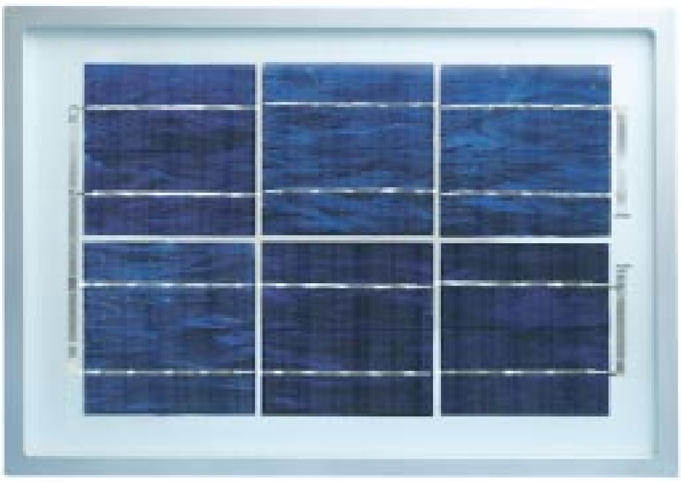

Fig. 2: Mini-module with solar cells of recrystallised wafer equivalents. The crystalline structure created by zone-melting recrystallisation of the silicon layer can be seen very clearly. Series connection of the six 10 x 10 cm^2 solar cells resulted in an open circuit voltage for the module of 3.2 V.

GaSb Modules for Thermophotovoltaic Applications

We have produced modules with GaSb-based photovoltaic cells for use in a thermophotovoltaic (TPV) generator. As the question of durability is particularly important for this application, we have carried out experiments on accelerated ageing. Finally, we have successfully used the modules in a test construction of a TPV generator at Fraunhofer ISE. Thus, GaSb TPV modules are now available to our clients.

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For several years, we at Fraunhofer ISE have been developing photovoltaic cells which convert thermal radiation in the infrared spectral region into electricity. Semiconductor materials which contain antimony, such as gallium antimonide (GaSb) or indium gallium arsenide antimonide (GaInAsSb), are suitable for this purpose. The pn junction in the photovoltaic cells can be produced in different ways, either by zinc diffusion into an n-doped GaSb substrate or by epitaxial film growth applying metal-organic vapour phase epitaxy (MOVPE). The two types of technology lead to different cell types. We have proven that the efficiency values of the two cell types are similar for the application in a real TPV generator. In our accelerated ageing investigations, both cell types showed excellent durability when operated with high current densities of 1.5 A/cm², but responded differently to the effect of an aggressively oxidising environment.

In order to apply the cells in our TPV prototypes (fig. 1), we constructed modules by connecting five GaSb cells in series on an aluminium nitride substrate. Characterising the modules in the TPV generator allowed us to determine the temperature coefficients. After making the corresponding correction, the measurements of the cells were found to agree with the measurements in the generator (fig. 2).

A module efficiency value of 15.4 % was determined, assuming the spectrum of a tungsten radiation emitter operated at 1200 °C.

The work is funded by a Fraunhofer project and a doctoral scholarship from the German Federal Foundation for the Environment BMU.

Fig. 1: TPV test generator operating at 1200 °C at Fraunhofer ISE. Eight GaSb modules, which are mounted on water-cooled supports, are located concentrically around the radiation emitter. One GaSb module and its cooling block have been removed to reveal the glowing radiation emitter. The aperture has an area of about 5 x 5 cm².

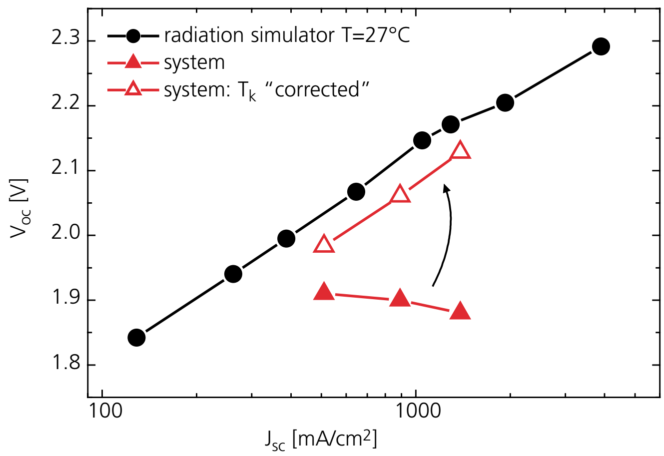
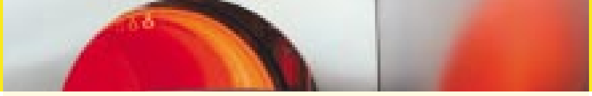


Fig. 2: Measurement results for the open circuit voltage of a GaSb module versus the short circuit current density, which correlates directly with the temperature of the radiation emitter. The module was measured with a simulator and in the test system shown in fig. 1. If the different operating temperatures are taken into account by using the experimentally determined temperature coefficient, the results agree very well with each other.



Organic Solar Cells

Organic solar cells, like organic light-emitting diodes and organic field-effect transistors, are essential functional components of polymer electronics, a rapidly developing area at present. The three main aspects of our work are the development of solar cell configurations which can be produced economically, the systematic investigation and optimisation of promising material combinations, and investigation of the long-term stability of solar cells.

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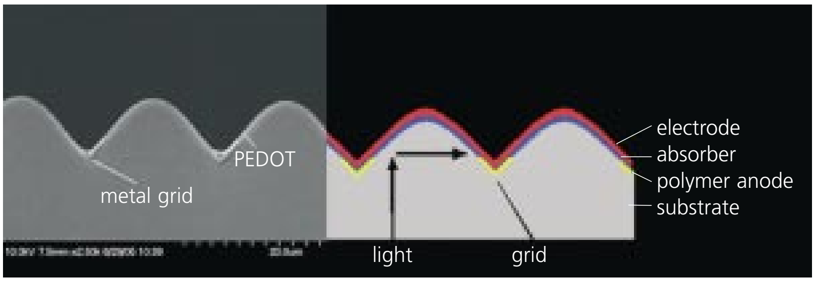

Fig. 1: Cross-section through the microstructured substrate of an organic solar cell with metal contacts and a polymer anode. The microstructure improves absorption of the solar radiation and eliminates the need for an ITO electrode. (Left: Scanning electron micrograph)

The rapid development of organic solar cells is reflected in the doubling of their efficiency value to almost 5 % during the past three years. Low material costs combined with efficient roll-to-roll processing technology are pre-conditions for the commercialisation of organic solar cells.

Important steps in this direction include further improvement in the efficiency value and the development of solar cell constructions based on inexpensive materials. Among other approaches, we aim to replace the expensive transparent electrode of indium tin oxide (ITO). For this reason, we are investigating transparent, sputtered silver films as well as polymer electrodes on microstructured substrates (fig. 1). We have produced solar cells with transparent silver films which have comparable efficiency values to standard solar cells with ITO electrodes. Polymer electrodes on microstructured substrates are supplemented by 2 µm wide metal contact strips. We were able to produce these very homogeneously by evaporation over an area of 6 x 6 cm^2.

We have set up highly automated characterisation equipment for the systematic optimisation of novel solar cell constructions and the investigation of promising absorber materials (fig. 2). Efficient investigation and optimisation of organic solar cells is supported by acquisition of the relevant processing parameters and their correlation with the experimental results in a data bank.

Fig. 2: Experimental equipment for automated measurement of the relevant solar cell parameters. The important measured characteristics include the solar cell characteristic I-V curve, the spectral response, the absorption, the linearity of the solar cell with respect to radiation intensity and the charge carrier mobility. With this equipment, the characteristic curves of 90 solar cells can be measured within an hour.

Reliability of PV Modules

Manufacturers of solar modules currently guarantee their performance for 20 years and longer. This is possible only because corresponding experience is available for the technical lifetime of the materials currently being used. If alternative, less expensive materials are used for module manufacture, it is difficult to estimate their reliability. In the cluster project entitled "Reliability of PV modules", we are co-operating with our partners to develop an accelerated ageing test for solar modules.

Michael Köhl, Tilmann Kuhn, Marco Tranitz*, Harry Wirth, Markus Heck, Helge Schmidhuber

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Fig. 1: Permeation measurement facility to determine the permeation coefficients of different gases and water vapour through films. The concentration of the gas to be tested is set on one side of the film. On the other side, a mass spectrometer measures the changing gas concentration in the sample holder (depth: 2 mm). The apparatus is located in a climatic chamber so that the temperature can be controlled.

Ageing processes in a module are influenced essentially by diffusion of water and oxygen. Standard testing procedures are only of limited relevance in evaluating high-barrier films under typical application conditions for modules. Therefore, we have designed and constructed a highly sensitive permeation measurement facility (fig. 1). The measurement facility allows the water vapour diffusion to be determined as a function of temperature. Figure 2 shows the permeation behaviour of a laminate which is primarily used in PV modules as a backing film, measured at 38 °C, and of a high-barrier film at 60 °C. The standard film has a permeation value for water vapour of 1.1 x 10^{-2} g/(m^2d mbar), the high-barrier film has a value of only 4.0 x 10^{-5} g/(m^2d mbar), although a higher temperature was chosen for the measurement. A further decisive factor for ageing is the radiation dose. We have designed an outdoor test stand for accelerated ageing, which concentrates the solar radiation on the samples by a factor of ten.

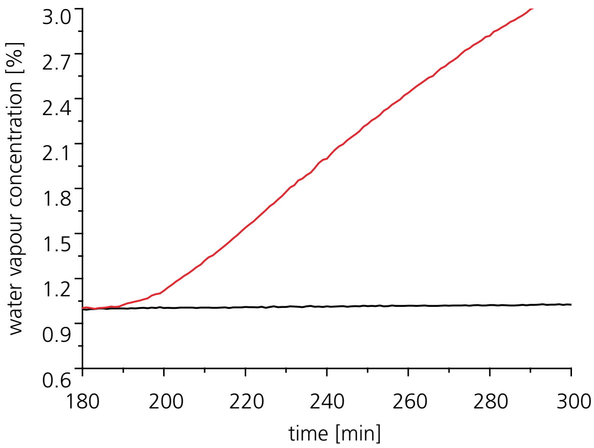

Fig. 2: Variation of the water vapour concentration with time in the measurement chamber for a high-barrier film (black) at 60 °C ambient temperature and a backing film commonly used in PV module technology (red) at 38 °C, measured as the response to a sudden change in the water vapour concentration in the climatic chamber.

The ageing processes in the laboratory and outdoors are simulated with physico-chemical models.

The project goal is to develop and verify a test to determine the lifetime of solar modules, in co-operation with six German module manufacturers and TÜV Immissionsschutz (emission control), by 2008. The cluster project on "Reliability of PV modules" is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety BMU.

Off-Grid Power Supplies

Two thousand million people without electricity, 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 all require off-grid electricity. Increasingly, regenerative energy sources or innovative energy converters are being used to supply it. Around 25 % 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 energy 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 independently on the medium term.

Miniature fuel cells, in particular, have great potential for 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

Village power supply systems are becoming increasingly important in rural electrification. Fraunhofer ISE monitors systems and develops partly automated data acquisition programs in co-operation with other research partners. Training the local technical staff is part of the process. The work concentrates on optimising system operation.
Photo source: Jörg Böthling, agenda

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Monitoring of Village Power Supply Systems in China

As part of the technical co-operation between China and Germany, Fraunhofer ISE is planning and supporting the technical monitoring of 112 village power supply systems in the Chinese province of Qinghai. Initial analyses of the measurement data have shown that the system operation can still be optimised. We draw on these results in advising on further programmes for village electrification.

Georg Bopp, Andreas Steinhüser

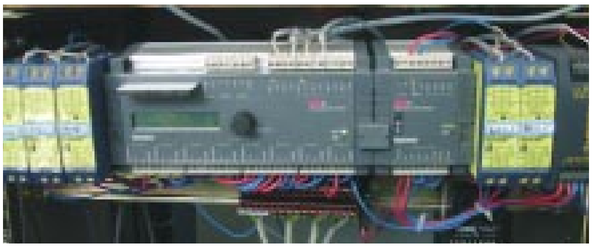

Fig. 1: This measurement data acquisition system is located in the village of Kesheng, 450 km away from Xining, the capital of Qinghai province. It records ten-minute averages of 15 measurement values. The data are transferred to Xining either via a telephone modem or with a replaceable memory card.

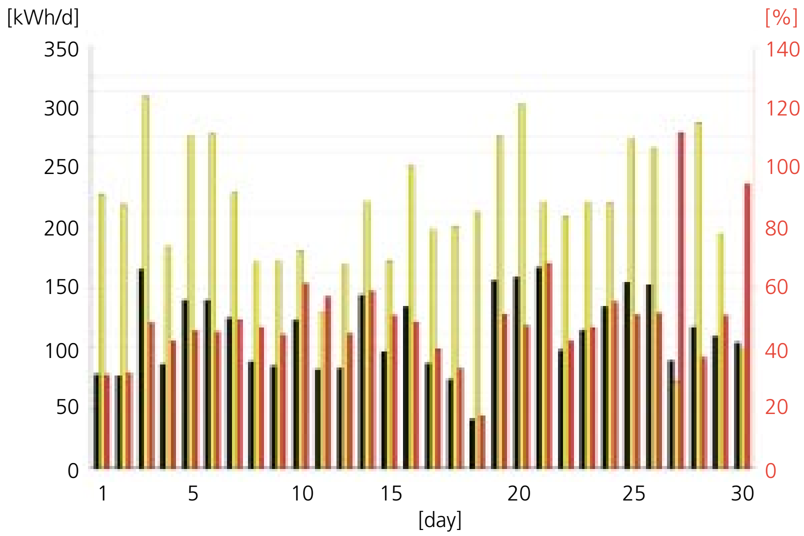

Fig. 2: A comparison of the solar electricity actually consumed (black columns) with the theoretically available amount of solar electricity (yellow columns) reveals that about half of the solar electricity which could be generated under ideal conditions by the PV system in Kesheng in April was not used. If the manually set, daily photovoltaic supply period were to be extended, the performance ratio of the system (red columns) could be increased from its current value of 50 %. On days when the performance ratio approaches or exceeds 100 %, energy stored on previous days is taken from the battery. The state of charge of the battery is not taken into account by the present operation management system.

Within the "Brightness Programme", the Chinese government equipped around 700 remote villages in the western provinces during the past two years with central photovoltaic systems supplying 10 to 40 kW. Fraunhofer ISE was commissioned by the Gesellschaft zur technischen Zusammenarbeit GTZ (German Development Co-operation) to develop a monitoring programme, with which the operation and performance of 112 photovoltaic village power systems in Qinghai province could be observed and sustainably maintained.

After preparing the concept and selecting reliable measurement data acquisition systems for automated and manual recording of data, in the spring of 2005 we trained Chinese partners for two village power supply systems in the installation and commissioning of the measurement data acquisition systems. After completing the training course, our partners installed ten further data acquisition systems on their own in other villages.

Since the autumn of 2005, we have co-operated with the Centre for Solar Energy and Hydrogen Research ZSW in Stuttgart to develop partly automated data analysis programs and have instructed our Chinese partners in their use on site.

Analysis of the first operating data revealed that the available solar energy is not used completely. Less energy is used than the solar system could supply due to the manual connection and disconnection of the electricity grid by the local operator. Thus, it would be possible to supply the users with more solar electricity without great expense by installing an intelligent operation management system, which took the solar radiation supply, the energy consumption and the battery state of charge into account.

Characterisation and Quality Control of Solar Home Systems

Solar Home Systems that are installed in practice often still have faults, some of them serious. This was demonstrated by laboratory tests for quality control, which we carried out at Fraunhofer ISE as part of a project on rural electrification in Morocco. Reliability and availability are not guaranteed for all of the Solar Home Systems and the operating costs are increased unnecessarily as a result. These faults could be avoided by continuous and comprehensive quality control, particularly before installation.

Norbert Pfanner, Rudi Kaiser, Frank Neuberger, Andreas Steinhüser, Voitech Svoboda

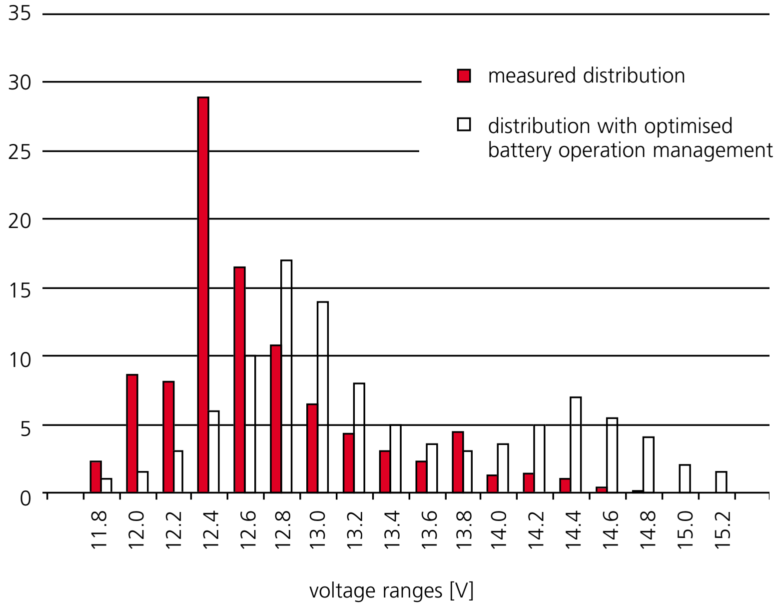

Fig. 1: The battery is often operated at too low voltages due to under-dimensioning and incorrect operation management. In particular, this shortens the battery lifetime.

Fig. 2: Hut in an African village powered by a Solar Home System.

Technical reliability and low system costs are the key to permanent success for photovoltaically powered systems such as Solar Home Systems (SHS). As part of a project on rural electrification in Morocco, Fraunhofer ISE was commissioned to investigate and evaluate three different SHS. In addition to investigations of the solar modules, charge controllers, lead-acid batteries, DC energy-saving lamps and the electric installation material, the performance of the complete systems was also to be tested.

To this end, we developed a harmonised group of laboratory test procedures with application-specific testing algorithms for the system components, and an outdoor test stand, on which the SHS was investigated over several months under realistic conditions. A load profile corresponding to the SHS user behaviour was generated on the basis of information supplied by the project managers.

The laboratory tests of the components revealed a sometimes serious lack of quality in the batteries, photovoltaic modules and DC energy-saving lamps. Only the charge controllers all proved to be of high quality. The long-term outdoor tests under realistic conditions exposed weaknesses in the system dimensioning.

The investigations showed that quality control of the systems used on site is necessary to guarantee reliable and economic operation of SHS.

The work at Fraunhofer ISE is concentrating on the development of charging strategies and procedures to determine the state of charge of batteries. To adapt the lighting systems, both new, highly efficient electronic components and also optical systems for efficient light guiding are being developed. All of the simulation tools, procedures and components that have been prepared at Fraunhofer ISE are available to our clients for correct dimensioning and operation of SHS.

Optimised Battery Management System for Stand-Alone Power Supply Systems

Lead-acid batteries have a relatively short lifetime compared to the other components of stand-alone regenerative energy systems. They represent a major cost factor for this reason. We have developed a battery management system which lengthens the battery lifetime significantly. This reduces the lifetime costs appreciably.

Rudi Kaiser

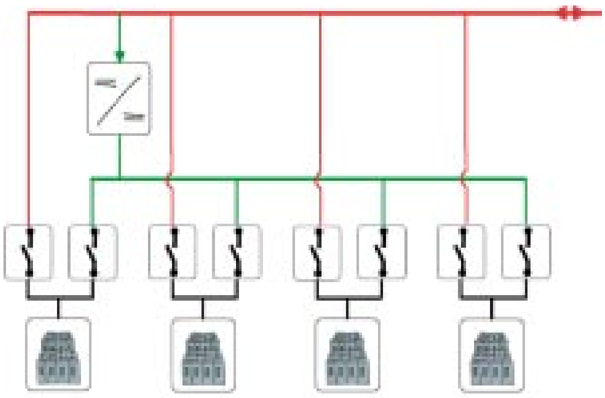

Fig. 1: The battery management system in this example controls four individual battery strings. The strings can be connected independently of each other and batteries can be fully charged via an integrated DC/DC converter. The battery system can replace a conventional battery bank without additional installation effort.

Lead-acid batteries play a central role in stand-alone regenerative power supply systems due to their widespread availability throughout the world and their relatively low investment costs. This situation has not been changed by the introduction of new battery technology.

In stand-alone power supplies, the energy input fluctuates strongly according to climatic and meteorological conditions. As a result, the batteries are frequently operated at low states of charge, are often cycled in a partly charged state and are recharged with only low currents. This affects the lifetime of lead-acid batteries very unfavourably.

Therefore, at Fraunhofer ISE we have developed a battery management system (BMS), which increases the lifetime and reliability of the battery storage bank and thus greatly reduces the maintenance need and lifetime costs. It is based on an innovative circuit concept, which makes new operation management strategies feasible. The battery bank is divided into several parallel individual strings, which can be individually connected and disconnected. The instantaneous states of the batteries in one string, such as the state of charge and state of health, are determined continuously. Based on this information, controlled discharges, reduced cycling in low states of charge, higher operating currents for the individual strings and intensive full charging with the aid of an integrated DC/DC converter can be carried out. The BMS takes account of both the ageing performance of the individual strings and also the battery type and technology. This enables the BMS to operate different strings individually and to combine the advantages of the different strings to complement each other.

In a stand-alone power system, the BMS could consist of robust battery strings which can be cycled frequently and other battery strings with a low self-discharge rate. The robust string could be responsible for the daily charge throughput and could be dimensioned to be relatively small, which would make new, more expensive types of battery technology (e.g. NiCd) more attractive. The other strings would provide the long-term energy storage. Inexpensive lead-acid batteries are advantageous for this application. This distribution would cause the investment costs to increase only slightly, whereas the operating costs would decrease strongly due to the lifetime being doubled.

A further decisive advantage of the BMS is that the reliability of the entire battery storage unit is increased. The parallel connection of several strings in the circuit concept offers multiple back-ups. If a single string suddenly breaks down, this does not mean that the complete system ceases to operate. In such a case, the BMS permanently disconnects the defect string and continues to operate with the remaining strings. Furthermore, the defect string can be replaced during normal operation.

The battery system can be connected by two terminals like a conventional battery unit by system integrators or planners, so that the complete system installation does not have to be greatly modified.

The development of the BMS was funded as part of the UESP project by the German Federal Ministry for Economics and Technology BMWi.

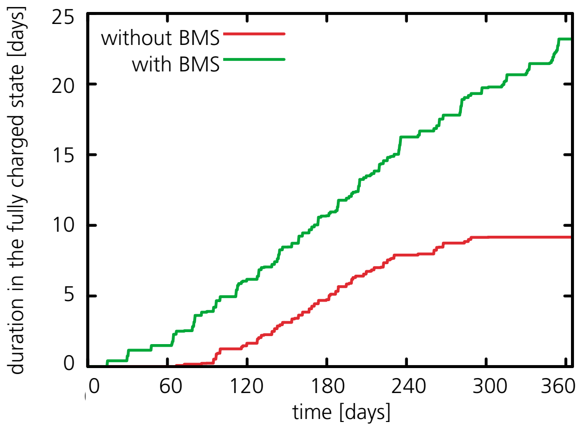

Fig. 2: The graph shows the cumulative number of days on which a battery system is fully charged over the course of one year (365 days). For a location near Freiburg, the low solar radiation intensity in winter means that it takes about 90 days for the battery without a BMS (red line) to be fully charged for the first time. After 300 days, i.e. from the end of October, there are no further days with full charges - the battery is thus operated only in a lower state of charge from then on. By contrast, the BMS (green line) ensures that the battery has been fully charged already after 30 days. Similarly, the battery continues to be fully charged on some days in autumn and winter. Over the year, the battery with the BMS is regularly fully charged (on a total of 24 days), whereas without the BMS, the fully charged state occurs less frequently (9 days in total).

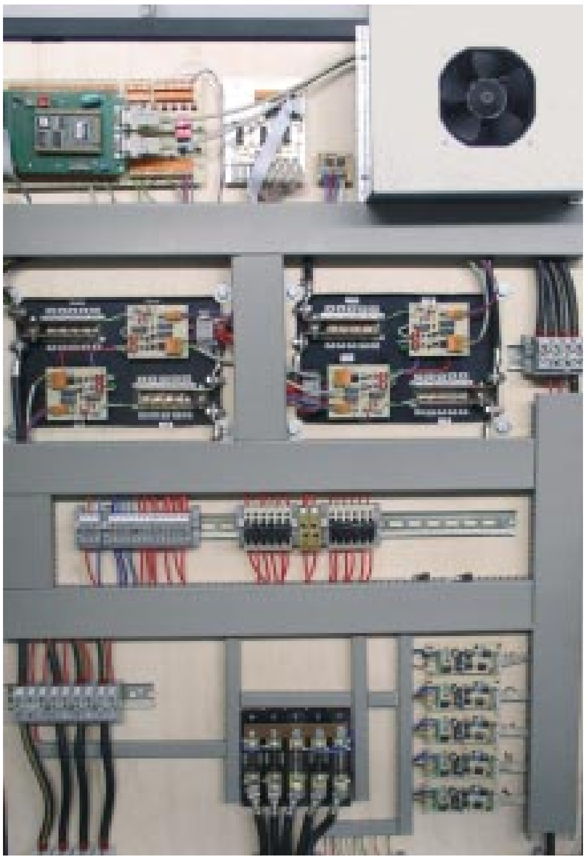

Fig 3: The battery management system has been set up here on a laboratory scale for four individual strings. The strings are switched via power semiconductor components (MOSFET), which can be controlled with negligible auxiliary power. An energy-efficient microcontroller, which is powered by the battery strings, is used for operation management of the BMS.

Stand-Alone Inverter allowing Parallel Connection for Low to Medium Power Systems

Photovoltaics is being used increasingly to supply electricity in regions remote from the grid. Whereas the "Solar Home System", as the simplest type of system, solely supplies DC power to the loads, an extension with an inverter also allows common, commercially available AC appliances to be used. At Fraunhofer ISE, we developed a robust and compact inverter, which can be connected in parallel to several inverters of the same type, and thus allows small and medium-sized domestic circuits to be constructed that can be extended simply and flexibly.

Daniel Aschoff, **Christoph Siedle**

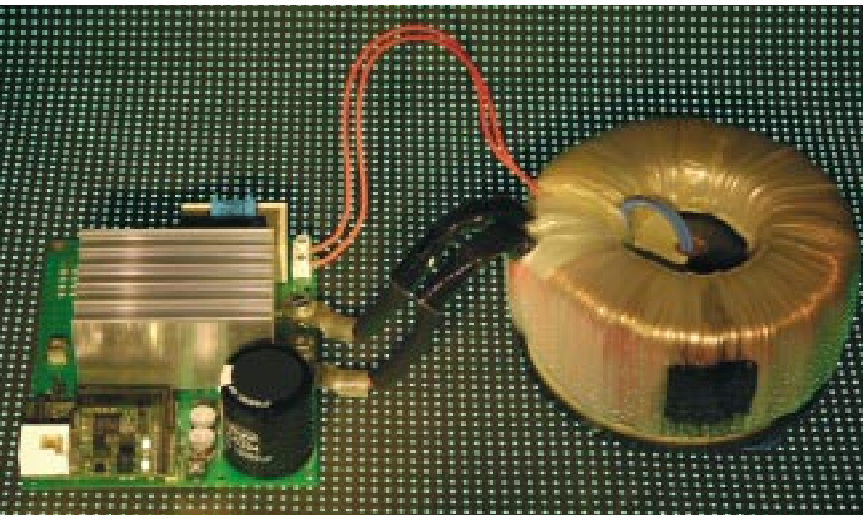

Fig. 1: The inverter consists of a MOSFET power stage, a 50 Hz transformer and a digital control unit with a signal processor, which also regulates the communications for synchronisation with other devices.

Stand-alone inverters supply electricity to their own circuit, which should differ as little as possible from the public grid with regard to supply reliability and robustness to disturbance. This results in a catalogue of specifications for the power stage, the controls and the parasitic consumption of the device. In addition, the inverters are usually transported in adverse circumstances and are often operated in extreme climatic conditions, so that mechanical robustness is imperative. Furthermore, they are generally installed and operated by people without technical training, so they must have the greatest possible tolerance to electric conncection errors. The fact that they are primarily used in developing countries also calls for an inexpensive solution.

Together with an industrial partner, we are developing a 500 W inverter with a 50 Hz transformer, which is supplied by the 12 V battery of a small solar system. The device operates a 230 V grid at optionally 50 Hz or 60 Hz. By rewiring the transformer coil, a 115 V grid can also be set up. A 1000 W model is also being implemented.

As stand-alone inverters, in contrast to grid-connected inverters, have to guarantee a 24-hour supply, we paid particular attention in the design phase to a low parasitic consumption. In addition, the inverter itself can recognise whether a load is connected and switch itself on and off accordingly.

Larger systems can be set up by parallel connection of up to four inverters. Depending on the load situation, individual inverters are automatically connected and disconnected to maintain a favourable total efficiency value. We have implemented the communications and complex operation management needed for this in a digital signal processor.

In a stand-alone system, high demands are made on the dynamic range of the inverter controls. Sudden load increases from open circuit to double the rated power within milliseconds, as are typical when electric machines or freezer compressors start up, are managed reliably by the controls, which are also implemented in the digital signal processor.

In designing the controls, we have also taken step-function or asymmetric loads on the two sinusoidal half-waves into account. These include the phase intersection controls that are commonly used in lamp dimmers and drills or the power control of electric appliances using half-wave operation. The asymmetric load leads to saturation of the transformer core and overloading of the inverter transistors. A specially developed anti-saturation controller combined with rapid current controls prevents the dangerous operating states for an inverter, saturation and overload, from occurring.

The power stage, which has been constructed to survive incorrect reverse-polarity connection, can withstand short-term threefold overloading, ensuring that e.g. refrigerator compressors can start reliably. To prevent overheating of the power stage, the temperature is monitored and a ventilator is switched on if necessary.

At the end of 2005, we took the prototype into operation, which had been further refined by our industrial partner for series production and to ensure electromagnetic compatibility. The inverter should enter the market in the middle of 2006.

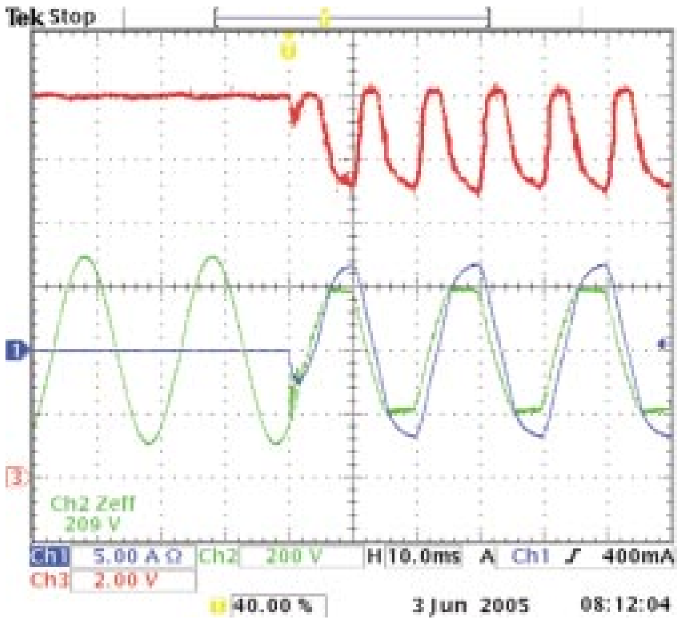

Fig. 2: The inverter can supply the current (purple) needed to start a refrigerator, even though the input voltage (red) periodically collapses due to internal resistance in the cables and battery. The output voltage (green) is lowered for several grid periods.

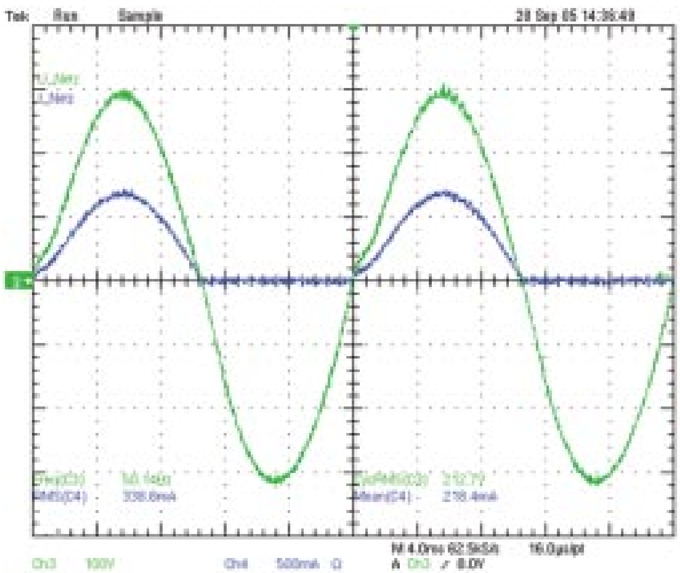

Fig. 3: An anti-saturation controller allows the operation of half-wave loads, despite the use of a 50 Hz transformer. The load current (purple) flows only during the positive half-wave. The transformer core reaches its operating limits around the positive voltage zero crossing, the control reaction distorts the voltage curve (green) only slightly.

Seawater Desalination with Process Heat from Thermal Solar Collectors

Together with the solar industry, Fraunhofer ISE is gaining access to new applications and market sectors for solar collectors such as seawater desalination, for example. Compact desalination systems are being developed, which can be operated off-grid with solar process heat and photovoltaically generated electricity.

Sebastian Basel, Michael Ebermeyer, Joachim Koschikowski*, Heiko Rebmann, **Matthias Rommel**, Sarah Schiel, Marcel Wieghaus*

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Fig. 1: The compact desalination systems developed at Fraunhofer ISE are operated solely by solar energy. As shown here in the Moroccan village of Kelaa, solar collectors with an area of 5.79 m^2 supply the thermal energy for membrane distillation and photovoltaic modules with a power of 106 W_p (upper module) and 70 W_p (lower module) supply the electricity to operate the pumps. The systems are thus completely independent of external sources of energy and can thus be operated in locations without a connection to the grid.

Conventional desalination processes must generally be operated for 24 hours a day with constant operating parameters. By contrast, the membrane distillation process developed at Fraunhofer ISE is also suitable for intermittent operation.

It requires only a few system components and can be applied in particularly simple and compact desalination systems without external power sources.

In 2005, four compact systems were set up for the first time in Gran Canaria, Egypt, Jordan and Morocco on the test fields of our project partners. Using the process heat from a collector area of 6 m^2, these compact systems produce about 80 to 100 litres of desalinated water per day with a specific energy demand of about 100 kWh_{th} per m^3 - about a seventh of the energy of evaporation.

At the beginning of 2006, we will construct two further systems which are about ten times larger, with a daily capacity of about 1000 litres and a collector field area of 80 m^2. New process heat collectors will be used, which have a double-glazed cover with anti-reflectively coated glass and can generate process heat up to 120 °C. To support the development of process heat collectors, we are currently extending the collector test facility at Fraunhofer ISE to allow measurement of the collector efficiency characteristics up to 200 °C. Our goal is to co-operate with the industry in opening up new application areas for solar process heat of up to 200 °C.

The project is funded by the European Union.

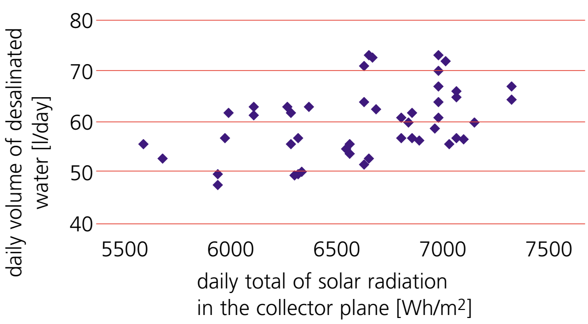

Fig. 2: The graph shows measured values for an identically constructed system to that pictured in fig. 1. The measured system was installed at the University of Alexandria, Egypt, not in the field as in Kelaa, Morocco. The measurement results from August to October 2005 show that as the solar radiation on the collector surface increases, the total amount of desalinated water increases approximately linearly on average. Operating experience has not yet been made for days with low radiation values. Each day, about 50 to 75 litres of desalinated water are produced under the operating conditions in Alexandria.

Ultrasonic Cleaning of Membranes in Decentralised Water Purification Systems

Around the world, more and more people in rural areas are relying on a decentralised supply of drinking water. For this application, Fraunhofer ISE is developing new water purification processes which can be operated independently with solar energy. Chemical cleaning agents are not required. Ultrasonic cleaning of the filter membrane presents a practicable and economic alternative.

Ulrike Seibert, Gisela Vogt, Joachim Went, Felix Holz

In rural areas which are not connected to a central water supply, there is often also a lack of mains electricity and the infrastructure for supplying and disposing of chemicals. We are developing solar-operated processes for water purification under such boundary conditions. We do not use any chemicals for the processes. The focus is on application in small, decentralised systems. Further development goals are a low maintenance demand, a long lifetime and a low energy consumption. The systems should be suitable for the filtration of surface water or hygienically contaminated well or spring water, and should be able to purify untreated water of fluctuating quality reliably.

In the ISUS project (In situ ultrasonic cleaning for small membrane systems in drinking water purification), we are investigating the application of ultrasonic cleaning for the membranes in water purification systems. In experiments, we determined the most effective method of ultrasonic excitation. Direct excitation with high frequencies had two advantages for membranes which were free to vibrate: High cleaning power for a low energy demand. Thus, with a frequency of 40 kHz and an amplitude of 1 µm, we achieved the shear rates of $90 \times 10^3\ s^{-1}$ required for cleaning. With this method, the rate is a factor of three higher than for other known procedures. We were able to transfer the results gained in laboratory experiments with membrane areas of 170 cm^2 to commercially available membrane modules with a membrane area of 0.5 m^2. We were able to demonstrate the cleaning effect also on capillary membranes in a commercially available ultrafiltration module.

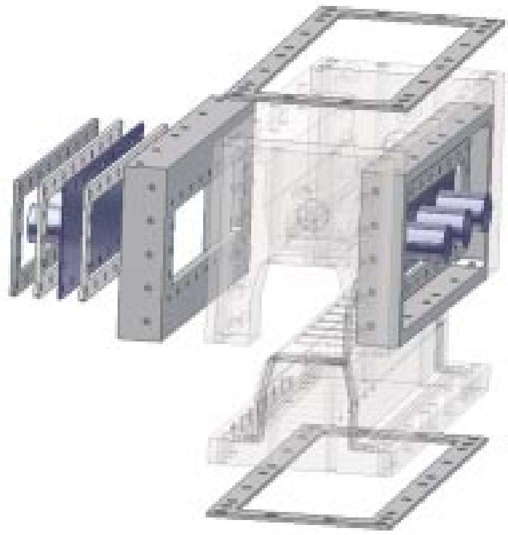

Fig. 1: We use a special transparent test cell to systematically investigate the effect of the ultrasonic intensity, frequency and excitation type on the cleaning mechanisms to remove undesired fouling from the membranes.

Fig. 2: A dyeing procedure is used to analyse the effect of different cleaning procedures optically. Here, the ultrasonic cleaning process with a frequency of 1 MHz is illustrated for a ceramic membrane plate with three images which were taken at intervals of 60 s. The dyed cover layers are loosened and swept away by the acoustic current, an ultrasonically excited motion of the fluid.

The project is funded within the InnoNet Programme by the German Federal Ministry for Economics and Technology BMWi and the companies, Dr. Hielscher GmbH, ITN-Nanovation GmbH and Grünbeck Wasseraufbereitung GmbH.

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 plants can make an important contribution to renewable generation of electricity. In this field, we are conducting research to improve optical components such as the absorber coatings in parabolic trough power plants, to achieve higher steam temperatures. We also prepare new concepts to control the reflectors for Fresnel reflector systems, and carry out simulations to dimension complete systems.

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 up to 25 % are achieved. In March 2005, Concentrix Solar GmbH, the most recent spin-off company from Fraunhofer ISE, was founded with the aim of marketing the FLATCON® technology (see also p. 110: new spin-off companies).

The liberalisation of the electricity markets and the entry of climate-protecting energy technology to the market means that the proportion of electricity generated by 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 micro-controllers 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

Performance measurement of a photovoltaic system by experts from Fraunhofer ISE. Comparisons have revealed that the actual performance of a product often deviates from the specifications by more than the stated tolerance. In co-operation with eight manufacturers and three testing laboratories, Fraunhofer ISE is now developing a procedure to improve the accuracy and reproducibility of performance measurements of monocrystalline and multi-crystalline silicon solar modules (see article on p. 74).

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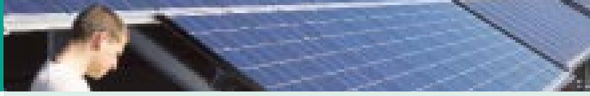


Optimisation of the Power Measurement of Silicon Photovoltaic Modules

Comparisons of the module power measurements by manufacturers with those by independent measurement laboratories show deviations that are greater than the specified tolerances for measurements made under standard test conditions according to all relevant standards. Together with eight manufacturers and three testing laboratories, we are now developing procedures to improve the accuracy and reproducibility of power measurements for monocrystalline and multicrystalline silicon photovoltaic modules.

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

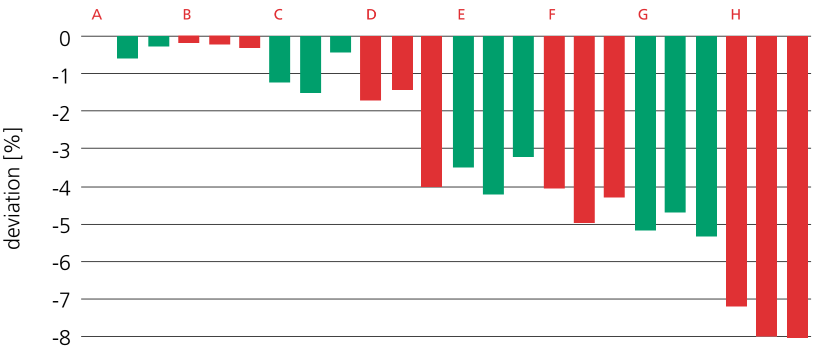


Fig. 1: Three modules of one type from each of eight manufacturers (A to H) were measured at Fraunhofer ISE. A comparison of the measured power values from the manufacturers (0% line) with the values measured by Fraunhofer ISE (red and green columns) showed deviations of up to 8 %. As the measurement uncertainty at Fraunhofer ISE is ± 2 %, the measurement uncertainty in the industry must be at least ± 4.5 % according to this initial analysis.

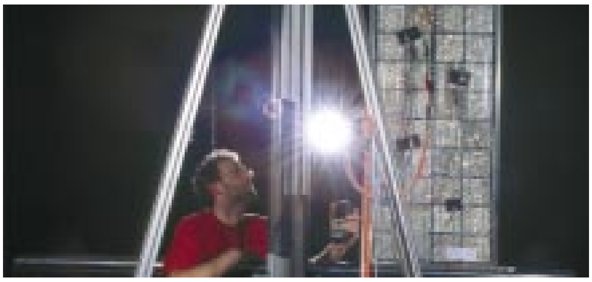


Fig. 2: Significant progress in the module calibration at Fraunhofer ISE was made by renewing the hardware and software of the measurement technology. Now that the homogeneity of the illumination has been improved significantly, the calibrated reference cells from the Physikalisch-Technische Bundesanstalt can be used directly for the module measurements. For standard measurements without correction for the spectral response, a measurement uncertainty of less than ± 4 % is expected and for precision measurements, this is reduced to about ± 2.5 %.

Most manufacturers guarantee a tolerance of ± 5 % for the power specifications of their module, some claim ± 3 %. However, if one module is measured by different manufacturers and testing laboratories, deviations are found which exceed the specified tolerances. Differences in the values are found for comparisons between measurements by different manufacturers, between manufacturers and testing laboratories, and among different testing laboratories. Thus, the power specifications for photovoltaic modules are not always comparable. This results in uncertainty, particularly among the project planners of larger PV power plants.

In a project with eight module manufacturers and two measurement laboratories, we are thus developing procedures to significantly improve the reproducibility and accuracy of power measurements on monocrystalline and multicrystalline silicon photovoltaic modules by the module manufacturers, and to increase their comparability with laboratory measurements by the testing institutes. The aim is to limit the tolerance in power measurements by the industry to ± 3 %. To this purpose, we are analysing the measurement sequence and developing a transparent description of the procedure to improve and standardise the module measurements.

The initial project results show deviations, some of them very large, between power measurements by the industry and the measurement laboratories. The reasons include inhomogeneous irradiation of the module area and differences in the spectral distribution among the manufacturers. There is also potential for improvement in the procedures for regular calibration of the reference modules used.

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

Operation Management of Low-Voltage Grids with Distributed Power Generation

Within the EU-funded DISPOWER project, Fraunhofer ISE developed the energy management system "PoMS" (Power Flow and Power Quality Management System) for low-voltage grids, with which the operation of distributed generators can be optimised technically and economically. We carried out the first field test of the system in the pilot ecological estate, "Am Steinweg" in Stutensee. We were able to prove that considerable savings in the operating costs were achieved by use of the energy management system.

Rainer Becker, **Thomas Erge**, Elena Franzen, Anselm Kröger-Vodde*, Hermann Laukamp, Hans-Georg Puls, Malte Thoma, Rico Werner, Christof Wittwer

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Fig. 1: The utility, MVV Energy AG, installed a CHP plant (at the back right of the photo) with peak-load boilers and a thermal buffer storage tank to supply heat and electricity to the ecological solar estate, "Am Steinweg" in Stutensee, near Karlsruhe. The system was extended with a photovoltaic system and a battery bank. Fraunhofer ISE optimised the system management with the PoMS energy management system.
Photo copyright: MVV Energie AG

Grids with a large proportion of distributed electricity generators place higher demands on grid planning and operation than conventional grids, particularly when fluctuating inputs from wind energy and photovoltaic systems predominate. Nevertheless, distributed generation also offers opportunities for optimisation according to primary energy or microeconomic criteria. Within the DISPOWER research project, we are developing the PoMS energy management system, with which a large number of distributed generators, storage units and loads in low-voltage grids can be controlled. The controls are based on optimised usage schedules, which are prepared on the basis of load and generation predictions. The first field test with PoMS was carried out in a solar estate in Stutensee near Karlsruhe, where the electricity is supplied by the utility, MVV Energie AG. In addition to the medium-voltage grid, the electricity for the estate is supplied by a 30 kW combined heat and power (CHP) plant, a 28 kW_p photovoltaic system and a battery bank with a capacity of 100 kWh. The grid operation was optimised according to the following alternative criteria:

- limitation of the peak load electricity from the medium-voltage grid
- balancing of the instantaneous consumption and generation ("virtual stand-alone operation")
- operation within specified voltage ranges in defined grid segments

We proved that costs of about €4000 per year for an estate with about 100 households could be saved by the energy management system. The costs for electricity and heating generation for the estate were also reduced by improved operation of the CHP plant and use of a thermal storage unit.

The work is funded by the European Union as part of the DISPOWER project.

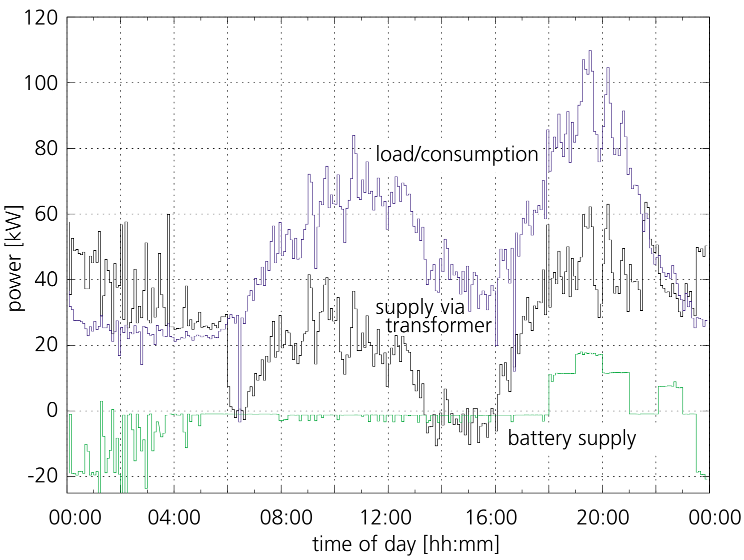
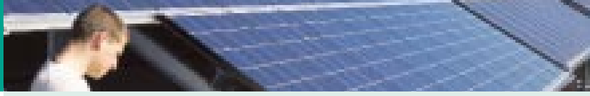


Fig. 2: The graph shows the electric load profile for the estate (purple line) and power drawn at the medium-voltage transformer (black line). Electricity fed into the grid from the photovoltaic systems and the CHP plant, which is not shown in this graph, reduces the amount of electricity drawn from the medium-voltage grid during the day. The battery storage unit (green line) is charged during the night (negative values) and discharged during the evening (positive values).



Load and Grid Management with Economic Incentive Structures

Increasing numbers of photovoltaic, wind energy and combined heat and power (CHP) plants feed their fluctuating power uncontrolled into low-voltage grids. This tends to make grid management more complicated. Together with energy utilities, we are developing new approaches with economic incentives and tariff models which will allow the supply and demand in low-voltage grids to be controlled and compensated better.

Georg Bopp, Sebastian Gölz,
Harald Schäffler

In summer 2005, Fraunhofer ISE and the utility, MVV Energie AG, carried out the project entitled "Washing with the Sun" in the "Am Steinweg" solar estate in Stutensee near Karlsruhe. The aim was to determine which type of communication and which incentives for the residents would enable the best load profile to be implemented for the available solar electricity. In the estate, the demand of 100 households is supplied partly by several distributed generators (CHP plant with 30 kW, a PV system with 28 kW_p, several small PV systems and a 100 kWh battery bank). The long-term goal is to achieve a balance between local generation and consumption and to make best use of the locally generated electricity. To this purpose, the participants received a message via e-mail, SMS or a pager each morning in July if generation of a large amount of electricity by the photovoltaic systems were expected on that day. At the same time, the participants were informed about the time when they could use the solar electricity optimally by switching on washing machines or dishwashers. Every participant who used this option was credited with a financial bonus, which was paid out at the end of the experiment.

Fig. 1: In a pilot experiment in Stutensee, the participants were informed when they could best "wash with the sun" by SMS, pager and e-mail.

Our analysis showed that a very large number of users followed the daily recommendations. The effects on the overall supply will be investigated and extrapolated on the basis of the recorded consumption values and the accompanying questionnaires. Based on these results, innovative incentive systems can then be developed and tested. In addition to targeted load control (e.g. of washing machines), it is conceivable that the tariff structure be adapted to the demands in decentralised grids.

Thus, we are also developing concepts for flexible electricity tariffs with partner institutes in the "Fraunhofer Energy Alliance". The electricity rates can varied in diverse ways: e.g. in dynamically adapted hourly rates, as a result of daily or weekly predictions, or on a seasonal basis - both for consumers and electricity suppliers. The resulting shifts in loads and generation could then limit grid load peaks, make optimal use of fluctuating, distributed generation or minimise the supply of power from the standard grid, for example. Progress in the metering technology for household customers means that wide-ranging possibilities for recording the load profile or remote reading of the meter are now available, which could not be included in the corresponding pilot tests in the 1990's. In comparison to conventional approaches to demand-side management (DSM), in which distributed systems are controlled directly, flexible electricity tariffs only offer incentives for customers to act in a certain way. The customer decides independently on the extent to which he/she chooses to profit from the offer. However, the disadvantage of indirect load control is compensated in two ways. Firstly, with flexible electricity rates, customers can be involved in DSM whose systems or electricity consumption alone would be too small for direct control. Secondly, if the number of participants is large, a statistically averaged and thus predictable reaction behaviour will result.

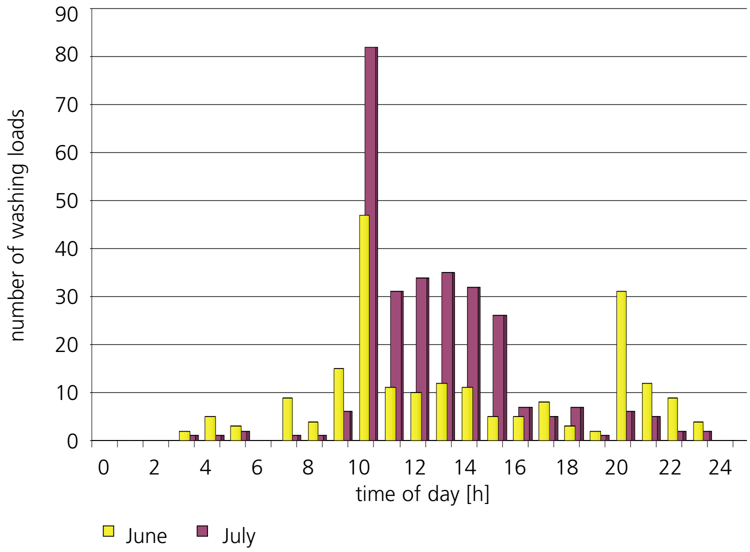


Fig. 2: On sunny days in July, the participants were recommended to switch on washing machines or dishwashers between 10 a.m. and 4 p.m.. Comparison of the washing times with the values from June (without a corresponding recommendation) shows that a large proportion of the participants responded to this recommendation and changed their washing times.

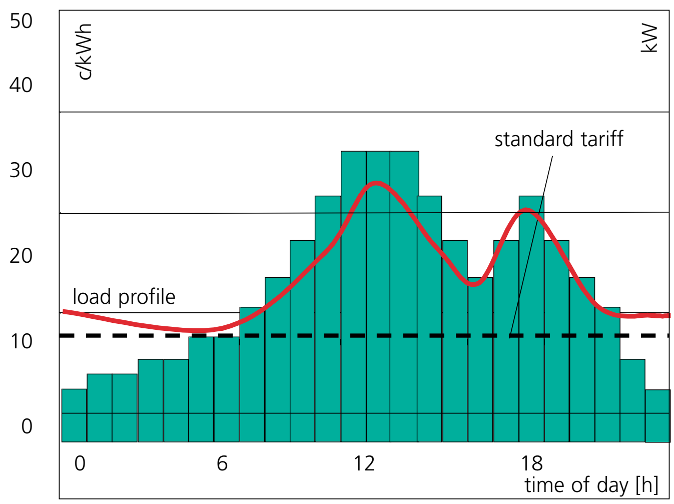
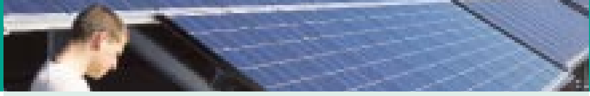


Fig. 3: Flexible electricity tariffs can be designed very differently according to the regional supply structure and the optimisation aims of an energy utility. The graph shows one possibility, in which the rate is adapted hourly to the load profile.



Operation Management Concepts for Electricity-Led Combined Heat and Power Plants

Fraunhofer ISE developed an operation management concept for the combined heat and power (CHP) plant of the "Am Steinweg" solar estate in Stutensee near Karlsruhe. The concept optimises electricity-led operation of the CHP plant with the help of a thermal storage unit, guarantees that thermal energy is supplied as needed, and simultaneously improves the economic viability of the CHP plant.

Christof Wittwer, Rainer Becker, **Thomas Erge**

The district heating system of the "Am Steinweg" solar estate in Stutensee is operated by the utility, MVV Energie AG, and includes a CHP plant, two boilers and a thermal storage tank. The storage tank means that the generation of thermal and electric energy can be decoupled to a large extent. Operation of the CHP plant can be electricity-led, independent of the prevailing heat demand, and can contribute to meeting the peak electricity load of the estate. At the same time, storage of heat generated in excess of the actual demand means that the CHP plant needs to be switched on less frequently, reducing the maintenance demand and energy losses.

Fraunhofer developed a customised operation management system for the CHP plant. We applied dynamic simulation models to evaluate different operation management strategies for the CHP plant, boiler and tank. The results then formed the basis for developing and optimising the control algorithms. The optimisation for the CHP plant of the Stutensee estate resulted in its operating time being increased by app. 20 %.

After optimisation, the algorithms were transferred directly to the control hardware of the CHP plant. The components each received their own interfaces, which are connected in a network and carry out decentralised communications and control functions with the help of embedded systems. In this way, the operator can access all system data at any time via the Internet and can also carry out remote maintenance.

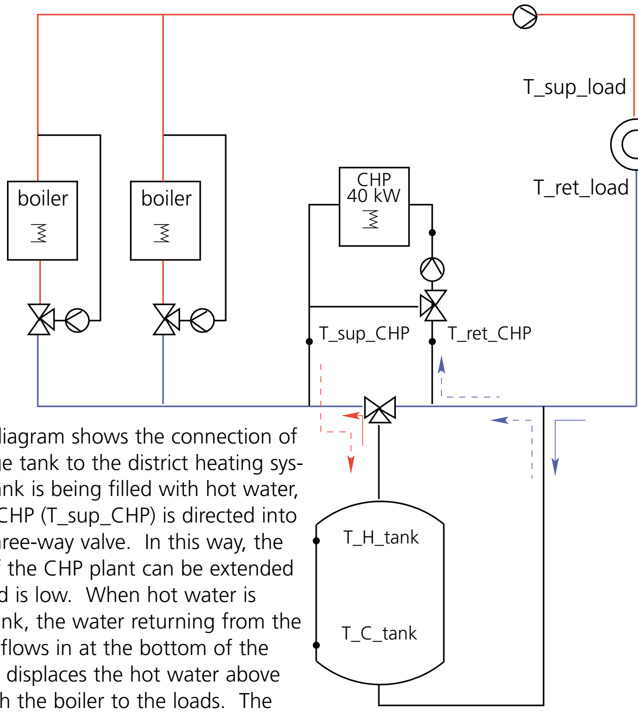


Fig. 1: The block diagram shows the connection of the thermal storage tank to the district heating system. When the tank is being filled with hot water, the supply to the CHP (T_sup_CHP) is directed into the tank via the three-way valve. In this way, the operating times of the CHP plant can be extended if the heat demand is low. When hot water is drawn from the tank, the water returning from the loads (T_ret_load) flows in at the bottom of the stratified tank and displaces the hot water above (T_H_tank) through the boiler to the loads. The boilers are used for additional heating if needed.

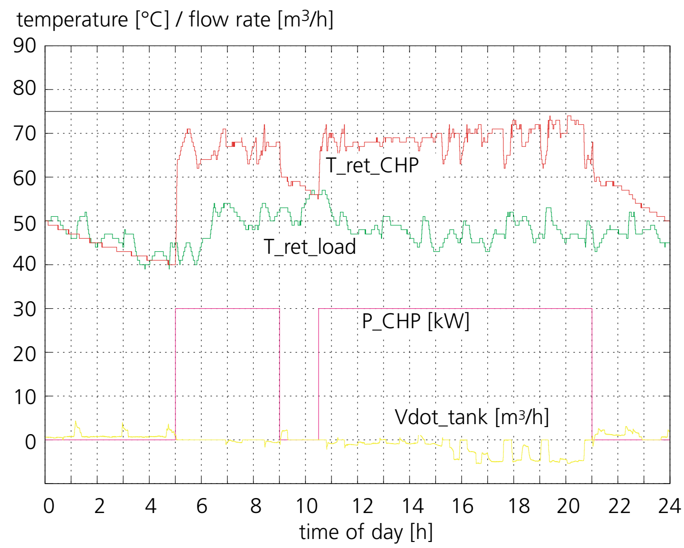


Fig. 2: The graph shows the daily profile for the charging and discharging of the storage tank. The tank is discharged from 9 p.m. until 5 a.m. (yellow line, positive flow rate), and during the day is predominantly charged while the CHP plant is operating (negative flow rate, green line). The operation management guarantees that the return temperature of the CHP plant (red line) does not increase above 75 °C, to make best possible use of the CHP plant heating power.

Novel Simulation Environment for Designing Distributed Generation Structures

Together with five other Fraunhofer Institutes, we are developing "MOSILAB", a generic simulation tool to describe and simulate heterogeneous technical systems with strong structural dynamics. The simulator is being tested and evaluated with applications from distributed energy generation, hygrothermal building simulation, and machining systems for milling and turning.

Matthias Vetter, Christof Wittwer, Simon Schwunk

When complex energy supply systems with many different components and energy flows (electricity, gas, cooling, heating) are to be simulated, a choice must be made between complex models, which can describe the behaviour of each component in detail but require long preparation and calculation times, and simple models, which are less accurate but more practicable. The MOSILAB (Modelling and Simulation Laboratory) simulation tool allows heterogeneous systems to be modelled and analysed both efficiently and accurately. To this end, the equations and model structure are modified dynamically during the simulation. For example, a fuel cell in the stationary state can be described by simple characteristic curves. However, a detailed model is used to describe the dynamic behaviour of the start-up process.

For the model description, the project partners are developing the object and equation-oriented language, MOSILA (Modelling and Simulation Language), which draws on the widespread MODELICA® language standard, and can support all of the MODELICA® language elements. Like other generic simulators, MOSILAB can be tailored to specific applications (generation of specific simulators). However, it differs in its description of the state-dependent modification of the model structure (model structure dynamics). Interfaces allow the integration of external C/C++ models and linking to foreign simulators, such as MATLAB/SIMULINK® and FEMLAB®.

Fig. 1: The MOSILAB simulation tool is being developed by Fraunhofer ISE together with five other Fraunhofer Institutes, FIRST, IIS/EAS, IBP, IWU and IPK. As well as participating in the simulator design, Fraunhofer ISE is developing model libraries for grid-connected fuel-cell systems in distributed energy supply systems.

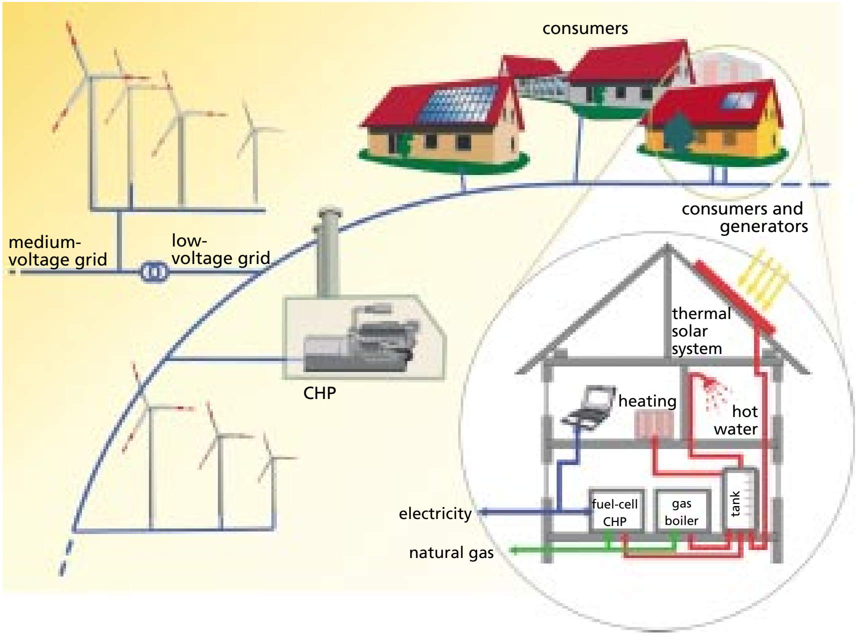


Fig. 2: In the simulation of heterogeneous energy systems, some components must be described in great detail, depending on their state (e.g. fuel cells), whereas simple models are adequate for other components. The MOSILAB simulation tool can vary the modelling depth during a simulation according to the existing boundary conditions (stationary state, start-up).

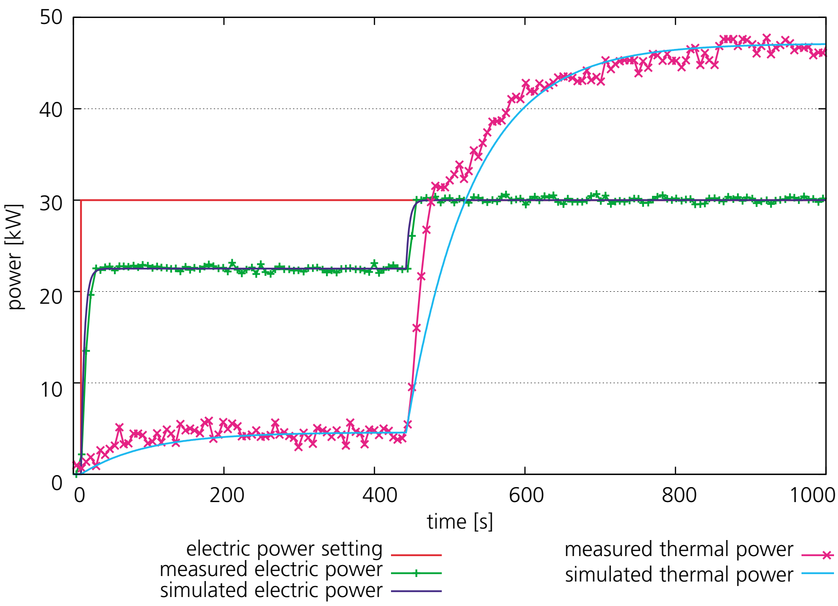
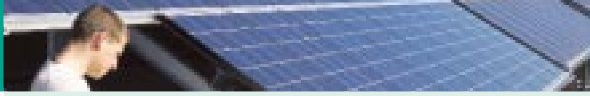


Fig. 3: Simulated and measured start-up behaviour of the motor CHP plant with an electric power of 30 kW and a rated thermal power of 50 kW. The measured and simulated profiles agree to a first approximation for the electric and thermal power.



Concentrix Solar GmbH - Most Recent Spin-Off Company from Fraunhofer ISE

Concentrix Solar GmbH is the most recent spin-off company from Fraunhofer ISE. Its business goal is to produce and market modules and systems based on the FLATCON® concentrator photovoltaic technology developed at the Institute. The target market is large photovoltaic power plants in sunny countries, a market segment which has begun to grow recently in Spain and Italy.

Andreas Bett, Frank Dimroth,
Hansjörg Lerchenmüller

Fig. 1: Photovoltaic concentrator system with 50 FLATCON® modules on a tracker. The optimised controls guarantee tracking accuracy of 0.1 °. The system feeds the generated electricity into the grid. The system shown here is located on the roof of Fraunhofer ISE.

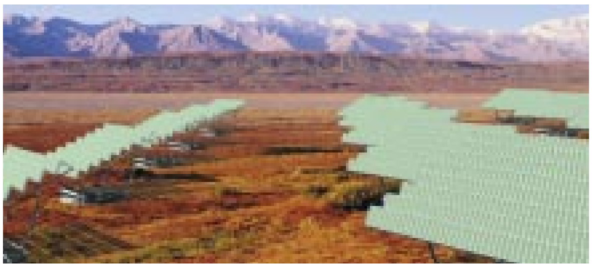


Fig. 2: Visualisation of a photovoltaic power plant consisting of many tracking units, each of which is equipped with several hundred modules.

Concentrator photovoltaic systems concentrate sunlight onto tiny solar cells with the help of lenses or other optical components. Technical approaches to save solar cell material by working with concentrated solar radiation have existed for many years. Fraunhofer ISE has many years of experience in developing and characterising concentrator photovoltaic cells and modules. Now concentrator technology is approaching a decisive breakthrough, because the efficiency value of high-efficiency solar cells based on III-V semiconductors has been increased significantly. The concentrator solar cells that were developed at Fraunhofer ISE and are used in the FLATCON® modules now achieve efficiency values exceeding 35 %. On the medium term, module efficiency values of up to 30 % can be reached with these cells (see also article on p. 52). In February 2005, Concentrix Solar GmbH was created as a spin-off from Fraunhofer ISE with the aim of leading the FLATCON® concentrator technology to industrial mass production.

Concentrix aims primarily to serve the market for larger power plant units from 100 kW to several MW in sunny regions. The high proportion of direct solar radiation in these regions means that concentrator power plants can be expected to show a clear cost advantage over conventional silicon technology there.

At present, a pilot production line is being planned, which is intended to supply modules for demonstration projects. The first commercial systems can be expected at the end of 2006.

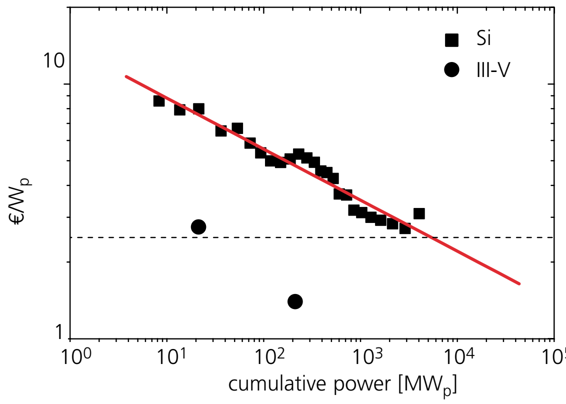


Fig. 3: To illustrate the cost reduction potential of concentrator photovoltaics, two values for concentrator photovoltaics have been plotted in the price-performance curve based on experience with conventional silicon PV modules. The two points are based on a production cost analysis for FLATCON® modules and trackers for a production capacity of 20 MW and 200 MW (assumption: a factor of 1.5 between cost and price). The dashed line indicates the 2.5 €/W_p level.

Solar Thermal Power Stations – Strategy Consultancy to the World Bank

The Global Environment Facility (GEF) and the World Bank are jointly supporting the market introduction of solar thermal power plants. Fraunhofer ISE co-operated with partner institutes from the Global Research Alliance (GRA) in a consultancy project to prepare strategic recommendations to the GEF / World Bank concerning their involvement in the market for solar thermal power plants.

Gabriel Morin, Hansjörg Lerchenmüller

In the period from 1996 to 1999, the Global Environment Facility (GEF) decided to support four solar thermal power station projects in Egypt, India, Morocco and Mexico with 50 million US dollars each and commissioned the World Bank to accompany the project development. The aim was to fund hybrid power plants with a solar electric power of app. 30 MW each. These are intended to input solar-generated heat from parabolic trough or solar tower collectors into a combined cycle power station which is also fuelled with natural gas. The additional costs due to the solar component of the electricity generation are to be covered by the funding. On commission to the World Bank, a study was carried out by a consortium from the Global Research Alliance, consisting of the Fraunhofer Institute for Systems and Innovation Research ISI, Fraunhofer ISE, the Commonwealth Scientific and Industrial Research Organisation CSIRO (Australia) and the Council for Scientific and Industrial Research CSIR (South Africa).

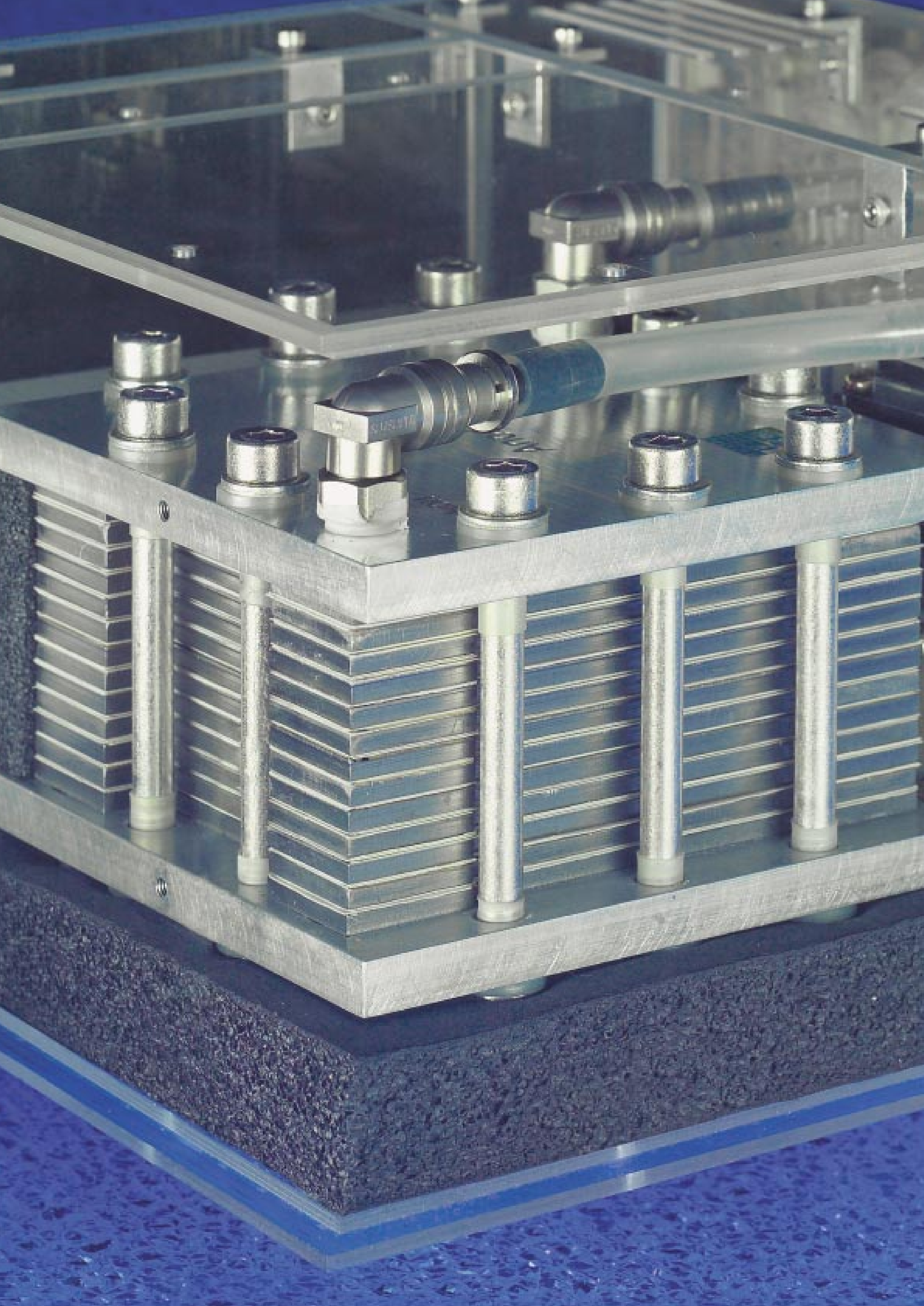
Fraunhofer ISE's role in the study was to present the technology and analyse the costs of solar thermal power plants. We were able to draw on experience with systems analysis of solar thermal power plants, which we had gained in the past in modelling power stations based on linear Fresnel collectors. Furthermore, Fraunhofer ISE was responsible for analysing and preparing recommendations for the project in Mexico.

The study examines different strategic scenarios for the GEF / World Bank concerning ways of supporting the market introduction of solar thermal power plants. It recommends to the GEF / World Bank that at least one part of the power station portfolio should be implemented rapidly, along with the other current global activities on market introduction of solar thermal power plants.

The study identifies three reasons for this recommendation: a low technical risk is combined with a large economic potential; the young sector could be considerably destabilised if the four projected power plants were not to be realised; developing and threshold countries, the target regions for the World Bank, are predominantly in sunny regions and are thus ideal locations for solar thermal power plants on the long term.

Since completion of the study, calls for tenders to build a power plants and for formation of industrial consortia for pre-qualification (a preparatory step before the call for tenders) have been issued for the projects in Morocco and Egypt respectively, which had been developed furthest in the initial stages.

Fig. 1: Solar thermal power plant based on parabolic trough collectors in California. Parabolic trough power plants with a total electric power of 354 MW have been installed there and have proven their commercial maturity with more than 15 years of continuous operation. (Source: US Department of Energy).



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. In the ideal case, regenerative energy is used in the form of renewably generated electricity for electrolysis. A second approach is by reforming 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.

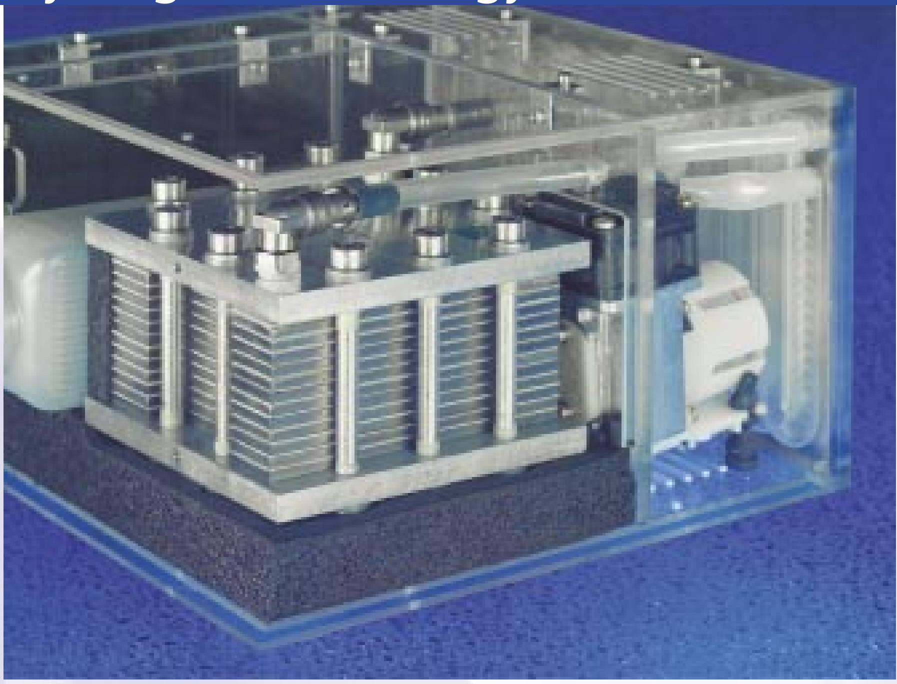
Innovative technology to obtain hydrogen and convert it efficiently to electricity and heat forms the core of our research for the hydrogen market sector. Together with our partners from science and industry, we develop components and complete fuel-cell systems, mainly for off-grid, portable and mobile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



Direct methanol fuel cell (DMFC) system for the power range up to 35 W_{el}. The tanks are filled with pure methanol; reaction water is used to dilute the methanol to the concentration needed for operation of the fuel cell. As a supplement to batteries in the low power range, methanol fuel cells present an excellent way to lengthen the operating time of off-grid and portable electric appliances appreciably (see article on p. 86).

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Power Supply based on Planar, Series-Connected Fuel Cells

Miniature planar fuel cells can be integrated simply into the casing of devices using the cells as power supply units. In addition, diffusion alone can be used to supply the fuel cell with oxygen from the air. We are currently extending our fuel cell development from hydrogen to methanol as the fuel. The goal is to operate with methanol without active system components as far as possible. In 2005, we concentrated on the development of microfluid concepts and production technology.

Carsten Agert, **Ulf Groos**, Steffen Eccarius, Timbul Hapataran Manurung, Julia Melke, Andreas Wolff*

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The energy consumption of small electronic devices (PDA, mobile phone, etc.) is increasing continuously. However, while microprocessors have become about 30 times faster during the last ten years, the energy density of batteries has only doubled. In this context, the miniature fuel cell is seen as a possible substitute or supplement to commercial accumulators and batteries. In particular, the direct methanol fuel is seen as a promising candidate, as liquid methanol as a fuel is relatively simple to handle and features a much higher energy density than batteries or accumulators.

For the corresponding applications, we are developing planar single cells which can be series-connected in one plane and operated in the self-breathing mode on the cathode side. In comparison to the classic stack configuration, this makes system integration simpler (e.g. in the device casing, see fig. 1). If large-area membrane-electrode assemblies (MEA) are to be used in low-cost mass production, defined regions of the electrodes must be electrically insulated from each other. We have developed the concept of laser ablation for this purpose, which allows the MEA to be microstructured very simply and quickly.

Fig. 1: Miniature fuel cells have the potential to lengthen the operating times of electronic devices considerably due to the increased energy storage density. Integration into mobile phones is seen as one of the most promising goals for miniaturisation.

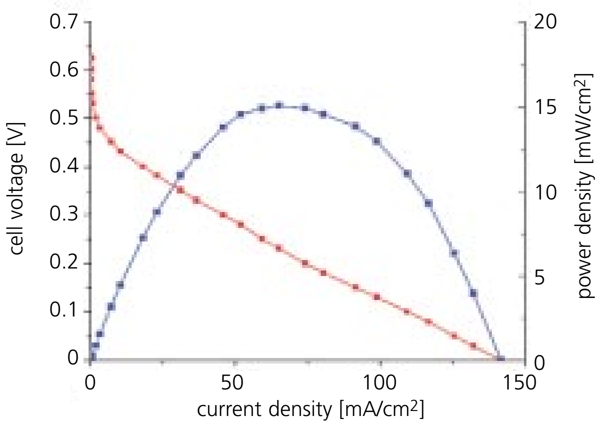


Fig. 2: Current-voltage characteristic curve of a planar fuel cell, which is operated in the self-breathing mode on the cathode side. In the case illustrated, the cell was operated with a 4M/l solution of methanol in water at a pumping rate of 1.5 ml/min (red = cell voltage).

One advantage of miniature planar fuel cells is the possibility to use gas distribution structures made of metal films, polymer materials or ceramics, with the potential of low production costs due to use of processes suitable for mass production. In addition, the fact that the materials are usually stiff and light favours use of the flat fuel cells as part of the casing for electronic devices. We have developed miniature fuel cells based on circuit board material, metal films, ceramics and polymers for this application, and determined their electrical characteristics (fig. 2).

One of the main challenges in operating a direct methanol fuel cell is that carbon dioxide bubbles form during the oxidation of methanol on the anode side. These bubbles can become lodged within the gas diffusion layer or the gas distribution structure and thus reduce the active cell area and the fuel cell power.

We have co-operated with the Institute for Microsystems Technology IMTEK of the University of Freiburg to simulate, construct and evaluate a microstructure which allows the gas bubbles to be removed purely passively (fig. 3). The geometrical configuration and the surface texture of the fluid-transporting microstructures causes the gas bubbles to move in one preferred direction due to capillary forces. As the bubble transport is purely passive, the system can be further simplified to allow completely passive operation.

The corresponding structures are finally replicated in various materials which are suitable for a mass production process. Electrically conductive, graphite composite materials, for example, can be produced by hot embossing or injection moulding, whereas thin metal films can be structured by etching or deep drawing (fig. 4). In order to guarantee a better contact and prevent corrosion, we passivate the surface with a thin gold film.

The work described above is part of the InnoNet project entitled "PlanarFC".

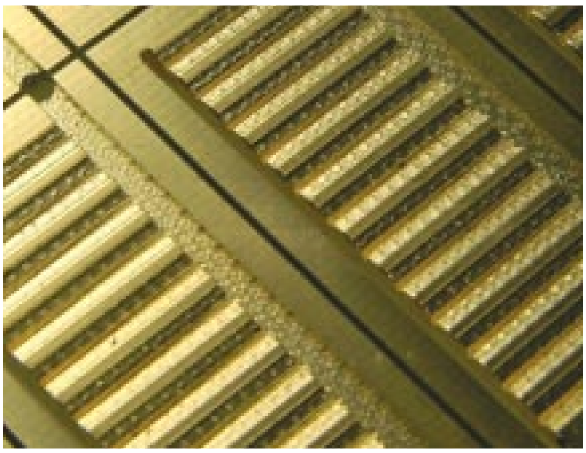


Fig. 3: Anode gas distribution structure of a miniature fuel cell operated with methanol. The microstructures for fluid transport cause the gas bubbles to move predominantly in one direction and thus prevent them from sticking.

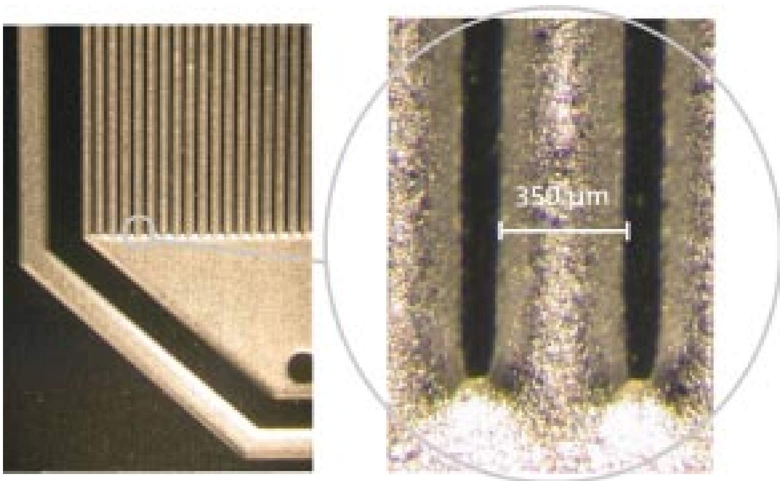


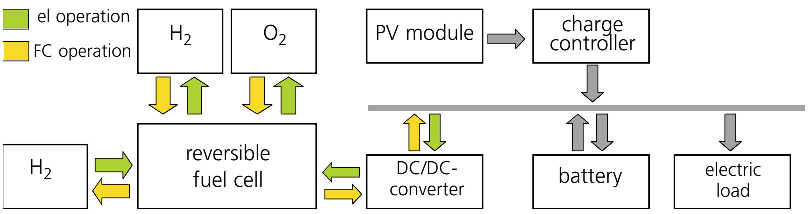
Fig. 4: Etched metal films with parallel channels, which are used as the anode gas distribution structure of a miniature fuel cell. The etching process allows extremely fine geometric structures to be produced, so that there is no need for a gas diffusion layer.

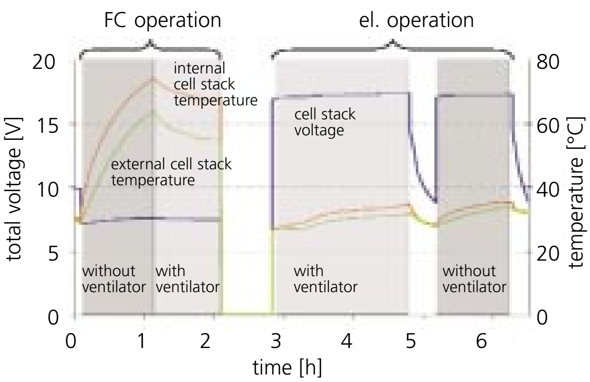
Reversible Fuel Cell Systems

We have developed a reversible fuel cell system for application in a stand-alone power supply and an uninterruptible power supply. Reversible fuel cells can be operated both as electrolysers and as fuel cells, and consequently offer a high potential to save volume, materials and thus also costs. We have developed and constructed two prototypes for a field test in Spain. The first system is to be used as a stand-alone power supply, the second system is to serve as an uninterruptible power supply.

Jan Hesselmann, Thomas Jungmann,
Werner Roth, Stephan Scherer,
Tom Smolinka, Ursula Wittstadt

Fig. 1: Part of a system for long-term energy storage applying a reversible fuel cell. The fuel cell prototype from our project partner, the Energy Research Centre of the Netherlands (ECN), can be seen in the foreground. Fraunhofer ISE developed the complete system consisting of the cell stack, gas purification and storage, controls and voltage conversion.





The principle of a stand-alone power supply based on a reversible fuel cell system is illustrated in fig. 1. In the electrolyser mode, water at a pressure of 9 bar is split into hydrogen (H_2) and oxygen (O_2), which is then temporarily stored in a metal hydride or in a pressure tank filled with zeolite. In the fuel-cell mode, the gases are fed back into the cell stack at 2 bar and react there to form water, generating electricity (and heat). During electrolyser operation, the battery serves as a buffer to even out fluctuations in the electricity generated by the PV generator. During fuel cell operation, the electric loads are supplied directly via the DC rail. Peak loads are met by the battery. If the system is used as an uninterruptible power supply, electricity is supplied not by the sun but by the electricity grid. In this case, the battery bridges the period needed until the system has started operation in the fuel cell mode.

The cell stack voltage and the battery voltage are adapted to each other with a newly developed, highly efficient, bidirectional DC/DC converter. As the electricity can be converted in both directions, one DC/DC converter is sufficient. By using a reversible fuel cell stack, it is possible to save material costs, mass and the space required in comparison to a system with two separate cell stacks. The prototypes are equipped with digital signal processors and operate fully automatically.

We are co-operating with six partners from Spain, the Netherlands, Germany and Sweden in this EU-funded project.

Fig. 2: Operating scheme of a stand-alone power supply with a reversible fuel cell. The arrows indicate the energy flows in the electrolyser (EL) and fuel-cell (FC) operation modes. The DC/DC converter operates bidirectionally.

Fig. 3: Thermal behaviour of the cell stack in the complete system. In the fuel-cell mode, the cell stack must be actively cooled by a ventilator. Active cooling is not necessary in the electrolyser mode.

Optimal Operation Management of Fuel Cell Systems

To optimise the safe and efficient operation management of fuel cells, we are investigating their dynamic performance with the help of mathematical models. For this reason, we are constructing a fuel cell system with model-based controls in a vacuum-cleaning robot. Our investigations are concentrating particularly on the dynamic performance of the complete system of a PEM fuel cell stack and peripheral components in the context of a fluctuating power demand, which depends on the task being carried out by the power consumer.

Jens Niemeyer*, Volker Krebs*, **Jürgen O. Schumacher**, Simon Philipps, Christoph Ziegler, Marco Zobel

* Universität Karlsruhe, Institut für Regelungs- und Steuerungssysteme

The fluctuating power demand of a load with time imposes special requirements on the controls of a fuel cell system. Our most recent work is thus concerned with investigating the dynamic performance of PEM fuel cell stacks in the low and medium power range. We are developing efficient mathematical models to describe and predict the time-dependent behaviour of the fuel cell stack and fuel cell systems. We identify the model parameters by time-dependent measurements in fuel cell test stands, and then validate the mathematical models by comparing simulations and experiments.

With the help of the models, we develop control strategies for safe and optimal operation management of the fuel cell stack. At present, we are constructing a fuel cell system with a model-based control procedure in a vacuum-cleaning robot. A navigation system in the robot maps the room to be cleaned, and thus allows the time-dependent load demand to be predicted and the operation management of the fuel cell system to be planned. In this way, we can investigate different system configurations; we apply simulation with a complete model of the fuel cell system to determine optimal matching of the components in the system.

This research project is supported by the State Foundation (Landesstiftung) of Baden-Württemberg.

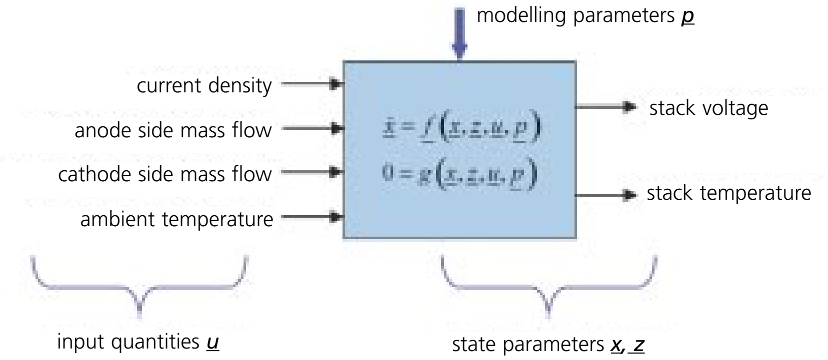


Fig. 1: We have formulated the model equations f as a differential algebraic system, i.e. consisting of a system of ordinary differential equations and additional algebraic equations g, which must also be satisfied. Differential quantities are designated here as x; z stands for quantities which can be determined with algebraic equations.

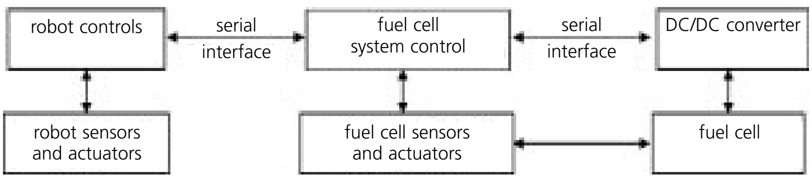


Fig. 2: A schematic diagram of the vacuum-cleaning robot components. The robot controls, the fuel cell system controls and the DC/DC converter communicate with each other via serial interfaces.

Fig. 3: The fuel cell system is being implemented in the commercially available vacuum-cleaning robot shown in the photo. A comprehensive navigation system maps the whole room and thus allows the load demand to be determined, which must be supplied by the fuel cell system. The vacuuming motor can be switched off while previously cleaned zones are traversed. A dust sensor is used to determine the power needed by the vacuuming motor.

Long-Term Investigations on the Degradation of PEM Fuel Cells

One factor limiting the economic competitiveness of fuel cell systems as power supplies is the lifetime of the fuel cell. In real operation, the generated power decreases with increasing operation time. These degradation effects have many causes, which have not yet been clearly identified. In order to make fuel cells economically attractive, we are carrying out long-term laboratory tests using commercially available materials, with the goal of revealing important ageing effects in PEM fuel cells.

Tom Smolinka, Ralf Thomann*,
Ursula Wittstadt

* Freiburger Materialforschungszentrum FMF,
University of Freiburg

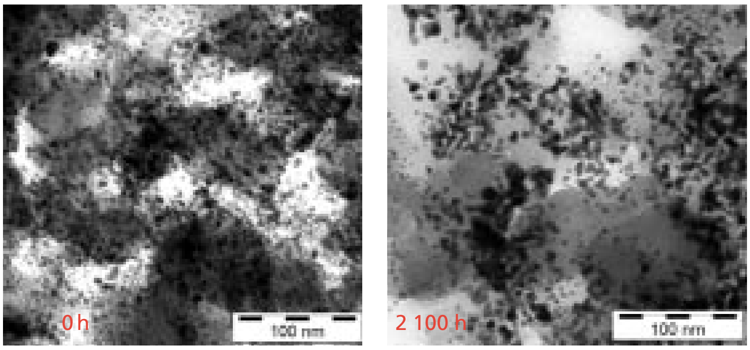


Fig. 1: Transmission electron micrographs of the cathode side of (left) a new membrane electrode assembly (MEA) and (right) a MEA after 2100 hours of operation. Agglomeration of the black catalyst particles is clearly visible. This is one possible cause for the cell power reduction over the operating lifetime.

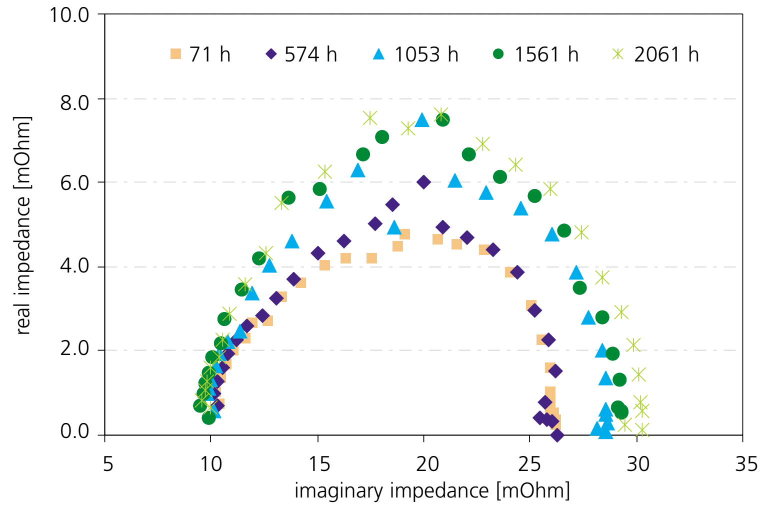


Fig. 2: Nyquist plot of impedance spectroscopy measurements, in which the real component of the impedance is plotted versus the imaginary component for frequencies from 50 mHz to 2 kHz. The arc radius increases as the cell operation time increases. This implies an increase in the charge transfer resistance of the electrode.

If a PEM fuel cell is to be used as a cost-effective power supply, its lifetime must reach several thousand to 40,000 hours. It is important to identify the ageing processes in the cells if high energy densities are to be guaranteed over the entire lifetime.

We are carrying out long-term investigations of commercially available materials with our fully automated test stands. Our investigations are concentrating on the membrane electrode assembly (MEA) of the fuel cell. Important parameters, such as the cell operating temperature, the fuel gas humidity and the composition of the reformer gas, are varied, so that their effect on the cell degradation can be studied in more detail. After operation with constant current density, we quantify the ageing rate of the cell by determining the voltage loss per operating hour at different times during the cell lifetime.

Comprehensive, in-situ characterisation is made at intervals of 500 h. In impedance spectroscopy measurements, we have observed an increase in the charge transfer resistance (fig. 2). With the help of cyclic voltammetry, we determine the loss of active electrode area. After completion of a long-term test, the MEA is analysed with a transmission electron microscope (fig. 1). We always see clear agglomeration of the catalyst particles here, which could be a reason for the loss in electricochemically active area.

The work is funded by the German Federal Ministry for Education and Research BMBF as part of a joint project.

Miniature Electrolyser for Charging Metal Hydride Storage Units

Metal hydrides are used in most portable fuel cell applications to store hydrogen. We have developed a miniature electrolysis system for decentralised and rapid charging of a metal hydride storage unit with extremely pure hydrogen. In twelve minutes, the system generates enough hydrogen from water to supply a camcorder with electricity for two hours, for example.

Beatrice Hacker, Jan Hesselmann, **Thomas Jungmann**, Holger Loew, Ursula Wittstadt

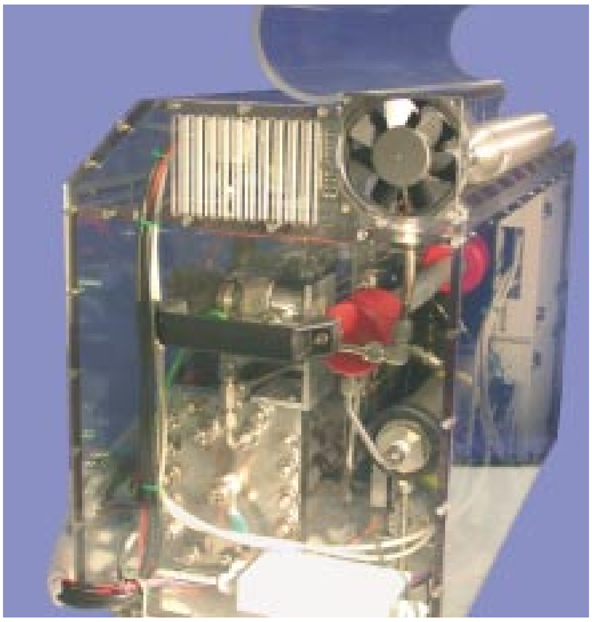


Fig. 1: Electrolyser system (280 x 550 x 380 mm³) for decentralised charging of metal hydride storage units with hydrogen at a pressure of 10 bar. We have achieved a gas production rate of 100 litres per hour with 15 series-connected electrolyser cells at a voltage of 27 V.

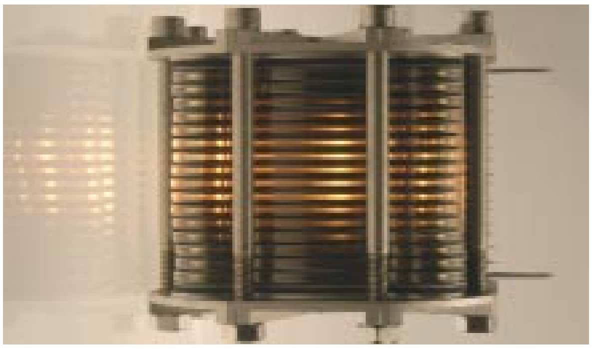


Fig. 2: The use of polymer bipolar plates makes the production of electrolyser stacks simple and cost-effective.

As the power consumption of portable electronic appliances increases, the application of miniature fuel cells as a supplement to conventional rechargeable batteries or accumulators is gaining interest. This is accompanied by the question of storage technology. Metal hydride storage units, which can be charged with hydrogen by an electrolyser, present an attractive option. In order to achieve a short charging time with our electrolyser system, we connect 15 electrolyser cells to form one stack. The individual cells are made of a special polymer in an injection moulding process which is suitable for series production. This not only reduces the costs for the bipolar plates by about 90 %, but also simultaneously halves the volume of the electrolyser stack, including the flexible end-plates.

To charge the metal hydride storage unit, the hydrogen is supplied at a pressure of 10 bar and is dried in a maintenance-free membrane module. In this way, we ensure that the capacity loss in the metal hydride, which is induced by impurities such as water, is less than 20 % after 2000 charging cycles. We can lengthen the service lifetime by a factor of eight by adding a second drying stage.

A microcontroller-based controls concept, which was also developed at Fraunhofer ISE, guarantees reliable system operation at the press of a button. Our safety strategy is implemented with hardware components and is based on a comprehensive safety analysis.

The work is funded by the German Federal Ministry for Economics and Technology BMWi, and is conducted in co-operation with seven partners from industry and research.

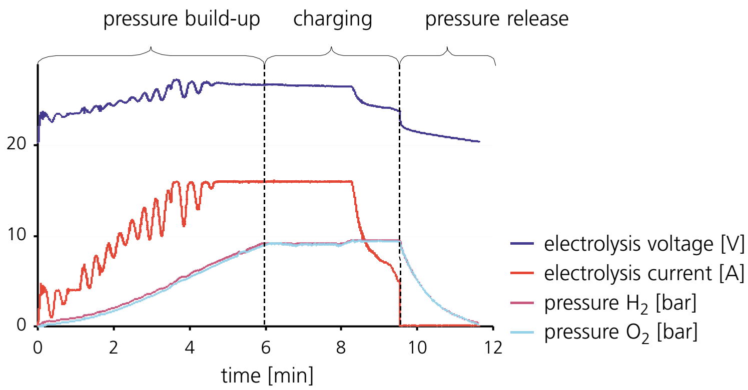


Fig. 3: In the test stand, we develop control strategies for charging the metal hydride storage unit. The "pressure build-up" and "charging" zones can be easily distinguished. If no further storage unit needs to be charged, the pressure is released.

Micro-Reformer for PEM Fuel Cells in the Power Range up to 300 W

We have developed a micro-reformer for integration into a very compact reformer / fuel cell system. This multiple-fuel reformer is operated with ethanol or also petrol, which it converts into a hydrogen-rich gas. After removal of the carbon monoxide, the gas can be used as the fuel for a polymer electrolyte membrane (PEM) fuel cell with 300 W_{el}. A catalytic burner is located in the centre of the reformer, which supplies the reaction heat for the steam reforming process.

Thomas Aicher, Lisbeth Rochlitz,
Achim Schaadt

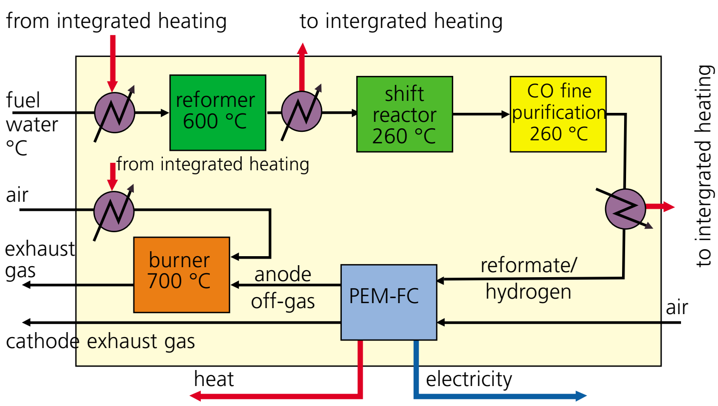


Fig. 1: Schematic diagram of the complete micro-reformer / fuel cell system, including usage of the generated heat (heat integration). The complete system should not exceed dimensions of 30 x 40 x 60 cm^3 and a mass of 20 kg, so that it can be transported easily by one person.

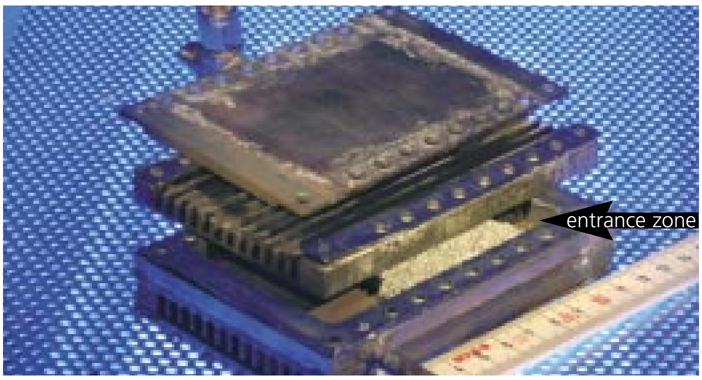


Fig. 2: The porous ceramic component in the anode off-gas catalytic burner creates a pressure drop after the entrance zone, so that the burner gases are distributed homogeneously over the entire cross-section. Directly above and below it is the reformer, with its catalytically coated channels.

By combining our expertise in hydrogen technology, we have developed a micro-reformer which generates hydrogen-rich gas from ethanol and petrol for the PEM fuel cells which were also developed at Fraunhofer ISE. Applications for a portable, reformer / fuel cell system include measurement stations on pipelines, environmental and traffic measurements, small auxiliary motors and off-grid medical equipment. The energy needed for steam reforming is provided by an anode off-gas catalytic burner with a porous ceramic component. This is located between the two reformer reactors and is operated in the co-current mode. In this way, heat released in the burner can be transferred directly by thermal conduction to the reformer catalyst. This minimises the thermal losses. We developed a concept for the educt pre-heating and evaporation, which allows us to use the heat of the exhaust gas and the hot reformate current completely (fig. 1). This results in a compact construction for the complete system and enables a theoretical reformer efficiency value exceeding 79 % (lower heating value LHV of the generated hydrogen / LHV of the fuel). Assuming a fuel cell efficiency value of 40 % (electric power / LHV of the supplied hydrogen), the total efficiency value for the system is about 35 %.

In the first measurements, we obtained a reformer product gas current with 68 vol. $\%_{dry}$ hydrogen by reforming ethanol at a temperature of 600 °C. This proportion can be increased by adding a water-gas shift reaction.

The Fraunhofer research project is also financially supported by a doctoral scholarship awarded by the German Federal Environmental Foundation DBU.

Kerosene Reformer for Fuel-Cell Applications in Aircraft

With the goal of reproducing the integration of a fuel cell system into an aircraft power supply system on a small scale, we developed a fully automated kerosene reformer and operated it continuously in an experiment for 300 hours. During this time, we investigated the long-term performance of the catalyst and the reformer efficiency for different load conditions. In parallel, we developed a reformer / fuel cell model based on Matlab/Simulink, which we validated with the help of the experimental results.

Johannes Full, Christian Siewek,
Bettina Lenz

Continually increasing numbers of passengers and more stringent legal regulations force the aviation industry to consider ways of saving energy on board passenger aircraft. Reformer / fuel cell systems could supply all the electricity needed while on the ground and part of the electricity during flight, with significantly higher efficiency than conventional systems for power supply on board. We are developing a kerosene reformer for this application, which supplies synthesis gas (hydrogen and carbon monoxide) to a solid oxide fuel cell (SOFC) developed by a project partner.

We used commercial process software to design the entire fuel cell system. On the basis of this simulation, we prepared a theoretical model of the system in Matlab/Simulink, which was embedded in a complete simulation of the mass and energy transport in an aeroplane. This was then used to vary the interfaces to the fuel cell system and determine the most efficient operating scenarios. When the electric load on the SOFC was varied from 70 kW to 120 kW, a system efficiency value (electric power / heating value of the supplied kerosene) from maximally 40.2 % at 70 kW to 28.5 % at 120 kW was determined. To validate the theoretically calculated values, a fully automated system (fig. 1) was constructed, which provided information on the performance of the heat exchanger, the burner, the reformer and the fuel cell.

We investigated catalyst ageing in a continuous experiment lasting 300 hours. The thermal power of the reformer was 3 kW (referred to the lower heating value of kerosene). The reformer efficiency value was calculated from measurements of the gas composition and the flow rate. Its variation with time is shown in fig. 2.

We carried out this work within the "Power Optimised Aircraft (POA)" project, which is funded by the European Union.

Fig. 1: Fully automated system for autothermal reforming of desulphurised kerosene Jet A-1 as the fuel for an SOFC (photo without SOFC). It is a system with integrated heating, i.e. the waste heat from the fuel cell is fed back to the reformer. The reformer system can be operated to track the fuel cell load, and can generate synthesis gas with a flow rate varying continuously between 10 and 45 Nl per minute.

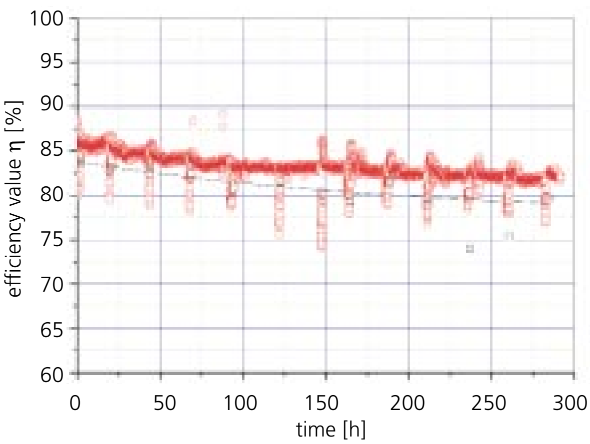
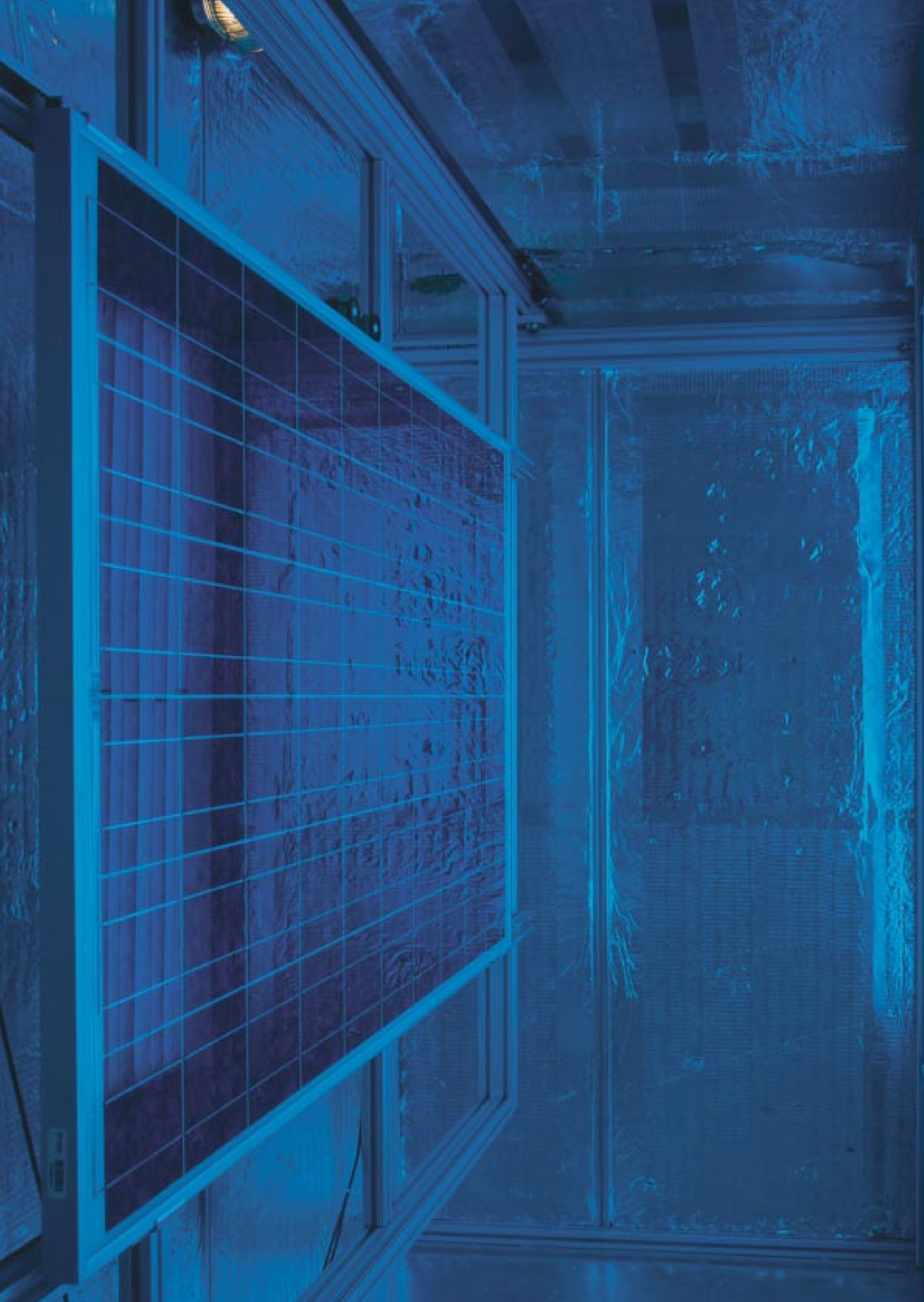


Fig. 2: Variation of the reformer efficiency value with time. The efficiency value is calculated from the flow rate and the measured composition of the product gas. The gas composition needed for the efficiency value calculations was determined both by IR gas analysis (red circles) and gas chromatography (GC - black squares). The black line is the line of best fit to the efficiency values calculated from the GC measurements. Outliers were caused when the system turned on or off.



Quality convinces

Service Units

Air-conditioning concepts, daylighting and solar control for office buildings with a future - these and other aspects of building technology are presented in the Fraunhofer Solar Building Innovation Center SOBIC. Fraunhofer SOBIC is a demonstration centre for solar building which is run jointly by Fraunhofer ISE and the Fraunhofer Institute for Building Physics IBP. It is conceived as an information and interaction platform for architects, planners, building service technicians and manufacturers of building components. Its aim is to accelerate technology transfer.

The long-term durability of new materials and components is becoming increasingly important for solar building and the integration of solar energy. Thus, we have 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 e.g. of solar collectors, building components or PV modules.

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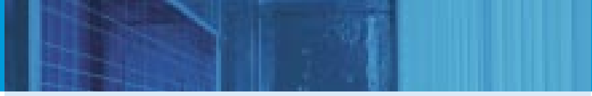
UV test stand for photovoltaic modules. The intensity of the UV radiation is 50 times higher than natural UV-B radiation and 7 times higher than natural UV-A radiation. Modules with dimensions up to 1.4 m x 2.4 m can be tested. Fraunhofer ISE is currently setting up a new centre to test the reliability of photovoltaic modules. When the accreditation process has been completed, it can act as a so-called "Testing Laboratory" according to ISO 17025 and IEC EE for the "Certification Body", VDE, and carry out tests according to IEC 61615 and 61646 for product authorisation (see article on p. 99).

Several of our laboratories are preparing for accreditation according to DIN EN ISO/IEC 17025. The testing centre for thermal solar systems (PZTS) is already accredited. Our calibration laboratory for PV modules (ISE CalLab Module), our thermal-optical testing laboratory (TOPLAB) and the newly established test centre for photovoltaics are currently involved in the accreditation procedure. Our other service units are the calibration laboratory for solar cells (ISE CalLab Cells), a test stand for ventilation units, a façade testing facility and daylighting measurement rooms.



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

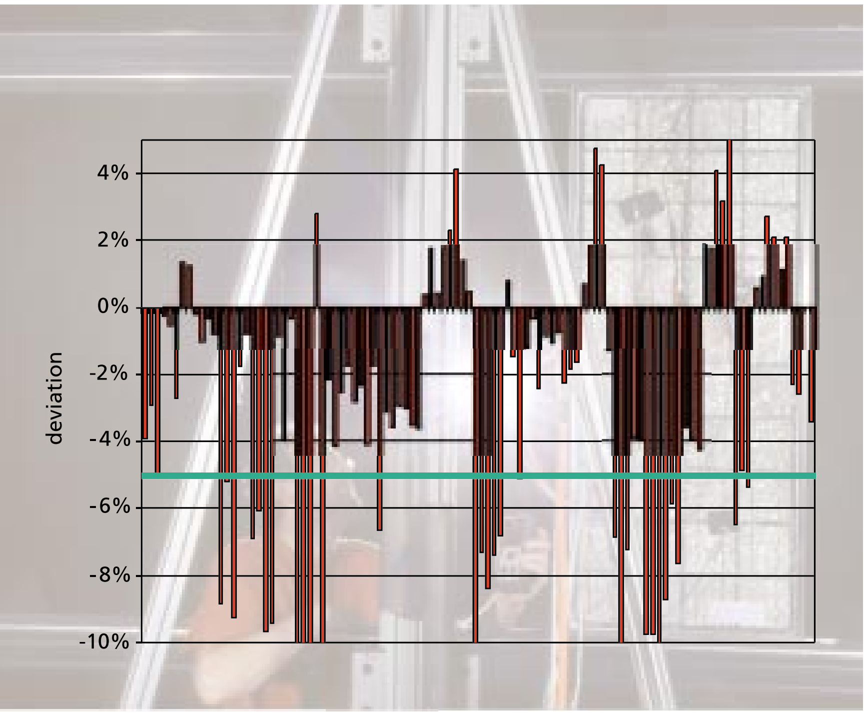


Fig. 1: The performance of photovoltaic modules with an area of up to 4 m^2 can be measured at Fraunhofer ISE with a high-precision, pulsed solar simulator. The measurement accuracy is better than ± 2.5 % for precision measurements and better than ± 4 % for standard measurements. A measurement test series 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 15 x 15 cm^2. 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 2 x 2 m^2, 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

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 is being established. After the accreditation process according to ISO 17025 and IEC EE has been completed, it will be an authorised "Testing Laboratory" for the "Certification Body", VDE, and able to carry out tests for product type approval complying with IEC 61615 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 decided to extend its relevant testing facilities and offer its services to module manufacturers in co-operation with VDE, which is a "Certification Body" of the IEC EE.

The following module tests will be conducted in the Test Centre:

- insulation resistance
- wet leakage currents
- temperature cycling
- damp heat
- humidity-freeze cycling
- UV irradiation (see fig. 1)
- nominal operating cell temperature (NOCT, see fig. 2)
- hot spot endurance
- bypass diode thermal test
- robustness of terminations
- outdoor exposure

The ISE CalLab (see p. 98), one of the leading laboratories for power measurements of modules, will carry 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.

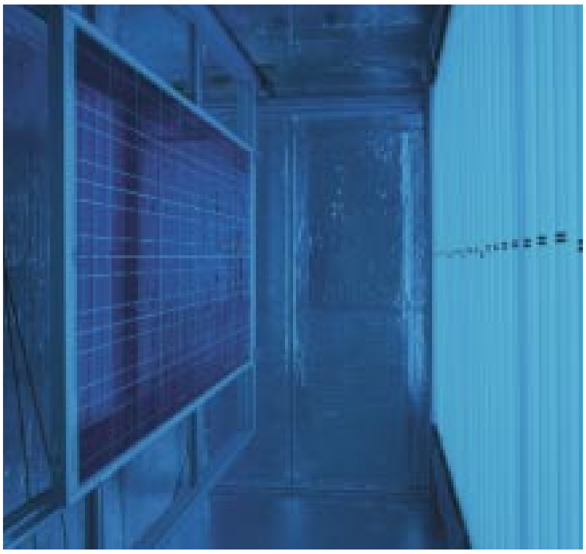


Fig. 1: UV test stand for photovoltaic modules with dimensions up to 1.4 x 2.4 m^2: The intensity of the UV radiation is 50 times higher than the natural UV-B radiation and 7 times higher than the natural UV-A radiation.

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 inverters and DC components such as lamps, batteries or television sets.

Rudi Kaiser, Bruno Burger, Heribert Schmidt

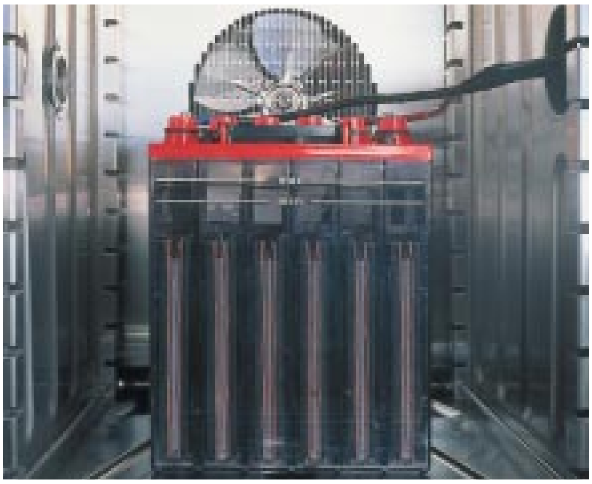


Fig. 1: In addition to efficiency and capacity, also the temperature dependence of properties such as the ageing and charging performance of storage batteries can be investigated. The photo shows the climatic chamber of the battery testing laboratory at Fraunhofer ISE.

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 can have their equipment tested and optimised in connection with the corresponding batteries.

Fig. 2: The photo shows a high-precision power measurement instrument used for exact determination of inverter efficiency.

Inverter Laboratory

We characterise inverters with respect to efficiency, MPP tracking performance, electromagnetic compatibility (EMC), burst and surge disturbance, compliance with the relevant standards and user friendliness. An EMC measurement chamber is available to characterise EMC behaviour. Our staff, who also work in standardisation committees, offer advice on technical questions or clarification of the standards which must be observed.

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.

Joachim Koschikowski*, Matthias Rommel, Arim Schäfer, Thorsten Siems*

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

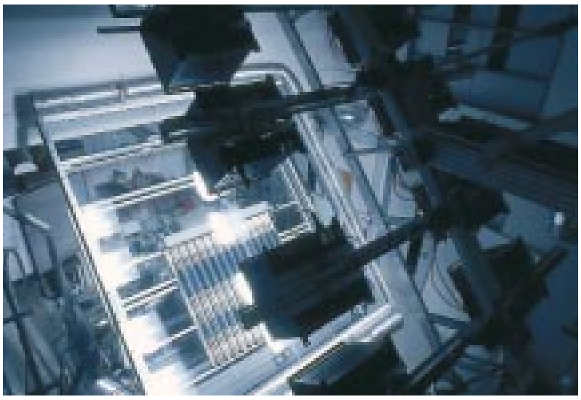


Fig. 1: Indoor test stand with solar simulator.

Certification of solar collectors

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

- 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
- SOLAR KEYMARK label
- 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)
- parameter identification with the ColSim simulation program developed at Fraunhofer ISE

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: 2.4 x 2 m^2. Other configurations of the test plane are possible (up to 3.5 x 3 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 °

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 mm^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
- development of customised design software for solar air collector systems

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, Sebastian Herkel

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Fig. 1: Automated test facility with two testing stations to measure ventilation units and exhaust-air heat pumps.

Fig. 2: Conditioning unit for outdoor air (insulation partly removed): The outdoor air flows in from the lower left through the pre-cooler/dehumidifier and the low-temperature chiller, then upwards to the ultrasonic humidifier and air heater. Two air currents can be separately conditioned as supply air and as a second heat source.

Fig. 3: Compact heating and ventilation unit during measurement with the test stand. The unit is specially designed for use in passive multi-storey buildings and has a small, integrated storage tank with a capacity of 240 litres.

Test facility for compact ventilation and heating units

On commission to our clients, we support the development of compact ventilation units with integrated exhaust-air heat pumps. With our test facility, we measure the energy efficiency of both the complete units and their components. We can choose from a wide spectrum of testing conditions. The automated test stand allows dynamically changing conditions to be applied, e.g. according to the EN 255-3 standard. From the measurements, we derive recommendations to optimise the components and their interaction. We support our clients in implementing new developments, e.g. by substituting components. Skilled staff with know-how on cooling technology and the necessary technical equipment are available.

Monitoring

In numerous occupied solar passive houses, we are measuring the performance of compact ventilation and heating units from various manufacturers in practice. Based on daily data analyses, we give direct recommendations to optimise operation. Possible fault causes are identified and corrected. From these measurements, we prepare proposals to optimise the equipment and controls.

Measurements of airtightness and air exchange rate

We measure the airtightness of ventilation units under real operating conditions with the help of tracer gas chromatography, applying the constant injection method. This can be done either with the test stand or in situ in the building, for large central systems. We use the same equipment to determine the air exchange rate in buildings according to the concentration decay method. Our measurement method meets the specifications of VDI 4300, Sheet 7. It allows SF_6 to be used as the tracer gas also in occupied buildings, if the analysis is made by gas chromatography using an electron capture detector.

Measurement of Building Façades and Transparent Components

We offer developers and planners a comprehensive range of detailed and accurate characterisation for innovative building components and materials. A special laboratory 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

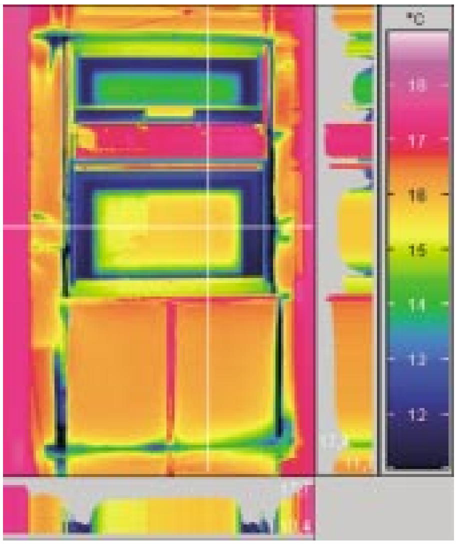


Fig. 1: Thermographic image of a façade module occupying the full height of a test cabin (viewed from indoors).

Thermal-Optical Measurement Laboratory TOPLAB and Lighting Laboratory

Existing measurement procedures such as those specified in DIN EN 410 are not adequate to describe the properties of advanced glazing and façade constructions. Thus, we have developed testing 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, e.g. photochromic, thermotropic or electrochromic
- air flow within the façade
- integrated photovoltaics.

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 DIN 52612
- angle-dependent transmittance and reflectance measurements with a large integrating sphere
- measurement of the angular distribution of transmitted and reflected light with a photo goniometer

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.

Within the ISO 9001:2000 certification programme, we regularly maintain and calibrate our measurement equipment, guaranteeing high accuracy.

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 have been made in the measurement rooms to date:
- glare protection tests
- user acceptance studies
- comparison of the lighting situation behind two façade systems

Façade testing facility

In addition to characteristic values obtained under well-defined boundary conditions in the laboratory, we measure complete façades under real climatic conditions. South-oriented test rooms are available. There, we investigate the dynamic performance of the test façades and record data on the temperatures in the internal cabins and within the façade component, the operative temperature, solar and visible transmittance, heating consumption of the test cabins and other building-science parameters at one-minute intervals.

Long-term investigations provide information on the stability, switching performance and loads on the façade. The optimisation of controllers can be experimentally validated. In combination with building simulation, the measured data serve to validate façade models in programs such as ESP-r and TRNSYS.

Fraunhofer Solar Building Innovation Center SOBIC

Fraunhofer SOBIC demonstrates energy-efficient and solar-assisted building technology. It supports the market introduction of scientific and technical results from the Fraunhofer Institutes for Solar Energy Systems ISE and for Building Physics IBP. It serves as an information and interaction platform for architects and planners, building technicians and manufacturers from the construction industry, and representatives of finance and politics. Fraunhofer SOBIC offers research services and marketing support to small and medium-sized enterprises.

Hans-Martin Henning, Christel Russ, Tilmann Kuhn, Sebastian Herkel

Fig. 1: The exhibition on "Thermal Insulation for Summer" in the rooms of Fraunhofer SOBIC in Freiburg, Emmy-Noether-Strasse 2, displays solar-control and glare-protection systems from different manufacturers. Façade systems, systems and components for passive and active cooling, and building concepts are also presented.

Fig. 2: Seminars, workshops, symposia and work meetings all serve the purpose of further education based on the results of research and development. At the same time, current market demands are taken into account. Well-equipped seminar and meeting rooms with a pleasant atmosphere support successful knowledge transfer.

The Fraunhofer Institute for Solar Energy Systems ISE in Freiburg and the Fraunhofer Institute for Building Physics IBP in Stuttgart have combined their expertise on energy-efficient and solar building in the Fraunhofer Solar Building Innovation Center SOBIC. Interested parties from all branches of the European construction industry and building services technology find competent partners here and a wide-ranging spectrum of services for the most recent technological developments. Two exhibitions serve as innovative, technical advice centres: new aspects of "Energy-Efficient Building and Living" are shown in the Fellbach exhibition centre entitled "Home and Garden", while Fraunhofer SOBIC in Freiburg presents "Energy Efficiency in Non-Residential Buildings". Both exhibitions display innovative products, components and systems, as well as building infrastructure technology, and support the main work of Fraunhofer SOBIC, the development of product and system strategies. The subjects of the exhibitions correspond to current market demands and include "Thermal Insulation for Summer" in Fraunhofer SOBIC, Freiburg.

Training courses and further education in the specialist seminars provide information on:
- sustainable energy supplies in buildings such as hospitals, passive houses or passive office buildings
- façade systems for solar control and glare protection, phase change materials or IR-reflective coatings
- innovative building services technology for non-residential buildings, such as passive cooling, solar-assisted air-conditioning and solar-control strategies
- implementation of new standards and regulations, for example the EU Guideline on Building Efficiency

In close co-operation with the two Institutes, Fraunhofer SOBIC offers customised solutions in the following areas:
- product authorisation
- integrated planning of buildings
- development and evaluation of façade systems
- innovative building technology, e.g. solar air-conditioning
- monitoring and evaluation, including visualisation.

Facts and Figures

Visiting Scientists

Benjamin Diaz
Universidad de La Laguna
Tenerife, Spain
15.7.2004-31.1.2005
Research area: Porous silicon and silicon nitride, anti-reflective coatings for solar cell technology

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

José Roberto Flores Hernández
Instituto de Investigaciones Electricas (IEE)
Puebla, Mexico
1.10.2001-30.9.2005
Research area: Electrolysis

Warren Hogarth
University of Queensland
Brisbane, Queensland, Australia
1.9.2005-31.12.2005
Research area: Fuel cell flow-field design

Prof. Hongmei Yu
Dalian Institute of Chemical Physics
Chinese Academy of Science
Dalian, China
11.7.2005-19.7.2005
Research area: Investigation of membrane-electrode assemblies for fuel cells

Participation in National and International Associations

Bundesverband Kraft-Wärme-Kopplung B.KWK
- Mitglied

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

Deutsche Elektrotechnische Kommission (DKE)
- Komitee 373: »Photovoltaische Solarenergiesysteme«

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

Deutsche Gesellschaft für Sonnenenergie
- Fachausschuss »Wärmepumpen«

Deutscher Wasserstoff-Verein
- Mitglied

Deutsches Institut für Normung DIN, Fachnormenausschuss
Heiz- und Raumlufttechnik (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 Comittee for Standardisation
CEN TC33 / WG3 / TG5
- member

European Desalination Society
- member

European Fuel Cell Group
- member

European Photovoltaic Industry Association (EPIA)
- associate member

European Solar Thermal Industry Federation (ESTIF)
- member

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

Fachverband Transparente Wärmedämmung
- Fachausschuss »Produktkennwerte«

Fachverband Transparente Wärmedämmung
- Mitglied

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

Fraunhofer-Verbund Energie
- Geschäftsführung

Freiburger Verein für Arbeits-und Organisationspsychologie
- erw. Vorstand

Global Research Alliance (GRA)
- Coordination of Thematic Focus on Energy

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

GVEP Global Village Energy Partnership
- member

Hauptkommission des Wissenschaftlich-Technischen Rates der Fraunhofer-Gesellschaft
- Vorsitz

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 Energy Agency IEA, Paris, France: Solar Heating & Cooling Programme SHCP
- Task 25: »Solar Assisted Air Conditioning of Buildings«
- Task 27: »Performance of Solar Facade Components«

Congresses, Conferences and Seminars organised by the Institute

- Task 28: »Sustainable Solar Housing«
- Task 33/4: »Solar Heat for Industrial Processes«
- Energy Conservation in Buildings and Community Systems ECBCS
- Heat Pump Programme HPP

Kompetenz- und Innovationszentrum Brennstoffzelle, KIBZ Stuttgart
- Mitglied

Kompetenznetzwerk Brennstoffzelle NRW, Nordrhein-Westfalen
- Mitglied

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

Stiftungsrat des Hanse Wissenschaftskollegs (HWK)
- Mitglied

Symposium Photovoltaische Solarenergie
- Wissenschaftlicher Beirat

VDMA The German Engineering Federation Productronics Association
Dachverband Deutsches Flachdisplay-Forum (DFF)
- member

Verein Deutscher Elektrotechniker
- ETG-Fachausschuss »Brennstoffzellen«

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

VDI-Gesellschaft Technische Gebäudeausrüstung
- Richtlinienausschuss 6018

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

OTTI-Fachforum
Lüftungstechnik
Regensburg, 24./25.1.2006

OTTI Energie-Kolleg
11. Symposium Innovative Lichttechnik in Gebäuden
Bad Staffelstein, Kloster Banz, 27./28.1.2005

Workshop SiliconFOREST 2005
Fortschritte in der Entwicklung von Solarzellen-Strukturen und Technologien
Falkau, 27.2.–2.3.2005

OTTI Energie-Kolleg
20. Symposium Photovoltaische Solarenergie
Bad Staffelstein, Kloster Banz, 9.–11.3.2005

OTTI Energie-Kolleg
15. Symposium Thermische Solarenergie
Bad Staffelstein, Kloster Banz, 27.–29.4.2005

9. Internationale Passivhaustagung 2005
Ludwigshafen, 29./30.4.2005

OTTI-Profiforum
Wiederaufladbare Batteriesysteme
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden Württemberg
Ulm, 10./11.5.2005

11. Symposium Energieoptimiertes Bauen
»Bürogebäude mit Zukunft«
Dessau, 12.-14.5.2005

Fraunhofer Solar Building Innovation Center SOBIC* gemeinsam mit Deutsche Bundesstiftung Umwelt
Wärmeversorgung von Passivhäusern (Seminar)
Osnabrück, 19.5.2005

Fraunhofer Solar Building Innovation Center SOBIC*
Solare Klimatisierung (Seminar)
Freiburg, Fraunhofer SOBIC, 31.5.2005

OTTI-Fachseminar
Netzferne Stromversorgung mit Photovoltaik
Freiburg, 16./17.6.2005

OTTI-Profiseminare
Photovoltaik-Anlagen
Freiburg, 21./22.6.2005

2nd European Solar Thermal Energy Conference ESTEC 2005
Freiburg, 21./22.6.2005

Intersolar
Kompaktseminar Photovoltaik-Technologie
Freiburg, 24.6.2005

Fraunhofer Solar Building Innovation Center SOBIC*
Solarunterstützte energieeffiziente Wohngebäude – Ergebnisse aus der IEA Task 28/30 (Seminar)
Freiburg, Fraunhofer ISE, 30.6.2005

3rd European Polymer Electrolyte Fuel Cell Forum PEFC
Luzern, Schweiz 4.-8.7.2005

»Building Integrated Photovoltaics (BIPV): Architecture, Engineering and Standards«
Seminar »Introduction to Building Integrated Photovoltaic (BIPV), General Approaches on BIPV System Design and Installation«,
Kuala Lumpur, Malaysia, 12.9.2005

»Policy and Financial Framework Promoting Sustainable Photovoltaic (PV) Markets«
Seminar »PV Interconnection: Myth and Facts from Regulatory and Technical Perspective«,
Kuala Lumpur, Malaysia,13.09.2005

Forschungsverbund Sonnenenergie FVS
Jahrestagung 2005
Köln, 22./23.9.2005

Fachforum Solare Kühlung und Klimatisierung im Rahmen der Internationalen Kongressmesse RENEXPO® 2005
Veranstalter: Erneuerbare Energien Kommunikations- und Informationsservice GmbH
Augsburg, 23.9.2005

f-cell (Fuel Cell Congress)
Stuttgart, 26.–28.09.2005

14. FMF-Kolloquium (Freiburger Materialforschungszentrum)
Titisee-Neustadt, 6./7.10.2005

International Conference
Solar Air-Conditioning
Bad Staffelstein, Kloster Banz, 6./7.10.2005

Fraunhofer Solar Building Innovation Center SOBIC*
Symposium zur EU-Gebäudeeffizienzrichtlinie
Freiburg, Solar Info Center, 27./28.10.2005

Fraunhofer Solar Building Innovation Center SOBIC* gemeinsam mit OTTI-Technik-Kolleg
OTTI-Profiseminar
EMV und Blitzschutz für Solaranlagen
Regensburg, 30.11–1.12. 2005

* Fraunhofer SOBIC is the joint demonstration centre of Fraunhofer IBP and Fraunhofer ISE.

Lecture Courses

Dr. Dietmar Borchert
Photovoltaik
Vorlesung SS 05
Technische Fachhochschule Georg Agricola
Bochum

Dr. Andreas Bühring
Technische Gebäudeausrüstung
Vorlesungen WS 04/05
Fernstudiengang Energiemanagement
Universität Koblenz-Landau

Dr. Bruno Burger
Leistungselektronische Systeme für regenerative Energiequellen
WS 05/06
Fakultät für Elektrotechnik und Informationstechnik
Universität Karlsruhe

Dr. Andreas Gombert
Optische Eigenschaften von Mikro- und Nanostrukturen
Vorlesung WS 05/06
Albert-Ludwigs-Universität Freiburg
Fakultät für Angewandte Wissenschaften

Dr. Stefan Glunz
Prof. Joachim Luther
Photovoltaische Energiekonversion
Vorlesung SS 05
Albert-Ludwigs-Universität Freiburg
Fakultät für Physik

Prof. Joachim Luther
Solare Energiekonversion
Oberseminar SS05,
Thermische Solarenergiewandlung
mit Dr. Werner Platzer
Vorlesung WS 05/06,
Solare Energiekonversion
Oberseminar WS 05/06,
Albert-Ludwigs-Universität Freiburg
Fakultät für Physik

Sebastian Herkel
Solare Energiesysteme
Vorlesung SS05
Fachbereich Architektur und Design
Staatliche Akademie der Bildenden Künste
Stuttgart

Christian Neumann
Technischer Ausbau
Vorlesungen SS05
Fachbereich Bauphysik und Technischer Ausbau
Universität Karlsruhe

Dr. Christel Russ
Energetische Sanierung von Gebäuden
Vorlesungen SS05
Fachhochschule Biberach

Prof. Roland Schindler
Halbleitertechnologie II (Bauelemente)
Vorlesung SS 05,
Photovoltaik II
Vorlesung SS 05,
Hableitertechnologie I (Technologie),
Vorlesung WS 05/06,
Photovoltaik I
Vorlesung WS 05/06,
Fernuniversität Hagen

Dr. Heribert Schmidt
Photovoltaik Systemtechnik
SS 05
Fakultät für Elektrotechnik und Informationstechnik
Universität Karlsruhe

Priv. Doz. Dr. Gerhard Willeke
Halbleitertechnologie und Physik der Solarzelle
Vorlesung SS 05
Universität Konstanz

Priv. Doz. Dr. Volker Wittwer
Energieversorgung für Mikrosysteme
Vorlesung SS 05

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

Trade Fairs and Exhibitions

OTTI Energie-Kolleg
20. SYMPOSIUM Photovoltaische Solarenergie
Bad Staffelstein, Kloster Banz, 9.–11.3.2005

Hanover Trade Fair
Hanover, 11.–15.4.2005

20th European Photovoltaic Solar Energy Conference and Exhibition
Barcelona, Spain, 6.–10.6.2005

Intersolar 2005
International Trade Fair and Congress for Solar Technolgy
Freiburg, 23.–25.6.2005

3rd European Polymer Electrolyte Fuel Cell Forum PEFC,
Lucerne, Switzerland, 4.–8.7.2005

f-cell (Fuel Cell Congress 2005)
Stuttgart, 26.–28.9.2005

Plastic Electronics 2005
International Conference & Showcase
Fraunhofer joint stand
Frankfurt, 4./5.10.2005)

Mikrosystemtechnik Kongress 2005
Freiburg, 10.–12.10.2005

Intelligent Building Middle East 2005, International Exhibition and Conference for Building Materials, Concepts and Technologies. Bahrain International Exhibition Center, Kingdom of Bahrain, 5.–7.12.2005

New Commercial Enterprise

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Patent Applications

Sarmimala Hore, Rainer Kern, Peter Nitz
"Dye Solar Cell with Enhanced Efficiency"

Sarmimala Hore, Rainer Kern, Andreas Hinsch
"Method offering stability for light-sensitive materials in contact with semiconductor oxides"

Sascha van Riesen, Rüdiger Löckenhoff, Gerhard Stahl, Ron Dietrich, Wolfgang Koestler
"Device with solar cell and integrated bypass diode"

Peter Koltay, Christian Litterst, Steffen Eccarius
"Device with a fluid-transporting channel and procedure to remove enclosures"

Tilmann Kuhn, Volker Wittwer, Andreas Gombert
"Sun-shading and glare-protection device, procedure for its production and its application"

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

Bruno Burger, Jan Hesselmann, Mario Zedda
"Device and procedure for heating a fuel cell or a fuel cell stack"

Alexander Susdorf, Albert Chigapov, Brendan Carberry
"Catalyst for low-temperature and room-temperature carbon monoxide elimination and method manufacturing the same"

Christian Bichler
"Thermal storage unit and application of the thermal storage unit in a heating system with a solar system and heat pump"

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

Martin Schubert, Stefan Rein, Jörg Isenberg, Wilhelm Warta, Stefan Glunz
"Procedure and device for inactivation of trapping effects in doped semiconductors"

Steffen Eccarius, Andreas Schmitz
"Direct methanol fuel cell"

Kuno Mayer, Daniel Kray, Sybille Baumann, Bernd Kolbesen
"Liquid jet processing"

Ferdinand Schmidt, Lena Schnabel, Hans-Martin Henning, Tomas Núñez, Stefan Henninger
"Configuration of heat exchanger plates which are in thermal contact with an adsorbent"

Stefan Reber, Achim Eyer, Fridolin Haas
"Process for recrystallisation of film structures applying zone-melting, device used for this purpose and its application"

Stefan Reber, Albert Hurrle, Norbert Schillinger
"Device and procedure for continuous chemical vapour deposition under atmospheric pressure and its application"

Thomas Aicher, Lothar Griesser
"Procedure for evaporation and reforming of liquid fuels"

Ferdinand Schmidt, Lena Schnabel, Hans-Martin Henning, Tomas Núñez, Stefan Henninger
"Cylindrical heat exchanger in thermal contact with an adsorbent"

Patents Granted

Heribert Schmidt, Dirk Uwe Sauer
"Acid testing"

Adolf Goetzberger, Thomas Kuckelkorn
"Device for light redirection and occlusion for stationary application with a translucent building façade for specific illumination of an interior room"

Andreas Gombert, Hansjörg Lerchenmüller
"Anti-reflective coating and procedure to produce it"

Andreas Bühring
"Compact heat pump unit with integrated primary-energy heat source for controlled ventilation and heating of low-energy buildings or passive houses and corresponding procedure"

Volkmar Boerner, Andreas Gombert, Benedikt Bläsi
"Procedure for the production of light-scattering elements"

Axel Heitzler, Christopher Hebling, Andreas Schmitz
"Fuel cell configuration"

Heribert Schmidt, Bruno Burger
"Device and procedure to suppress a DC component in the output current of inverters"

Christian Schlemmer, Wolfgang Graf, Andreas Georg, Andreas Gombert
"Metal emitter stable at high temperatures and procedure to produce it"

Eric Schneiderlöchner, Jochen Rentsch, Ralf Preu
"Procedure to reduce optical reflection from semiconductor surfaces"

Wolfgang Graf, Rainer Rox
"System with glazing element and gas supply device"

Inaugural and Doctoral Theses

Lectureship Inaugural Thesis

Andreas Gombert
"Large-area micro-structured surfaces with optical functions"
Lectureship inaugural thesis,
University of Freiburg
Freiburg, 2005

Doctoral Theses

Karen Forberich
"Organische Photonische-Kristall-Laser"
(Organic photonic-crystal lasers)
Doctoral thesis, University of Freiburg
Freiburg, 2005

Michael Hermann
"Bionische Ansätze zur Entwicklung energieeffizienter Fluidsysteme für den Wärmetransport"
(Bionic approaches to development of energy-efficient fluid systems for heat transport)
Doctoral thesis, University of Karlsruhe (TH)
Karlsruhe, 2005

José Roberto Flores Hernández
"Optimisation of components for water electrolysis with respect to their application in cost-effective and robust off-grid energy supply systems"
Doctoral thesis, University of Freiburg
Freiburg, 2005

Sarmimala Hore
"Enhancing the efficiency of dye solar cells by tuning the trap states in nanocrystalline TiO_2"
Doctoral thesis, University of Freiburg
Freiburg, 2005

Wolfgang Hoßfeld
"Tageslichtsteuerung mit prismatischen Mikrostrukturen im Übergangsbereich von diffraktiver und geometrischer Optik"
(Daylighting control with prismatic micro-structures in the transitional zone between diffractive and geometrical optics)
Doctoral thesis, University of Freiburg
Freiburg, 2005

Rudi Jörg Kaiser
"Optimierung eines Batteriemanagementsystems zum Einsatz in photovoltaischen Stromversorgungssystemen"
(Optimisation of a battery management system for application in photovoltaic power supply systems)
Doctoral thesis, University of Ulm
Ulm, 2005

Andreas Mohr
"Silicon concentrator cells in a two-stage photovoltaic system with a concentration factor of 300x"
Doctoral thesis, University of Freiburg
Freiburg, 2005

Michael Niggemann"
Fundamental investigations on periodic nano- and microstructured organic solar cells"
Doctoral thesis, University of Freiburg
Freiburg, 2005

Anders Ødegård
"Weiterentwicklung kleiner Direktmethanol-brennstoffzellen"
(Further development of small direct-methanol fuel cells)
Doctoral thesis, University of Duisburg
Duisburg, 2005

Jochen Rentsch
"Trockentechnologien zur Herstellung von kristallinen Siliziumsolarzellen"
(Dry technological approaches to produce crystalline silicon solar cells)
Doctoral thesis, University of Freiburg
Freiburg, 2005

Thomas Schlegl
"GaSb-Photovoltaikzellen für die Thermophotovoltaik"
(GaSb photovoltaic cell for thermophotovoltaics)
Doctoral thesis, University of Regensburg
Regensburg, 2005

Andreas Schmitz
"System development of miniaturised planar fuel cells"
Doctoral thesis, Technical University of Berlin
Berlin, 2005

Oliver Schultz
"High-efficiency multicrystalline silicon solar cells"
Doctoral thesis, University of Constance
Constance, 2005

Benoît G. Sicre
"Nachhaltige Energieversorgung von Niedrigstenergiehäusern auf Basis der Kraft-Wärme-Kopplung im Kleinstleistungsbereich und der Solarthermie"
(Sustainable energy supply for lowest-energy houses based on small combined heat and power plants and thermal use of solar energy)
Doctoral thesis, Technical University of Chemnitz
Chemnitz, 2005

Tom Smolinka
"Entwicklung und Charakterisierung einer Reformatgas tauglichen PEM-Brennstoffzelle"
(Development and characterisation of a PEM fuel cell suitable for reformate gas)
Doctoral thesis, University of Ulm
Ulm, 2005

Christoph Ziegler
"Regelung und Dynamik kleiner Brennstoffzellen"
(Control and dynamics of small fuel cells)
Doctoral thesis, University of Constance
Constance, 2005

Press Releases

www.ise.fraunhofer.de/english/press

08.08.2005
Photochromic Systems on their way towards Architectural Applications
Fraunhofer ISE Presents the Newest Developments in Transparent Solar Control

10.03.2005
Bringing the Sun to the Point
Concentrix Solar GmbH founded in Freiburg

24.03.2005
Fraunhofer-Gesellschaft founds Energy Alliance

30.03.2005
Hanover Trade Fair:
Hydrogen Technology made by Fraunhofer
Wether-Resistant Miniature Fuel Cells and Durable SOFC Stacks

08.06.2005
Becquerel Prize for Joachim Luther
EU Commission recognises scientist's successful contribution to photovoltaics

08.08.2005
International Solar Energy Society honours Prof. Joachim Luther
ISES Special Service Award for services to solar energy

08.08.2005
Fuel Cell Technology Goes International:
Research Co-Operation between Fraunhofer ISE and the University of South Carolina

13.10.2005
German Environmental Award 2005
Outstanding Achievements in Solar Energy

Lectures

Agert, C.
»Mikrobrennstoffzellensysteme für portable Anwendungen«, 93. Bunsen-Kolloquium Wasserstoff und Brennstoffzellen, Schwerin, Germany, 16./17.6.2005

Agert, C.
»Mikrobrennstoffzellensysteme: Energiewirtschaftliche Relevanz, Marktübersicht, Potenzial für Produktinnovationen«, 4. Brennstoffzellenforum Hessen, Wiesbaden, Germany, 13.9.2005

Agert, C.
»From Research Results to Commercial Success«, EUREC College of Members, Almeria, Spain, 9.11.2005

Aicher, T.; Martin, H.[1]
»Natural Convection in Heat Exchangers – A New Incentive for More Compact Heat Exchangers?«, 5th International Conference on Enhanced, Compact and Ultra-Compact Heat Exchangers, Whistler, Canada, 11.–16.9.2005
([1]: Universität Karlsruhe, Thermische Verfahrenstechnik, Karlsruhe, Germany)

Aicher, T.; Szolak, R.; Bett, A. W.; Schlegl, T.; Gombert, A.; Gopinath, A.; Hebling, C.; Luther, J.
»TPV Systems and Simulation«, CLEAN ENERGY POWER 2005, Berlin, Germany, 27.1.2005

Aicher, T.
»TPV- Prinzip und Stand der Entwicklungen«, Workshop Thermoelektrik/Thermophotovoltaik, Berlin, Germany, 3.6.2005

Aicher, T.
»Technologien der Erdgasreformierung«, Fachseminar Brennstoffzellen-BHKWs, Weiterbildungszentrum Brennstoffzelle Ulm (WBZU), Ulm, Germany, 3.3.2005

Aicher, T., Griesser, L.[1]
»Novel Process for Evaporation of Liquid Hydrocarbons«, 3rd European Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005
([1]: Engineering and Project Management, Zurich, Switzerland)

Aicher, T.
»Steam Reforming of Methane and (Bio-) Ethanol«, Gastvortrag im Rahmen des Post-Graduate Course Bioenergy - Theory & Applications, Helsinki University of Technology, Espoo, Finland, 3.11.2005

Aicher, T.
»Grundlagen der Reformierung«, Gastvortrag im Rahmen der Vorlesung Brennstoffzellen und Batterien an der TU Karlsruhe, Germany, 28.11.2005

Baur, C.; Meusel, M.; Dimroth, F.; Bett, A. W.; Nell, M.[1]; Strobl, G.[1]; Taylor, S.[2]; Signorini, C.[2]
»Analysis of the Radiation Hardness of Triple- and Quintuple-Junction Space Solar Cells«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005
([1]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([2]: European Space Research & Technology Centre, Noordwijk, The Netherlands)

Baur, C.; Bett, A. W.
»Modelling of II-V Multi-junction Cells Based on Spectrometric Characterisation«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Baur, C.; Bett, A. W.
»Measurement Uncertainties of the Calibration of Multi-Junction Solar Cells«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005

Bett, A. W.; Baur, C.; Dimroth, F.; Schöne, J.[1]
»Metamorphic CalnP-GalnAs Layers for Photovoltaic Applications«, Materials Research Society Fall Meeting, Boston, Massachusetts, USA, 28.11.–3.12.2004
([1]: Technische Fakultät der Christian-Albrechts-Universität, Kiel, Germany)

Bett, A. W.
»Hocheffiziente III-V Solarzellen – Herstellung, Charakterisierungen und Anwendungen«, Seminar für Festkörperphysik, Universität Kiel, Germany, 3.2.2005

Bett, A. W.
»Photovoltaic Cells for TPV Applications«, Clean Energy Power 2005, 1st Conference on TPV: Science to Business, ICC Berlin, Germany, 27.1.2005

Bett, A. W.; Baur, C.; Lerchenmüller, H.[1]; Siefer, G.; Dimroth, F.; Willeke, G.
»The FLATCON® Concentrator PV-Technology«, 3rd Conference on Solar Concentrators for the Generation of Electricity or Hydrogen, Scottsdale, Arizona, USA, 1.–6.5.2005
([1]: Concentrix Solar GmbH, Freiburg, Germany)

Bett, A. W.
»III-V Materialien für die Photovoltaik«, Seminar Fraunhofer Institut für Angewandte Festkörperphysik IAF, Freiburg, Germany, 19.4.2005

Bett, A. W.
»Recent Developments in III-V Multi-Junction Space Solar Cells«, 7th European Space Power Conference, Stresa, Italy, 9.–13.5.2005

Bett, A. W.; Lerchenmüller, H.[1]; Jaus, J.; Willeke, G.
»Cost and Market Perspectives for FLATCON® - Systems«, Conference on Solar Concentrators for the Generation of Electricity or Hydrogen, Scottsdale, Arizona, USA, 1.–5.5.2005
([1]: Concentrix Solar GmbH, Freiburg, Germany)

Bett, A. W.; Burger, B.; Dimroth, F.; Siefer, G.; Lerchenmüller, H.
»Flatcon PV System: Technology and Perspectives« 2005 Taiwan Symposium on HCPV System, Taiwan, 15/16.11.2005

Bett, A.W.
»Kaskaden-Solarzellen mit Wirkungsgraden über 35 %«, Physikalisches Kolloquium Universität Kassel, Germany, 10.11.2005

Bett, A.W.
»Multi Junction Solar Cells in Europe«, FULL-SPECRTUM and SOLAR ELERCTRICITY, Amphitheatre Building 36, JRC ISPRA, Italy, 23./24.11.2005

Biro, D.; Gräff, M.
»Simulation einer F&E Solarzellenfertigungslinie«, Arena User Meeting, Freiburg, Germany, 20.9.2005

Bläsi, B.; Gronbach, A.; Mick, J.[1]; Müller, C.[1]; Schumann, M.; Gombert, A.
»Interference Lithography: Pushing the Limits«, Diffractive Optics 2005, Warsaw, Poland, 3.–7.9.2005
([1]: Institut für Mikrosystemtechnik IMTEK, Freiburg, Germany)

Bopp, G.
»Elektrische Sicherheit, Errichtungsbestimmungen, Blitzschutz und EMV«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Bopp, G.
»Welche EMV-Normen und Grenzwerte sind für Solaranlagen relevant ?«, Profiseminar EMV und Blitzschutz für Solaranlagen, OTTI-Technik-Kolleg, Regensburg, Germany, 30.11–1.12.2005

Bopp, G.
»Erzeugen PV-Anlagen Elektrosmog?«, Profiseminar EMV und Blitzschutz für Solaranlagen, OTTI-Technik-Kolleg, Regensburg, Germany, 30.11–1.12.2005

Bopp, G.
»Beispielhaft ausgeführter Blitzschutz bei Kollektoranlagen und netzgekoppelten PV-Anlagen«, Profiseminar EMV und Blitzschutz für Solaranlagen, OTTI-Technik-Kolleg, Regensburg, Germany, 30.11–1.12.2005

Borchert, D.; Gronbach, A.; Rinio, M.; Kenanoglu, A.; Zippel, E.; Castels, F.
»Process Steps for the Production of Large Area (n) a-Si:H/(p) c-Si Heterojunction Solar Cells«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Bracke, R.[1]; Bühring, A.; Wigbels, M.[2]; Müller, P.[3]
»Wärmepumpen und oberflächennahe Geothermie«, Wärme und Kälte Energie aus Sonne und Erde, Köln, Germany, 22./23.9.05
([1]: Fachhochschule Bochum-GeothermieZentrum GZB) ([2]:Fraunhofer UMSICHT, Oberhausen, Germany) ([3]:Fachhochschule Dortmund/ TZWL, Germany)

Bühring, A.
»Aktueller Stand der Weiterentwicklung von Lüftungs-Kompaktgeräten«, Internationale Passivhaustagung 2005, Ludwigshafen, Germany, 29./30.4.2005

Bühring, A.
»Development and Measurements of Compact Heating and Ventilation Devices with Integrated Exhaust Air Pump for High Performance Houses«, 8th International Energy Agency Heat Pump Conference 2005, Las Vegas, USA, 30.5.–2.6.2005

Bühring, A., Bichler, C.
»Aktueller Stand der Weiterentwicklung von Lüftungs-Kompaktgeräten mit Abluftwärmepumpe«, 3. Forum Wärmepumpe, Berlin, Germany, 13./14.10.05

Bühring, A.
»Entwicklung von Lüftungs-Kompaktgeräten mit Abluftwärmepumpe«, OTTI-Profiforum Lüftungstechnik, Regensburg, Germany, 25./26.1.2005

Bühring, A.
»Neue Entwicklungen im Bereich von Wärmepumpen«, Expertenhearing Wärmepumpen des Bremer Energie-Konsens, Bremen, Germany, 20.1.2005

Bühring, A.
»Grundlagen der Lüftungstechnik, Luftheizung und Lüftungs-Kompaktgeräte für Passivhäuser«, Energietage Südtirol, Bozen, Italy, 22.4.2005

Burger, B.; Rüther, R.[1]
»Site-Dependent System Performance and Optimal Inverter Sizing of Grid-Connected PV Systems« 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005
([1]: Universidade Federal de Santa Catarina/UFSC, Florianopolis, Brazil)

Burger, B.
»Auslegung und Dimensionierung von Wechselrichtern für netzgekoppelte PV-Anlagen«, 20. Symposium Photovoltaische Solarenergie, OTTI Technologie-Kolleg, Bad Staffelstein, Germany, 9.–11.3.2005

Burger, B.
»Power Electronics for Renewable Energies«, International Workshop on Power Electronics New Wave, Tokyo, Japan, 11.4.2005

Burger, B.
»Wechselrichter für Inselsysteme«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Burger, B.
»Hocheffiziente Wechselrichter zur Einspeisung regenerativer Energie«, ECPE/ETG Seminar Energieeinsparung und rationelle Energienutzung durch Leistungselektronik, Erlangen, Germany, 13.10.2005

Burger, B.
»Wechselrichter für die Photovoltaik«, Power Electronic Systems Laboratory, ETH Zurich, Switzerland, 6.12.2005

Campesato, R.[1]; Flores, C.[1]; Iurato, F.[1]; Barde, H.[2]; Uebele, P.[3]; Strobl, G.[3]; Bett, A. W.; Smekens, G.[4]; Vanbegin, J.[4]; Caon, A.[5]
»Advanced Solar Cells for Missions to Mars«, 7th European Space Power Conference, Stresa, Italy, 9.–13.5.2005
([1]: CESI S.p.A., Milano, Italy) ([2]: Astrium SAS, Europe) ([3]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([4]: E.N.E., Brussels, Belgium) ([5]: ESA, Noordwijk, The Netherlands)

Dimroth, F.; Baur, C.; Bett, A.W.; Meusel, M.[1]; Strobl, G.[1]
»III-V Junction Photovoltaic Cells for Space and Terrestrial Concentrator Applications«, 31st IEEE Photovoltaic Specialist Conference, Orlando, Florida, 3-7.1.2005
([1]: RWE-Space Solar Power GmbH, Heilbronn, Germany)

Eccarius, S., Manurung, T., Hebling, C.
»Characterization of DMFCs for Portable Devices«, Third European Polymer Electrolyte Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005

Eccarius, S., Flores, C.[1]; Wittstadt, U.; Hebling, C.
»Optimization of Membrane Electrode Assembly for SPE Water Electrolysis by Design of Experiment«, 1st Symposium on Manufacturing of MEAs for Hydrogen Applications, Dayton, Ohio, USA, 9.–11.8.2005
([1]: CESI S.p.A., Milano, Italy)

Erge, T.; Kroeger-Vodde, A.; Laukamp, H.; Puls, H.-G.; Thoma, M.; Wittwer, C.
»Optimierung des Einsatzes von PV-Anlagen in dezentral organisierten Stromnetzen durch intelligentes Betriebsmanagement«, OTTI Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005

Erge, T.; Strauss, P.[1]; Meyer, T.; Degner, T.[1]
»DISPOWER – Distributed Generation with High Penetration of Renewable Energy Sources«, in: Tagungsband, First International Conference on the Integration of RES and DG, Brussels, Belgium, 3.12.2004
([1]: Institut für Solare Energieversorgungstechnik ISET, Kassel, Germany)

Erge, T.; Kroeger-Vodde, A.; Laukamp, H.; Puls, H.-G.; Thoma, M.; Wittwer, C.
»Optimisation of PV System Operation in Decentralised Electricity Grids by Realisation of Intelligent Operation Management«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Erge, T.
»Die Bewertung von Ertragsgutachten bei der Erstellung von Finanzierungskonzepten für Photovoltaikanlagen«, 26. Forum Solarpraxis, Berlin, Germany, 17.–18.11.2005

Forberich, K.
»Organic Photonic Crystal Lasers« Universität Linz, Austria, 3.6.2005

Glunz, S.W.
»Defect-Related Issues in Crystalline Silicon Solar Cells«, Japan-Germany Colloquium on Semiconductor Physics, Dresden, Germany, 15.2.2005

Glunz, S.W.
»Stand und Perspektiven der Photovoltaik«, 69. Jahrestagung der Deutschen Physikalischen Gesellschaft, Berlin, Germany, 9.3.2005

Glunz, S. W.; Grohe, A.; Hermle, M.; Hofmann, M.; Janz, S.; Roth, T.; Schultz, O.; Vetter, M.; Martin, I.[1]; Ferré, R.[1]; Bermejo, S.; Wolke, W.; Warta, W.; Preu, R.; Willeke, G.
»Comparison of Different Dielectric Passivation Layers for Application in Industrially Feasible High-Efficiency Crystalline Silicon Solar Cells«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Universidad Politècnica de Catalunya, Barcelona, Spain)

Goetzberger, A.
»Flächennutzung von Solarkraftwerken: Erweiterung der Wirkungsgraddefinition«, OTTI Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005

Goldschmidt, J. C.
»Die Energiewende ist möglich – Potenziale, Technologie, Regelstrategien und wirtschaftliche Aspekte der Nutzung von erneuerbaren Energiequellen«, Lions Club Bad Orb, Germany, 12.1.2005

Goldschmidt, J. C.; Schultz, O.
»Vorhersage von Solarzellenparametern aus ortsaufgelösten Lebensdauermessungen«, Silicon Forest 2005, Silicon Forest 2005, Falkau, Altglashütten, Germany, 27.2.2005

Goldschmidt, J. C.; Schultz, O.; Glunz, S. W.
»Predicting Multi-Crystalline Silicon Solar Cell Parameters from Carrier Density Images«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Gölz, S.; Bopp, G.; Preissler, E.[1]
»SHS-Modelle im Praxisvergleich, Projekterfahrungen mit Kreditmodellen und dem Betreiber-Ansatz«, in: OTTI-Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005
([1]: Freie Consultant)

Gölz, S.
»Nichttechnische Aspekte der ländlichen Elektrifizierung«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Gombert, A.
»Mikrostrukturierte Kunststoffoberflächen in Solar- und Displaytechnik«, Transparente Kunststoffe, Würzburg, Germany, 1./2.6.2005

Gombert, A.
»Selective Emitters for Thermophotovoltaic (TPV) Systems«, Clean Energy Power, Berlin, Germany, 27.1.2005

Gombert, A.
»Mottenaugenstrukturen zur Entspiegelung«, Technische Universität Berlin, Germany, 28.1.2005

Gombert, A.
»Diffractive and Subwavelength Micro-optics for Light Management«, POLYMICRO/NEMO Workshop on Micro-Optics – Benefits for Industry, Vrije Universiteit Brussel, Belgium, 7.4.2005

Grohe, A.; Schneiderlöchner, E.; Fleischhauer, B.; Hofmann, M.; Glunz, S.W.; Preu, R.; Willeke, G.
»Status and Advancement in Transferring the LFC Technology to Screen-printed Solar Cells«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Groos, U.
»Brennstoffzellen-Technologie«, Seminarveranstaltung der Universität Koblenz, Germany, 20.12.2004

Groos, U., Hebling, C.
»Potenzial der Photovoltaik für mobile, elektronische Geräte«, 2. Workshop Energieversorgungen in mobilen Anwendungen, Erlangen, Germany, 10.11.2005

Groos, U.; Letzner, L.
»The Market for Portable Fuel Cell Applications«, Introducing Hydrogen Energy Technologies ina Global Market: Certification & Listing Issues in Major, Hamburg, Germany, 1.9.2005

Guter, W.; Dimroth, F.; Meusel, M.; Bett, A. W.
»Optimierung von Tunneldioden in III-V Mehrfachsolarzellen«, 69. Jahrestagung der Deutschen Physikalischen Gesellschaft, Berlin, Germany, 4.- 9.3.2005

Guter, W.; Dimroth, F.; Meusel, M.; Bett, A. W.
»Entwicklung von Interband-Tunneldioden für hohe Stromdichten«, 20.Workshop des DGKK Arbeitskreises, Duisburg, Germany, 8./9.12.2005

Hebling, C.; Oedegaard, A.
»Fuel Cells for Grid-Independent Power Generation«, Kyocera Fuel Cells Workshop, Kagoshima, Japan, 14.3.2005

Hebling, C.; Oszcipok, M.
»Portable PEM Fuel Cells for Outdoor Applications«, 3rd Sino-German Workshop, Shanghai, China, 3.5.2005

Hebling, C.; Groos, U.
»Forschung und Entwicklung von Mikrobrennstoffzellen«, Mikrosystemtechnik Kongress Freiburg 2005, Freiburg, Germany, 10.-12.10.2005

Hebling, C.; Eccarius, S.; Litterst, C.[1]; Zengerle, R.[1]; Koltay, P.[1]
»Novel Structure for Passive CO_2 Degassing in Micro-DMFC«, Power MEMS 2005, Tokyo, Japan, 28.-30.11.2005
([1]: University of Freiburg, Dept. of Microsystems Engineering, Laboratory for MEMS Applications, Freiburg, Germany)

Henning, H.-M.
»Gesamtanlagen – Auslegung, Wirtschaftlichkeit, Förderprogramme«, Fachforum Solare Kühlung und Klimatisierung aus Biomasse, RENEXPO 2005, Augsburg, Germany, 23.9.2005

Henning, H.-M.
»Thermally Driven Cooling Technique – Open Cycles«, Institut National de l'Energie Solaire INES, Chambéry, France, 20.1.2005

Henning, H.-M.
»Design of Solar Assisted Air-Conditioning Systems«, Institut National de l'Energie Solaire INES, Chambéry, France, 20.1.2005

Henning, H.-M.
»Neues, hocheffizientes Verfahren zur sorptiven Luftdurchfeuchtung - ECOS«, Fachforum Lüftungstechnik, Regensburg, Germany, 27.1.2005

Henning, H.-M.
»Solare Klimatisierung – Vorstellung realisierter Anlagen, Wirtschaftlichkeit«, Clean Energy Power CEP 2005, Berlin, Germany, 27.1.2005

Henning, H.-M.
»Solare Kühlung und Klimatisierung«, Gesellschaft für technische Zusammenarbeit GTZ, Eschborn, Germany, 24.2.2005

Henning, H.-M.
»Solar Cooling«, World Sustainable Energy Days WSED 2005, Wels, Austria, 3.3.2005

Henning, H.-M.
»Kälteanlagen für den Betrieb mit (Ab)Wärme – Funktionsweise, Anlagen und Stand der Technik«, RENEXPO 2005-Internationale Fachmesse und Kongress, Augsburg, Germany, 22.-25.9.2005

Henning, H.-M.
»Solar Assisted Air Conditioning of Buildings – An Overview«, 4th Annual Regional Conference (ARC), Athens, Greece, 25.–27.9.2005

Henning, H.-M.; Noeres, P.[1]; Lokurlu, A.[2]; Braun, R.[3]
»Solare Kühlung und Klimatisierung – Belüftung und Wärmerückgewinnung«, Forschungs-Verbund Sonnenenergie FVS Jahrestagung 2005, Köln, Germany, 22./23.9.2005
([1]: Fraunhofer UMSICHT, Oberhausen, Germany)
([2]: Solar-Institut Jülich, Germany)
([3]: Fachhochschule Gelsenkirchen, Germany)

Henning, H.-M.
»Solar Thermal Energy for Air-Conditioning of Buildings – Advanced Technologies Adapted to Local Climatic Conditions«, Intelligent Building Middle East 2005, Manama, Kingdom Bahrain, 5.-7.12.2005

Henning, H.-M.
»Thermisch aktive Materialien: Grundlagen und Anwendungen«, LMU München, FB Physikalische Chemie, München, Germany, 14.12.2005

Hermle, M.; Schneiderlöchner, E.; Grupp, G.; Glunz, S. W.
»Comprehensive Comparison of Different Rear Side Contacting Methods«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Holz, F.
»Netzferne Elektrifizierung vom Solar Home System über Alpenvereinshäuser bis hin zur Dorfstromversorgung«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Hube, W.[1]; Crisinel, M.[2]; Vollmar, T.[2]; Platzer, W.[1]
»Glass Facade Elements With Internal Fluid Flow«, GLASS in BUILDINGS, Bath, United Kingdom, 7./8.4.2005
([1]: Projektgesellschaft Solare Energiesysteme PSE, Freiburg, Germany) ([2]: Steel Structures Laboratory ICOM, Swiss Institute of Technology Lausanne EPFL, Lausanne, Switzerland)

Isenberg, J.; Schubert, M. C.; Biro, D.; Froitzheim, A.[1]; Warta, W.
»Sheet Resistance Imaging (SRI) – A Contactless and Spatially Resolved Method for the Determination of Doping Inhomogeneities«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Shell Solar GmbH, München, Germany)

Isenberg, J.; Breitenstein, O.[1]; Rakotoniaina, J. P.[1]; Hahn, G.[2]; Kaes, M.[2]; Pernau, T.[2]; Seren, S.[2]; Warta, W.
»Lock-In Thermography – A Universal Tool for Local Analysis of Solar Cells«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Max Planck Institute of Microstructure Physics, Halle, Germany)
([2]: University of Konstanz, Germany)

Janz, S.; Reber, S.; Habenicht, H.;
»C-Si Thin-Film Solar Cells on Ceramic Substrates with SiC Intermediate Layers«, 15th International Science and Engineering Conference, Shanghai, China, 10.–15.10.2005

Jaus, J.; Rentsch, J.; Preu, R.;
»Determining Trade-Offs Between Costs of Production and Cell/Module-Efficiency with the Concept of Indifference Curves«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Kaiser, R.
»Batterien in netzfernen Stromversorgungsanlagen«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Kaiser, R.
»Geschlossene Bleibatterien«, Profiforum Wiederaufladbare Batteriesysteme, OTTI-Energie-Kolleg, Ulm, Germany, 10./11.5.2005

Kiefer, K.
»Stand der Technik bei Solarstromanlagen«, Workshop Erneuerbare Energien der HVB Group, Hypovereinsbank, München, Germany, 2.2.2005

Kiefer, K.
»Gute und schlechte Erträge bei PV Anlagen in Freiburg«, Workshop Klimaschutz durch das Handwerk-Schwerpunkt Photovoltaik, Handwerkskammer Freiburg, Germany, 22.2.2005

Kiefer, K.
»Stand der Technik und Betriebserfahrungen mit netzgekoppelten Photovoltaik-Anlagen«, 2. Expertenforum Rhein-Neckar-Pfalz, Bauen mit Photovoltaik, Weinheim, Germany, 14.6.2005

Kiefer, K.
»Erträge von netzgekoppelten Photovoltaik-Anlagen«, OTTI Profiseminar Photovoltaik-Anlagen, Freiburg, Germany, 21.6.2005

Kiefer, K.
»Qualitätssicherung bei netzgekoppelten PV-Anlagen«, OTTI Profiseminar Photovoltaik-Anlagen, Freiburg, Germany, 21.6.2005

Kiefer, K.
»Optimale Erträge durch lückenlose Qualitätssicherung«, Fraunhofer ISE Kompaktseminar Photovoltaik-Technologie, Freiburg, Germany, 24.6.2005

Köhl, M.
»Solare Energiegewinnung - wo ist Forschung und Entwicklung noch notwendig?«, Institutskolloquium der Innovent e.V., Jena, Germany, 13.7.2005

Kray, D.; Baumann, S.; Mayer, K.; Schumann, M.; Bando, M.; Eyer, A.; Willeke, G. P.
»Wafering Research at Fraunhofer ISE«, 15th Workshop on Crystalline Silicon Solar Cells and Modules: Materials and Processes, Vail, Colorado, USA, 7.–10.8.2005

Kray, D.; Baumann, S.; Mayer, K.; Willeke, G. P.; Schönfelder, S.; Bagdahn, J.
»Mechanical Assessment of Innovative Maskless Microstructuring Techniques«, IZM-Workshop Thin Semiconductor Devices, München, Germany, 22.11.2005

Luther, J.
»Thermophotovoltaic Generation of Electricity«, Clean Energy Power , Berlin, Germany, 27.1.2005

Luther, J.
»Die Solarwirtschaft der Zukunft – Chancen aus wissenschaftlicher Sicht«, Jobbörse Erneuerbare Energien, Gelsenkirchen, Germany, 28.4.2005

Luther, J.
»Photovoltaics – the Basis for Sustainable Energy Systems and Industrial Innovations«, Becquerel Prize Honorary Lecture, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Luther, J., Luque A.
»Concentrating Photovoltaics for Highest Efficiencies and Cost Reduction«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Luther, J.
»PV Integration in Architecture, Technological Aspects for BIPV«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Luther, J.
»Sonnenergie – Baustein für den Klimaschutz und Wirtschaftsfaktor«, Vortrag anlässlich der Verleihung des Internationalen Rheinland-Preises für Umweltschutz 2005 der TÜV Rheinland Group, Köln, Germany, 17.6.2005

Luther, J.
»Sustainable Energy Systems«, Alfred Nobel Symposium, Tamsvik, Sweden, 20.6.2005

Luther, J.
»Von der Interpretation des Photoeffekts zur photovoltaischen Stromerzeugung«, Vortrag zum Einsteinjahr 2005 an der Albrecht-Ludwigs-Universität, Physikalisches Kolloquium SS 2005, Freiburg, Germany, 27.6.2005

Luther, J.
»World in Transition – Towards a Sustainable Energy System«, ISES Solar World Congress 2005, Honorary Lecture – ISES Special Service Award 2005, Orlando, Florida, USA, 10.8.2005

Luther, J.
»Erneuerbare Energien- die Basis für eine nachhaltige Energieversorgung«, Deutsche Gesellschaft für Sonnenenergie DGS, München, Germany, 29.10.2005

Luther, J.
»New Materials for Cost Reduction and Innovation in Solar Energy Utilisation«, Fraunhofer-Verbund Werkstoffe und Bauteile VWB, Brussels, Belgium, 7./8.11.2005

Luther, J.
»A Suite of Innovative Tools and Approaches to Enhance Knowledge Diffusion, Information Sharing and Access and Research Integration across the Science-technology Divide«, AHGSET Workshop, Oak Ridge, Tennessee, USA, 15./16.11.2005

Luther, J.
»Potenziale der Sonnenenergie – Heutige Technologien und Trends«, Fraunhofer-Forum, München, Germany, 21.11.2005

Löckenhoff, R.; van Riesen, S.[1]; Meusel, M.[2]; Dimroth F.; Bett, A. W.
»Large Area Monolithic Interconnected Modules (MIMs) for Compact Concentrator Modules«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: RWE Space Solar Power GmbH Heilbronn, Germany)

Mick, J.[1]; Müller, C.[1]; Gombert, A.; Bläsi, B.
»Maskless Origination of Microstructures with Optical Functions on Large Areas«, Microlithography 2005, San Jose, California, USA, 27.2.–4.3.2005
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Mick, J.[1]; Bläsi, B.; Gombert, A.; Reinecke, H.[1]; Müller, C.[1]
»Große dreidimensionale Mikrostrukturen mittels Interferenzlithographie«, Mikrosystemtechnik Kongress 2005, Freiburg, Germany, 10.–12.10.2005
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Mohr, A.; Roth, T.; Epmeier, M.[1]; Glunz, S. W.
»Silicon Concentrator Cells in an One-Axis Tracking Concentrator System with a Concentration Ratio of 300X«, 31st IEEE Photovoltaic Specialist Conference and Exhibition, Orlando, Florida, USA, 3.–7.1.2005
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Neumann, C.
»Grenzen und Möglichkeiten »passiver« Kühlung«, Effizientes und Solares Kühlen, Linz, Austria, 19.4.2005

Niggemann, M.; Glatthaar, M.; Gombert, A.; Hinsch, A.; Lewer, P.; Wagner, J.; Wittwer, V.; Zimmermann, B.
»Functional Microprism Substrates for Organic Solar Cells«, European Materials Research Society EMRS, Spring Meeting 2005, Strasbourg, France, 31.5.–3.6.2005

Niggemann, M.; Glatthaar, M.; Gombert, A.; Graf, W.; Georg, A.; Hinsch, A.; Lewer, P.; Wagner, J.; Wittwer, V.; Zimmermann, B.
»Functional Substrates for Flexible Organic Solar Cells«, Optics and Photonics 2005, San Diego, California, USA, 31.7– 4.8.2005

Niggemann, M.; Gombert, A.; Müller, C.; Ruf, D.
»Micro- and Nanaostructured Organic Electronic Devices« Mikrosystemtechnik Kongress 2005, Freiburg, Germany, 10.–12.10.2005

Oszcipok, M.; Zedda, M.; Hesselmann, J.; Huppmann, M.; Junghardt, M.; Riemann, D.; Hebling, C.
»Portable Fuel Cell Systems for Outdoor Applications« 9th Grove Fuel Cell Symposium, London, United Kingdom, 4.-6.10.2005

Platzer, W.; Simmler, H.[1]; Bryn, I.[2]
»Energy Performance of Facades and Buildings – IEA as Support for the European Directive?«, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005
([1]: EMPA Dübendorf, Switzerland)
([2]: Erichsen&Horgen AS, Oslo, Norway)

Platzer, W.; Hube, W.[1]; Adelmann, W.; Crisinel, M.[2]; Vollmar, T.[2]
»Development of a Glass Facade with Internal Fluid Flow«, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg, Germany) ([2]: EPFL Ecole Polytechnique Fédérale de Lausanne, Switzerland)

Platzer, W.
»Performance Assessment for Solar Shadings – State of the Art«, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005

Platzer, W.; Stramm C.; Amberg-Schwarb, S.; Köhl, M.
»Development of Innovative Insulation Systems on the Basis of Vacuum Insulation Panels«, 7th International Vacuum Insulation Symposium, Zurich, Switzerland, 28./29.9. 2005

Preu, R.
»Lasertechnologien für kristalline Si-Solarzellen«, Technologieseminar: Laseranwendung in der Photovoltaik, Göttingen, Germany, 8.11.2005

Reber, S.; Eyer, A.; Haas, F.
»High-Throughput Zone-Melting Recrystallization for c-Si Thin-Film Solar Cells«, 16th American Conference on Crystal Growth and Epitaxy, Montana, USA, 10.–14.7.2005

Reber, S.; Eyer, A.; Haas, F.; Schillinger, N.; Janz, S.; Schmich, E.
»Progress in Crystalline Silicon Thin-Film Solar Cell Work at Fraunhofer ISE«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Rein, S.; Glunz, S. W.
»Advanced Lifetime Spectroscopy – Defect Parameters of Iron in Silicon and a New Fingerprint«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Rentsch, J.; Jaus, J.; Preu, R.; Roth, K.[1]
»Economical and Ecological Aspects of Plasma Processing for Industrial Solar Cell Fabrication«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005
([1]: Roth&Rau AG, Hohenstein-Ernstthal, Germany)

Rinio, M.; Zippel, E.; Borchert, D.
»Spatial Redistribution of Recombination Centres by the Solar Cell Process«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Riede, M.; Liehr, A.; Kern, R.; Willeke, G.; Gombert, A.; Luther, J.
»Analyse der Schlüsselparameter in Organischen Solarzellen mittels Datamining«, 14. FMF-Kolloquium, Titisee Neustadt, Germany, 6./7.10.2005

Riepe, S.; Ghosh, M.[1];Müller, A.[1]; Lautenschlager, H.; Schindler, R.; Warta, W.
»Lifetime Characteristics and Gettering Effects in n-type Multicrystalline Silicon Block Material«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Deutsche Solar AG, Freiberg, Germany)

Rommel, M.; Siems, T.; Schüle, K.; Mehnert, S.; Becker, R.
»Wieviel Dampf produziert ein Kollektor im Stillstandsfall?«, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005

Roos, A.[1]; Covalet, D.[2]; Fanton, X.[3]; Persson, M.-L.[1]; Platzer, W.; Nielson, T. R.[4]; Wilson, H. R.[5]; Zinzi, M.[6]; Köhl, M.; Heck, M.; Chevalier, B.[7]
»Energy Performance of Switchable Glazing – IEA Solar Heating and Cooling Programme, Task 27«, 10th International Conference on Durability of Building Materials and Components, Lyon, France, 17.–20.4.2005
([1]: Uppsala University, Uppsala, Sweden) ([2]: EDF R&D, Moret sur Loing, France) ([3]: Saint Gobain, Paris, France) ([4]: Technical University of Denmark, Lyngby, Denmark) ([5]: Interpane, Lauenförde, Germany) ([6]: ENEA, Rome, Italy) ([7]: Centre Scientifique et Technique du Bâtiment CSTB, Grenoble, France)

Roth, W.
»Strategie zur erfolgreichen Bewerbung von Unternehmenskonsortien um Projekte internationaler Entwicklungsbanken«, 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005

Roth, W.
»Erfahrungen aus der Bildung von Unternehmenskonsortien zur Bewerbung um Projekte internationaler Entwicklungsbanken«, Thüringer Außenwirtschaftstag 2005 – Auftragsbeschaffung durch Beteiligung an internationalen Ausschreibungen, Weimar, Germany, 28.4.2005

Roth, W.
»Netzferne Stromversorgung mit Photovoltaik«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Roth, W.
»Anwendungen – Industrieprodukte und Kleinsysteme«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Roth, W.
»Anwendungen – Telekommunikation und Telematik«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Roth, W.
»Fallbeispiel Ländliche Energieversorgung – Strategie zur erfolgreichen Bewerbung um Projekte internationaler Entwicklungsbanken«, Intersolar, Freiburg, Germany, 23.6.2005

Roth, W.
»BIKE – Bayerische Initiative zur Konsortialbildung für internationale Entwicklungsprojekte«, in: Veranstaltungsunterlagen, Internationale Aufträge gewinnen! Geschäftschancen in Projekten der Weltbank und anderer internationaler Organisationen, Bayreuth, Germany, 5.7.2005

Roth, W.
»Strategische Maßnahmen zur erfolgreichen Bewerbung von Unternehmenskonsortien um Projekte internationaler Entwicklungsbanken«, in: Tagungsunterlagen, Internationale Ausschreibungen – Chancen nutzen, Leipzig, Germany, 25.10.2005

Russ, C.; Göttsche, J.[1]
»Energieversorgung in Niedrigstenergie-Wohngebäuden«, ForschungsVerbund Sonnenenergie FVS Jahrestagung 2005, Köln, Germany, 22./23.9.2005
([1]: Solar- Institut Jülich, Germany)

Russ, C.
»Bauliche und energetische Bewertung von 50 Demonstrationsprojekten«, Seminar Solarunterstützte energetische Wohngebäude – Ergebnisse aus der IEA Task 28738, Freiburg , Germany, 30.6.2005

Russ, C.
»Solarunterstützte energieeffiziente Wohngebäude« Symposium EU -Gebäudeeffizienzrichtlinie, Beiträge der Forschung für die Praxis, Freiburg, Germany 28./29.10.2005

Russ, C,
»Efficient Building Design for Very Low Energy Houses«, Seminar VESTA, Cernay, France, 8.11.2005

Russ, C,
»Sommerlicher Wärmeschutz in Wohngebäuden«, Hausmesse SIC Energie rund ums Haus, Freiburg, Germany, 25.4.2005

Sastrawan, R.[1]; Hinsch, A.; Beier, J.[2]; Belledin, U.[1]; Hemming, S.[3], Kern, R .; Vetter, C.[2]
»Upscaling Dye Solar Modules with Durable Glass Frit Sealing«, 15th International Science and Engineering Conference, Shanghai, China, 10.–15.10.2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany) ([3]: PSE GmbH, Forschung, Entwicklung, Marketing, Freiburg, Germany)

Sastrawan, R.[1]; Hinsch, A.; Beier, J.[2]; Belledin, U.[1]; Hemming, S.[3]; Hore, S.[1]; Kern, R.; Prahl, C.; Renz, J.; Vetter, C.[2]; Würfel, U.[1]; Luther, J.; Petrat, F.-M.[4]; Prodi-Schwab, A.[4]
»Towards Manufacturing Dye Solar Cells», 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([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 GmbH, Marl, Germany)

Schmidhuber, H.
»Fertigungstechniken der Zukunft – vom Wafer zum Modul«, S. A. G. Partnertag, Glottertal, Germany, 25.2.2005

Schmidhuber, H.
»Verkapselung von hocheffizienten kristallinen Silicium-Solarzellen«, 2. Symposium High-Tech Kunststoffe und ihre innovativen Anwendungen, Würzburg, Germany, 11./12.5.2005

Schmidhuber, H.
»Neueste Techniken in der PV-Modulproduktion«, Fachforum Solarstadt München, Germany, 4.4.2005

Schmidhuber, H.; Klappert, S.; Stollhof, J.; Erfurt, G.; Preu, R.
»Laser Soldering – a Technology for Better Contacts?«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Schmidt, H.
»Aufbau und Funktionsweise von Solarzelle, Modul und Solargenerator«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Schmidt, H.
»Laderegler und Überwachungseinrichtungen für Batterien in photovoltaischen Energieversorgungen«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Schmidt, H.
»EMV-gerechtes Geräte- und Anlagendesign«, Fachseminar EMV und Blitzschutz für Solaranlagen, OTTI-Energie-Kolleg, Regensburg, Germany, 30.11.2005

Schnabel, L; Schmidt, F.; Henning, H.-M.
»Simulation Study on the Kinetics of Water Vapour Adsorption on Different Kinds of Adsorptive Materials«, OTTI Energie-Kolleg International Conference Solar Air-Conditioning 2005, Bad Staffelstein, Germany, 6./7.10.2005

Schossig, P.; Tamme, R.; Göttsche,J.; Huenges, E.; Drück,H.; Kabus, F.; Dötsch, C.
»Wärmespeicher für die Hausenergieversorgung«, ForschungsVerbund Sonnenenergie FVS Jahrestagung 2005, Köln, Germany, 22./23.9.2005
([1]: DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. Köln, Germany) ([2]: Solar Institut Jülich, Germany) ([3]: GFZGeoForschungsZentrum Potsdam, Germany) (4: ITW Universität Stuttgart, Germany) (5: GTN Geothermie Neubrandenburg, Germany) (6: Fraunhofer UMSICHT, Oberhausen, Germany)

Schossig, P.
»Phase Change Materials for Cold Storage Applications«, IEA TASK 32 Workshop, Fontainebleau, France, 24.11.2005

Schöne, J.; Dimroth, F.; Druschke, I.; Bett, A. W.; Spiecker, E.[1]; Jäger, W.[1]
»Charakterisierung metamorpher GaInAs Pufferschichten auf GaAs und Ge«, Deutsche Gesellschaft für Kristallwachstum und Kristallzüchtung DGKK Workshop, 9./10.12.2004
(1: Technische Fakultät der Christian-Albrechts-Universität zu Kiel, Kiel, Germany)

Schöne, J.; Dimroth, F.; Bett, A. W.; Speiker, E.; Jäger, W.
»High Efficient Triple Junction Solar Cells from III-V Materials: Study and Optimization of Growth«, Sehlendorf Seminar, Kiel, Germany, 7.–9.9.2005

Schöne, J.; Dimroth, F.; Bett, A. W., Szeczesek, P.[1] Amarirei, A.[1], Polychroniadis, E.K.[1]
»Phasenseparation in den III-V Verbindungshalbleitern GaInAs und GaInAsSb«, 20. Workshop des DGKK Arbeitskreises, Duisburg, Germany, 8./9.12.2005
([1]: Department of Physics, Aristotle University of Thessaloniki, Greece)

Schubert, M. C.[1]; Isenberg, J.; Rein, S.; Warta, W.
»Ortsaufgelöste temperaturabhängige Lebensdauerspektroskopie mit Carrier Density Imaging«, Workshop Silicon Forest 2005, Falkau, Altglashütten, Germany, 27.2.–2.3.2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Schultz, O.; Hofmann, M.; Glunz, S. W.; Willeke, G.
»Silicon Oxide / Silicon Nitride Stack System for 20% Efficient Silicon Solar Cells«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005

Schultz, O.; Glunz, S. W.; Kray, D.; Dhamrin, M.[1]; Yamaga, I.[2]; Saitoh, T.[1]; Willeke, G. P.
»High-Efficiency Multicrystalline Silicon Solar Cells on Gallium-Doped Substrate«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Tokyo University of Agriculture and Technology, Koganei, Tokyo, Japan) ([2]: Dai-ichi Kiden Co., Tokyo, Japan)

Schultz, O.
»High-Efficiency Multicrystalline Silicon Solar Cells«, Workshop Silicon Forest 2005, Falkau, Altglashütten, Germany, 27.2.–2.3.2005

Seibert, U.;
»Anwendung – Wasseraufbereitung, Desinfektion und Entsalzung«, Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Siefer, G.; Bett, A. W.
»Experimental Comparison Between the Power Outputs of FLATCON® Modules and Silicon Flat Plate Modules«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005

Siefer, G.; Dimroth, F.; Lerchenmüller[1], H.; Peharz, G.; Schöne, J.; Bett, A. W.
»FLATCON® Concentrator Technology - Ready for the Market«, 3rd International Workshop on Crystal Growth Technology, Beatenberg, Switzerland, 10.–18.9.2005
([1]: Concentrix Solar GmbH, Freiburg, Germany)

Smolinka, T.; Grünerbel, M.[1]; Wittstadt, U.; Lehnert, W.[1]
»Performance and Endurance of PEFC Single Cells and Stacks Fed with Hydrogen and Reformate«, 3rd European Polymer Electrolyte Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005
([1]: Zentrum für Sonnenenergie- und Wasserstoff-Forschung ZSW, Ulm, Germany)

Specht, M.[1]; Zuberbühler, U.[1]; Wittstadt, U.
»Regenerativer Wasserstoff – Erzeugung, Nutzung und Syntheserohstoff«, FVS Jahrestagung 2004: Wasserstoff und Brennstoffzellen – Energieforschung im Verbund, Berlin, Germany, 25./26.11.2004
([1]: Zentrum für Sonnenenergie- und Wasserstoffforschung ZSW, Stuttgart, Germany)

Steinhüser, A.
»Photovoltaik-Hybridsysteme«, Vorlesung an der Universität Karlsruhe, Germany, 31.5.2005

Steinhüser, A.
»Computerunterstützte Auslegung von Photovoltaik-Systemen«, Vorlesung an der Universität Karlsruhe, Germany, 31.5.2005

Steinhüser, A.
»Netzferne Photovoltaik-Anlagen«, Vorlesung an der Universität Karlsruhe, Germany, 31.5.2005

Steinhüser, A.
»Computerunterstützte Auslegung und Simulation von Photovoltaiksystemen«, Fachseminar Netzferne Stromversorgung mit Photovoltaik, OTTI-Energie-Kolleg, Freiburg, Germany, 16./17.6.2005

Went, J.
»High-Intensity Ultrasonic Fields: A Promising Antifouling Strategy for UF Membranes in Decentralized Drinking Water Treatment Plants», International Conference and Exhibition for Filtration and Separation Technology FILTECH, Wiesbaden, Germany, 11.–13.10.2005

Went, J.
»Leistungsultraschall: Eine viel versprechende Strategie gegen die Membranverblockung bei der Ultrafiltration in dezentralen Trinkwasseraufbereitungsanlagen», Workshop: Kavitation, Physikalisch Technische Bundesanstalt, Braunschweig, Germany, 17./18.11.2005

Wienold, J.; Kuhn, T.
»Blendungsbewertung von Tageslicht am Büroarbeitsplatz«, OTTI Energie-Kolleg 11. Symposium Innovative Lichttechnik in Gebäuden, Bad Staffelstein, Germany, 27./28.1.2005

Wienold, J.;Christoffersen, J.;
»Towards a New Daylight Glare Rating«, Luxeuropa 2005 , Berlin, Germany, 19.–21.9.2005

Willeke, G.
»SOLAR PV Technology Trends«, REFF Wall Street, New York, USA, 23./24.6.2005

Wilson, H.R.
»Intelligente Fenster«, ISFH Kolloquium, Hameln, Germany, 25.10.2005

Wittwer, V.
»PERFORMANCE- eine neue EU- Initiative«, 2. Workshop Photovotaik-Modultechnik, TÜV Rheinland, Köln, Germany, 2.12.2005

Wolke, W.; Preu, R.; Catoir, J.; Emanuel, G.; Ruske, M.[1]; Liu, J. [1]
»Surface Passivation for Solar Cells by Large Scale Inline Sputtering of SiN:H«, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Applied Films GmbH, Alzenau, Germany)

Ziegler, C.[1]; Philipps, S.; Niemeyer, J.[1]; Schumacher, J. O.
»Dynamic Modeling of a PEM Fuel Cell Stack«, 3rd European Polymer Electrolyte Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005
([1]: Control Systems Laboratory, University of Karlsruhe, Germany)

Ziegler, C.; Yu, H.; Schumacher, J.
»Analysis of the PEM Fuel Cell Dynamics«, 3rd European Polymer Electrolyte Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005

Ziegler, C.; Yu, H. M.; Schumacher, J. O.
»Simulation of Cyclo-Voltammograms in PEM Fuel Cells«, Computational Fuel Cell Dynamics III, Banff, Canada, 19.–24.3.2005

Ziegler, C.; Tranitz, M.; Schumacher, J.O.
»A Model for Planar Self-breathing Proton Exchange Membrane Fuel Cells in FEMLAB«, FEMLAB Conference, Frankfurt am Main, Germany, 2.–4.11.2005

Zimmermann, B.; Mingirulli, N.; Glatthaar, M.; Niggemann, M.; Riede, M.; Hinsch, A.
»Influence of Electrode Material on the Built-In Potential and Photovoltaic Performance of Organic Bulk-Heterojunction Solar Cells«, European Materials Research Society EMRS Spring Meeting 2005, Strasbourg, France, 31.5.–3.6.2005

Publications

Abbott, P.; Bett, A. W.
»Cell-Mounted Spectral Filters for Thermophotovoltaic Applications«, in: Proceedings, 6th International Conference on Thermophotovoltaic Generation of Electricity, Freiburg, Germany, 14.–16.6.2004, AIP Conference Proceedings 738, pp. 24-25

Aicher, T.; Martin, H.[1]
»Natural Convection in Heat Exchangers – A New Incentive for More Compact Heat Exchangers?«, in: Proceedings, 5th International Conference on Enhanced, Compact and Ultra-Compact Heat Exchangers, Whistler, Canada, 11.–16.9.2005
([1]: Universität Karlsruhe, Thermische Verfahrenstechnik, Karlsruhe, Germany)

Aicher, T.; Pasel, J.[1]; Peters, R.[1]
»Wasserstofferzeugung aus Dieselkraftstoffen«, in: Tagungsband, ForschungsVerbund Sonnenenergie, FVS-Jahrestagung, Berlin, Germany, 25./26.11.2004
([1]: Institut für Energieverfahrenstechnik IWV-3, Forschungszentrum Jülich GmbH, Germany)

Aicher, T.; Griesser, I.[1]
»Novel Process for Evaporation of Liquid Hydrocarbons«, in: Tagungsband, 3rd European Polymer Electrolyte Fuel Cell Forum PEFC, Lucerne, Switzerland, 4.–8.7.2005, p.52
([1]: Lothar Griesser Engineering, Zurich, Switzerland)

Aicher, T., Blum, L.[1], Specht, M.[2]
»Wasserstoffgewinnung aus Erdgas – Anlagenentwicklung und Systemtechnik«, in: Tagungsband, ForschungsVerbund Sonnenenergie, FVS-Jahrestagung, Berlin, Germany, 25./26.11.2004
([1]: Forschungszentrum Jülich, Germany)
([2]: Zentrum für Sonnenenergie- und Wasserstoffforschung ZSW, Stuttgart, Germany)

Aicher, T.; Höhlein, B.[1]; Grube, T.[1]; Reijerkerk, J.[2]; Jörissen, L.[3]
»Wasserstofflogistik – Produktion, Konditionierung, Verteilung, Speicherung und Betankung«, in: Tagungsband, ForschungsVerbund Sonnenenergie, FVS-Jahrestagung, Berlin, Germany, 25./26.11.2004
([1]: Forschungszentrum Jülich, Germany)
([2]: Linde Gas AG, Germany) ([3]: Zentrum für Sonnenenergie- und Wasserstoffforschung ZSW, Stuttgart, Germany)

Baur, C.; Meusel, M.; Dimroth, F.; Bett, A. W.; Nell, M.[1]; Strobl, G.[1]; Taylor, S.[2]; Signorini, C.[2]
»Analysis of the Radiation Hardness of Triple- and Quintuple-Junction Space Solar Cells«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, , Orlando, Florida, USA, 3.–7.1.2005, pp. 548-551
([1]: RWE Space Solar Power GmbH, Heilbronn, Germany) (2: European Space Research & Technology Centre, Noordwijk, The Netherlands)

Baur, C.; Meusel, M.; Dimroth, F.; Bett, A. W.
»Investigation of Ge Component Cells«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005, pp. 675-678

Baur, C.; Bett, A. W.
»Measurement Uncertainties of the Calibration of Multi-Junction Solar Cells«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005, pp. 583-585

Baur, C.; Bett, A. W.
»Modeling of III-V Multi-Junction Cells Based on Spectrometric Characterisation«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 183-186

Becker, R.; Wittwer, C.
»Emulation vernetzter Regelungssysteme für solarthermische Energieversorgungssysteme«, in: Tagungsband, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005, pp. 364-369

Bett, A. W.; Baur, C.; Dimroth, F.; Schöne, J.[1]
»Metamorphic CaInP-GaInAs Layers for Photovoltaic Applications«, in: Proceedings, Materials Research Society Fall Meeting, Boston, Massachusetts, USA, 28.11.–3.12.2004, Vol. 836, pp. 223-233
([1]: Technische Fakultät der Christian-Albrechts-Universität, Kiel, Germany)

Bett, A. W.; Baur, C.; Dimroth, F.; Guter, W.; Meusel, M.[2]; Strobl, G.[1]
»Recent Developments in III-V Multi-Junction Space Solar Cells«, in: Proceedings, 7th European Space Power Conference, Stresa, Italy, 9.–13.5.2005, ESA SP-589
([1]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([2]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Bett, A. W.; Campesato, R.[1]; Flores, C.[1]; Lurato, F.[2]; Barde, H.[3]; Uebele, P.[4]; Strobl, G.[4]; Baur, C.; Smekens, G.[5]; Vanbegin, J.[5]; Caon, A.[6]
»Advanced Solar Cells for Missions to Mars«, in: Proceedings, 7th European Space Power Conference, Stresa, Italy, 9.–13.5.2005, NREL-CD-520-38172
([1]: CESI S.p.A, Milano, Italy) ([2]: Politecnico di Milano, Italy) ([3]: Astrium SAS, France) ([4]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([5]: E.N.E., Brussels, Belgium) (6: ESA, Noordwijk, The Netherlands)

Bett, A. W.; Baur, C.; Lerchenmüller, H.; Siefer, G.; Dimroth, F.; Willeke, G.
»The FLATCON® Concentrator PV-Technology«, in: Proceedings, 3rd Conference on Solar Concentrators for the Generation of Electricity or Hydrogen, Scottsdale, Arizona, USA, 1.–6.5.2005, NREL CD August 2005

Bett, A. W.; Siefer, G.; Baur, C.; Riesen, S. v.; Peharz, G.; Lerchenmüller, H.; Dimroth, F.
»The FLATCON® Concentrator PV-Technology ready for the market«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp.114-117

Bläsi, B.; Gronbach, A.; Mick, J.[1]; Müller, C.[1]; Schumann, M.; Gombert, A.
»Interference Lithography: Pushing the Limits«, in: Proceedings, Diffractive Optics 2005, Warsaw, Poland, 3.–7.9.2005
([1]: Institut für Mikrosystemtechnik IMTEK, Freiburg, Germany)

Bopp, G.; Gabler, H.[1]; Haugwitz, F.[2]; Liu, H.[3]; Li, Z.[3]; Müller, H.[2]; Steinhüser, A.
»Monitoring of PV Village Power Supply Systems in China«, in: Proceedings, 15th International Photovoltaic Science and Engineering Conference, Shanghai, China, 10.–15.10.2005
([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)

Borchert, D.; Rinio, M.; Tölle, R.[1]; Janßen, L.[2]; Nositschka, W. A.[3]; Kurz, H.[2]
»Silicon Nitride for Backside Passivation of Multicrystalline Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([1]: Shell Solar GmbH, Munich, Germany)
([2]: RWTH Aachen University, Aachen, Germany)
([3]: now with: Saint Gobin Glass Deutschland GmbH, Herzogenrath, Germany)

Borchert, D.; Gronbach, A.; Rinio, M.; Kenanoglu, A.; Zippel, E.; Castels, F.
»Process Steps for the Production of Large Area (N) A-SI:H/(P) C-SI Heterojunction Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Bracke, R.[1]; Bühring, A.; Wigbels, M.[2]; Müller, P.[3]
»Wärmepumpen und oberflächennahe Geothermie«, in: Tagungsband, Wärme und Kälte-Energie aus Sonne und Erde, Köln, Germany, 22./23.9.2005
([1]: Fachhochschule Bochum- Geothermie-Zentrum GZB) ([2]:Fraunhofer UMSICHT, Oberhausen, Germany) ([3]:Fachhochschule Dortmund/ TZWL, Germany)

Brendle, W.; Nguyen, V.; Brenner, K.; Rostan, P. J.; Grohe, A.; Schneiderlöchner, E.; Rau, U.; Schubert, M. B.; Werner, J. H.
»Low Temperature Back Contacts for High Efficiency Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Browne, W.[1]; Wheldon, A.[1]; Norton, M.[1]; Iborra; Villarejo, A.; Jódar, E.; Glunz, S.; Mohr, A; Roth, T.; Bett, A. W.; Gawehns, N.[3]; McCann, M.[3]; Fath, P.[3]; Jimenez, J.; Alcedo, L.[4]; Bremerich, M.[5]; Clive, B.[6]; Andreu, J.[7]; Weatherby, C.[8]; Bentley, R.[8]; Brooker, J.[8]; Wheeler, S.[8]; Teruel, J.[8]
»Progress on „CONMAN" EU R&D Project – Improvement of Photovoltaic Concentrating Systems and Technology Transfer to a Manufacturer« 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 2035-2038
([1]: University of Reading, Reading, UK)
([2]: Universitat Politecnica Cartegena, Cartegena, Spain) ([3]: Universität Konstanz, Konstanz) ([4]: ENWESA, Madrid, Spain) ([5]: Jungbecker, Olpe, Germany) ([6]: Optical Products, London, UK) ([7]: University Barcelona, Spain) ([8]: Whitfield Solar, Reading, UK)

Bühring, A.
»Development and Measurements of Compact Heating and Ventilation Devices with Integrated Exhaust Air Pump for High Performance Houses«, in: Proceedings, 8th International Energy Agency Heat Pump Conference 2005, Las Vegas, USA, 30.5.–2.6.2005, CD-ROM

Bühring, A.
»Aktueller Stand der Weiterentwicklung von Lüftungs-Kompaktgeräten«, in: Tagungsband, 9. Internationale Passivhaustagung 2005, Ludwigshafen, Germany, 29./30.4.2005, pp.139-144

Bühring, A., Bichler, C.
»Aktueller Stand der Weiterentwicklung von Lüftungs-Kompaktgeräten mit Abluftwärmepumpe«, in: Tagungsband, 3. Forum Wärmepumpe, Berlin, Germany, 13./14.10.2005, pp. 98-105

Bühring, A.
»Entwicklung von Lüftungs-Kompaktgeräten mit Abluftwärmepumpe«, in: Tagungsband OTTI-Profiforum Lüftungstechnik, Regensburg, Germany, 25./26.1.2005

Bühring, A.; Jäschke, M.[1]; Bichler, C.
»Aktueller Stand der Weiterentwicklung von Lüftungs-Kompaktgeräten mit Abluftwärmepumpe«, EB - Energieeffizientes Bauen, November 2005, pp. 3-11
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH)

Dhamrin, M.[1]; Kamisako, K.[1]; Saitoh, T.[1]; Schultz, O.; Glunz, S.W.; Eguchi, T.[2]; Hirasawa, T.[2]; Yamaga, I.[2]
»Effect of Fe-Ga Pairs Dissociation and Association Processes on Recombination Lifetimes in Multicrystalline Silicon Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 765-768
([1]: Tokyo University of Agriculture and Technology, Tokyo, Japan) ([2]: Dai-ichi Kiden, Tokyo, Japan)

Campesato, R.[1]; Flores, C.[1]; Iurato, F.[1]; Barde, H.[2]; Uebele, P.[3]; Strobl, G.[3]; Bett, A. W.; Smekens, Baur, C.; Vanbegin, J.[4]; Caon, A.[5]
»Advanced Solar Cells for Missions to Mars«, in: Proceedings, 7th European Space Power Conference, Stresa, Italy, 9.–13.5.2005, ESA SP-589
([1]: CESI S.p.A., Milano, Italy) ([2]: Astrium SAS) ([3]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([4]: E.N.E., Brussels, Belgium) ([5]: ESA, Noordwijk, The Netherlands)

Diez, S.; Rein, S.; Glunz, S. W.
»Analyzing Defects in Silicon by Temperature- and Injection-Dependent Lifetime Spectroscopy (T-IDLS)«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 1216-1219

Dimroth, F.; Meusel, M.; Baur, C.; Bett, A. W.; Strobl, G.[1]
»3-6 Junction Photovoltaic Cells for Space and Terrestrial Concentrator Applications«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005, pp. 525-529
([1]: RWE-Solar Space Power, Heilbronn, Germany)

Eccarius, S.; Manurung, T.; Hebling, C.
»Characterization of DMFCs for Portable Devices«, in: Proceedings, 3rd European Polymer Electrolyte Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005

Eccarius, S.; Litterst, C.; Wolff, A.; Tranitz, M.; Koltay, P.; Agert, C.
»Systemaspekte in Mikro-Brennstoffzellen-Systemen«, in: Proceedings, Mikrosystemtechnik Kongress 2005, Freiburg, Germany, 10.–12.10.2005

Erge, T.; Kröger-Vodde, A.[1]; Laukamp, H.; Puls, H.-G.; Malte, T.; Wittwer, C.
»Optimisation of PV System Operation in Decentralised Electricity Grids by Realisation of Intelligent Operation Management«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 2498-2501
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg, Germany)

Erge, T.; Kroeger-Vodde, A.; Laukamp, H.; Puls, H.-G.; Thoma, M.; Wittwer, C.
»Optimierung des Einsatzes von PV Anlagen in dezentral organisierten Stromnetzen durch intelligentes Betriebsmanagement«, in: Tagungsband, OTTI-Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp. 242-247

Erge, T.:
»Die Bewertung von Ertragsgutachten bei der Erstellung von Finanzierungskonzepten für Photovoltaikanlagen«, in: Tagungsband, 26. Forum Solarpraxis, Berlin, Germany, 17.–18.11.2005

Erge, T.:
»Monitoring Concept for Low Voltage Electricity Grids with Distributed Generation«, Highlight of the European Research Project DISPOWER, Freiburg, Germany, November 2005

Eyer, A.; Haas, F.; Hurrle, A.; Janz, S.; Lutz, F.; Schillinger, N.; Reber, S.
»High Throughput CVD and ZMR for Crystalline Silicon Thin-Film Solar Cells«, in: Proceedings, 15th International Science and Engineering Conference, Shanghai, China, 10.–15.10.2005, p. 318

Flores, J. R.; Klinke, S.; Wittstadt, U.; Hacker, B.
»Fabrication Improvements in the Preparation of the MEAs by Hot-Pressing and Chemical Reduction Methods Using Design of Experiments«, in: Proceedings, 9th Grove Fuel Cell Symposium, London, United Kingdom, 4.–6.10.2005, p. P3.23

Forberich, K.; Gombert, A.; Stroisch, M.[1]; Gerken, M.[1]; Lemmer, U.[1]; Diem, M.[2,3]; Pereira, S.[4]; Busch, K.[2,5]
»Two-Dimensional Organic Photonic Crystal Lasers«, in: Proceedings, Diffractive Optics 2005, Warsaw, Poland, 3.–7.9.2005
([1]: Lichttechnisches Institut, Karlsruhe, Germany) ([2]: Department of Physics and College of Optics & Photonics, University of Central Florida, Orlando, USA) ([3]: Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, Karlsruhe, Germany) ([4]: Centre d'Optique, Photonique et Laser, Université Laval, Sainte-Foy Québec, Canada) ([5]: Institut für Theoretische Festkörperphysik, Universität Karlsruhe, Karlsruhe, Germany)

Georg, A.[1]; Krasovec, U. O.[2]; Topic, M.[2]; Georg, A.; Drazic, G.[3]
»Preparation and Characterisation of Nano-Structured WO_3-TiO_2 Layers Applied in Photo-electrochromic Devices«, in: Journal of Sol-Gel Science and Technology, 36, 2005, pp. 45-52, ([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Faculty of Electrical Engineering, Ljubljana, Slovenia) ([3]: Josef Stefan Institute, Ljubljana, Slovenia)

Georg, A.
»Hell oder dunkel? Schaltbare Verglasung«, in: Glas+Rahmen, Juni 2005, p. 22-23

Glunz, S. W.; Grohe, A.; Hermle, M.; Hofmann, M.; Janz, S.; Roth, T.; Schultz, O.; Vetter, M.[1]; Martin, I.[1]; Ferré, R.[1]; Bermejo, S.; Wolke, W.; Warta, W.; Preu, R.; Willeke, G.
»Comparison of Different Dielectric Passivation Layers for Application in Industrially Feasible High-Efficiency Crystalline Silicon Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 572-577
([1]: Universidad Politècnica de Catalunya, Barcelona, Spain)

Glunz, S. W.
»Stand und Perspektiven der Photovoltaik«, in: AKE-Tagungsband, 69. Jahrestagung der Deutschen Physikalischen Gesellschaft, Berlin, Germany, 4.–9.3.2005, pp. 93-106

Gölz, S.; Bopp, G.; Preissler, E.[1]
»SHS-Modelle im Praxisvergleich, Projekterfahrungen mit Kreditmodellen und dem Betreiber-Ansatz«, in: Tagungsband, OTTI-Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005
([1]: Freie Consultant)

Gölz, S.
»Another Perspective on Rural Electrification«, in: Photon International, March 2005, p. 96

Gombert, A.; Heck, M.; Kübler, V.[1]; Köhl, M.; Carlsson, B.[2]; Möller, K.[2]; Brunold, S.[3]; Zinzi, M.[4]; Jorgensen G.[5]; Chevalier, B.
»Results Of Durability Testing Of Antireflective Glazing«, in: Tagungsband, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005
([1]: Holotools GmbH, Freiburg, Germany)
([2]: SP Swedish National Testing and Research Institute, Boras, Sweden) ([3]: Institut für Solartechnik SPF, Rapperswil, Switzerland) ([4]: ENEA, Roma, Italy) ([5]: NREL, Golden, Colorado, USA)

Goetzberger, A.
»Flächennutzung von Solarkraftwerken: Erweiterung der Wirkungsgraddefintion«, OTTI-Energie-Kolleg, 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp. 202-206

Goldschmidt, J. C.; Schultz, O.; Glunz, S. W.
»Predicting Multi-Crystalline Silicon Solar Cell Parameters from Carrier Density Images«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 663-666

Grohe, A.; Schneiderlöchner, E.; Fleischhauer, B.; Hofmann, M.; Glunz, S.W.; Preu, R.; Willeke, G.
»Status and Advancement in Transferring the LFC Technology to Screen-printed Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,

Grohe, A.; Zastrow, U.[1]; Meertens, D.[2]; Houben, L.[2]; Brendle, W.[3]; Bilger, G.[3]; Schneidernlöchner, E.[4]; Glunz, S.; Preu, R.; Willeke, G.
»Progress in the Characterisation of Laser-Fired Contacts«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, ([1]: Institute of Photovoltaics, Research Centre Jülich GmbH, Jülich, Germany) ([2]: Institute of Solid State Research, Ernst-Ruschka-Centre, Jülich, Germany) ([3]: Institute of Physical Electronics, University of Stuttgart, Germany) ([4]: Deutsche Cell GmbH, Freiberg, Germany)

Grupp, G.; Biro, D.; Emanuel, G.; Preu, R.; Schitthelm, F.[1]; Willeke, G.
»Analysis of Silver Thick-Film Contact Formation on Industrial Silicon Solar Cells«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.1.–7.1.2005
([1]: Deutsche Cell, Freiberg, Germany)

Grupp, G.; Huljic, D. M.[1]; Preu, R.; Willeke, G.; Luther, J.
»Preparation Temperature Dependence of the Microstructure of Ag Thick-Film Contacts on Silicon Solar Cells – A Detailed AFM Study of the Interface, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Q-Cells, Talheim, Germany)

Gschwander, S.; Schossig, P.; Henning, H.-M.;
»Phase Change Slurries as Heat Transfer and Storage Fluid for Low and Medium Temperature Applications«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 7/8.10.2005, pp. 144-149

Guter, W.; Dimroth, F.; Meusel, M.; Bett, A. W.
»Tunnel Diodes for III-V Multi-Junction Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 515-518

Guter, W.; Dimroth, F.; Meusel, M.; Bett, A. W.
»Optimierung von Tunneldioden in III-V Mehrfachsolarzellen«, in: Proceedings, 69. Jahrestagung der Deutschen Physikalischen Gesellschaft, Berlin, Germany, 4.–9.3.2005, www.dpg-tagungen.de/archive/2005/hl58.pdf

Haussmann, T.; Schossig, P.; Henning, H.-M.; Rogg, H.
»Aktiv durchströmte Bauteile mit Latentwärmespeicher«, in: Tagungsband, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005, pp. 428-433

Haussmann, T.; Schossig, P.
»Überhitzungsschutz bei Leichtbauten durch integrierte Latentwärmespeicher«, in: Erneuerbare Energie der AEE Österreich, Ausgabe 2005-2, pp. 35-37

Hebling, C., Huppmann, M., Oszcipok, M.
»Außentaugliche Mikrobrennstoffzellen«, Tagungsband, f-cell 2005, 26./27.9.2005

Hebling, C., Hakenjos, A., Agert, C.
»Micro Fuel Cell Systems as Device-Integrated Power Supplies»; in: mst news, Nr. 4/05 – August 2005

Henning, H.-M.
»Solar Assisted Air-Conditioning of Buildings – An Overview«, in: Proceedings, Heat Transfer in Components and Systems for Sustainable Energy Technologies: Heat-SET 2005, Grenoble, France, 5.–7.4.2005, Editions Greth France, Editor B. Thonon, pp. 207-219

Henning, H.-M.
»Solar Cooling: Technology, Market Potential, Vision – Overview on State of the Art Technology and Market Perspectives«, in: Proceedings, 2nd European Solar Thermal Energy Conference estec 2005, Freiburg, Germany, 21./22.6.2005, pp. 37-42

Henning, H.-M.
»Solare Klimatisierung - Stand der Entwicklung«, in: Erneuerbare Energie, Österreich, 2005-2, Juni 2005, pp.12-15

Henning, H.-M.
»Solar Air- Conditioning R&D in the Framework of the International Energy Agency (IEA)«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp. 21-25

Henning, H.-M.
»Entwicklungsbedarf von Kleinabsorptionskälte? – Beteiligung an einer Diskussion im Forum der Zeitschrift«, in: KI Luft- und Kältetechnik, November 2005

Henning, H.-M.; Motta, M.[1]
»A Novel High Efficient Solar Assisted Sorption System for Building Air-Conditioning (ECOS): Cycle Performance and Potential Application«, in: Proceedings, 2nd European Solar Thermal Energy Conference estec 2005, Freiburg, Germany, 21./22.6.2005, pp. 45-51
([1]: Politecnico di Milano, Italy)

Henning, H.-M.; Motta, M.[1]
»A Novel High Efficient Sorption System for Air Dehumidification (ECOS)«, in: Proceedings, International Sorption Heat Pump Conference, Broomfield, Colorado, USA, 22.–24.6.2005, CD-ROM
([1]: Politecnico di Milano, Italy)

Henning, H.-M.; Ziegler, F.[1]; Eisenmann, W.[2]; Köhler, S.[3]
»Energetische Nutzung von Wärmequellen niedriger Temperatur«, in: Themenheft 2005, ForschungsVerbund Sonnenenergie, FVS Jahrestagung 2005, Köln, Germany, 22./23.9.2005, pp. 24-44
([1]: TU Berlin, Institut für Energietechnik, Germany) ([2]: Institut für Solarenergieforschung ISFH GmbH, Emmerthal, Germany)
([3]: GeoForschungsZentrum (GFZ) Potsdam, Germany)

Henning, H.-M.; Noeres, P.[1]; Lokurlu, A.[2]; Braun, R.[3]
»Solare Kühlung und Klimatisierung – Belüftung und Wärmerückgewinnung«, in: Themenheft 2005, ForschungsVerbund Sonnenenergie, FVS Jahrestagung 2005, Köln, Germany, 22./23.9.2005, pp. 45-54
([1]: Fraunhofer UMSICHT, Oberhausen, Germany) ([2]:Solar-Institut Jülich, Germany)
([3]: FH Gelsenkirchen, Germany)

Henning, H.-M.; Lokurlu, A.[1]; Buck, R.[2]; Dötsch, C.[3]
»Solarunterstützte Kraft-Wärme-Kälte-Kopplung – Hybridsysteme im Trend«, in: Themenheft 2005, FVS Jahrestagung 2005, Köln, Germany, 22./23.9.2005, pp. 111-117
([1]: Solar-Institut Jülich, Germany) ([2]: Deutsches Zentrum für Luft- und Raumfahrt e.V. DLR, Bonn, Germany) ([3]: Fraunhofer Umsicht, Oberhausen, Germany)

Henning, H.-M.; Wiemken, E.
»Decision Scheme for the Selection of the Type of Solar Assisted Air-Conditioning System for a given Load«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp. 231-235

Henning, H.-M.; Wiemken, E.
»Solar Assisted Cooling at the University Hospital Klinikum Freiburg«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp.178–182

Henning, H.-M.; Wiemken, E.
»Solar Assisted Air-Conditioning in the Frame of the Solarthermie 2000plus Programme«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp.157–161

Henning, H.-M.; Wiemken, E.
»Economic Issues of Solar Assisted Air-Conditioning Applications«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp. 183–187

Herkel, S.; Knapp, U.; Pfafferott, J.
»A Preliminary Model of User Behaviour Regarding the Manual Control of Windows in Office Buildings«, in: Proceedings, The 9th International Building Performance Simulation, Montreal, Canada, 15.–18.8.2005

Hermann, M.
»Entwicklung des FracTherm-Absorbers – Simulationen und Experimente«, in: Tagungsband, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005

Hermle, M.; Létay, G.; Mack, B.; Bett, A. W.
»Simulation of Single Junction GaAs Solar Cells Considering Optical Coupling«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 511-514

Hermle, M.; Schneiderlöchner, E.; Grupp, G.; Glunz, S. W.
»Comprehensive Comparison of Different Rear Side Contacting Methods«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 810-813

Hinsch, A.; Kern, A.[1]; Niggemann, M.; Beier, J.[2]; Luther, J.
»Neue Entwicklungen bei Farbstoff- und organischen Solarzellen«, in: Book of Abstracts, Jährliches Kolloquium des Freiburger Materialforschungszentrum FMF, Titisee, Germany, 7./8.10.2004
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) (2: Institut für Angewandte Photovoltaik INAP, Gelsenkirchen, Germany)

Holz, F.; Steinhüser, A.; Kaiser, R.
»Anforderungen an Konzepte zur saisonalen Energiespeicherung in autonomen Stromversorgungen – Bewertung aktueller Lösungsansätze«, in: Tagungsband, OTTI Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp. 273-277

Hore, S.[1]; Durrant, J. R.[2]; Hinsch, A.[1]; Luther, J.[1]
»Enhancing the Efficiency of Dye Solar Cells via Tuning of the Density of States in TiO_2 Semiconductor«, in: Tagungsband, 11th Freiburger Materialforschungszentrum FMF Kolloquium, Titisee, Germany, 7./8.10.2004,
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Centre for Electronic Materials and Devices, London, UK)

Horzel, J.[1]; Grupp, G.[2]; Preu, R.; Schmidt, W.[1]
»Experimental Investigation Towards High Throughput Rapid Thermal Firing of EFG SI Solar Cells« in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: RWE Schott Solar GmbH, Alzenau, Germany) ([2]: Evergreen Solar)

Hube, W. [1]; Crisinel, M.[2]; Vollmar, T.[2]; Platzer, W.[1]
»Glass Facade Elements With Internal Fluid Flow«, in: Proceedings, GLASSinBUILDINGS, Bath, United Kingdom, 7./8.4.2005, pp. 303-311
([1]: Projektgesellschaft Solare Energiesysteme PSE, Freiburg, Germany) ([2]: Steel Structures Laboratory ICOM, Swiss Institute of Technology Lausanne EPFL, Lausanne, Switzerland)

Isenberg, J.; v. d. Heide, A.[1]; Warta, W.
»Spatially Resolved Assessment of Power Losses Due to Bulk Material Quality and Metalization Problems«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005
([1]: Energy Research Center ECN, Solar Energy, Petten, The Netherlands)

Isenberg, J.; van der Heide, A.; Warta, W.
»Range of Loss Mechanisms Accessible by Illuminated Lock-In Thermography (ILIT)«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 136-139

Isenberg, J.; Schubert, M. C.; Biro, D.; Froitzheim, A.; Warta, W.
»Sheet Resistance Imaging (SRI) – A Contactless and Spatially Resolved Method for the Determination of Doping Inhomogeneities«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 674-677

Isenberg, J.; Breitenstein, O.[1]; Rakotoniaina, J. P.[1]; Hahn, G.[2]; Kaes, M.[2]; Pernau, T.[2]; Seren, S.[2]; Warta, W.
»Lock-In Thermography – A Universal Tool for Local Analysis of Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 590-593
([1]: Max Planck Institute for Microstructure Physics, Halle, Germany) ([2]: University of Konstanz, Konstanz, Germany)

Janz, S.; Reber, S.; Lutz, F.; Schetter, C.
»Conductive SiC as an Intermediate Layer for CsiTF Solar Cells«, in: Proceedings, European Materials Research Society EMRS Spring Meeting 2005, Strasbourg, France, 31.5.–3.6.2005

Janz, S.; Reber, S.; Lutz, F.; Schetter, C.
»SiC as an Intermediate Layer for CsiTF Solar Cells on Various Substrates«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp.1016-1019

Janz, S.; Reber, S.; Habenicht, H.
»C-Si Thin-Film Solar Cells on Ceramic Substrates with SiC Intermediate Layers«, in: Technical Digest; 15th International Science and Engineering Conference, Shanghai, China, 10.–15.10.2005, pp. 873

Jaus, J.; Rentsch, J.; Preu, R.
»Determining Trade-Offs Between Costs of Production and Cell/Module-Efficiency with the Concept of Indifference Curves«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Jungmann, T.; Grootjes, A. J.[1]; Kopte, D.; Makkus, R. C.[1]; Wittstadt, U.
»Development and Characterisation of a Reversible Fuel Cell for Autonomous Power Supply and Uninterruptible Power Supply«, in: Proceedings, 9th Grove Fuel Cell Symposium, London, United Kingdom, 4.–6.10.2005, pp. P3.21
([1]: Energy Research Centre Netherlands ECN, The Netherlands)

Kaiser, R.
»Geschlossene Bleibatterien«, in: Seminarband Wiederaufladbare Batteriesysteme, OTTI-Energie-Kolleg, Ulm, Germany, 10./11.5.2005, pp. 23–46

Kiefer, K.; Vaassen, W.[1].
»Qualitätsanforderungen an Solarmodule«, in: Tagungsband, OTTI Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp. 52-60
([1]: TÜV Rheinland, Köln, Germany)

Kiefer, K.; Digel, R.[1]
»Die Effizienz der PV-Anlagen steigt kontinuierlich«, in: Erneuerbare Energien, Ausgabe 11/2005, pp. 64-66
([1]: Deutsche Stiftung Umwelt, Osnabrück, Germany)

Köhl, M.; Jorgensen, G.; Brunold, S.; Carlsson, B.; Heck, M.; Möller, K.
»Life-Time Estimation of Polymeric Glazing Materials for Solar Applications«, in: Proceedings, 10th International Conference on the Durability of Building Materials & Components, Lyon, France, 17.–20.4.2005

Köhl, M.; Heck, M.; Noller, K.
»Degradation of the Efficiency of Vacuum Insulation Panels by Gas Permeation through Barrier Films«, in: Proceedings, 10th International Conference on Durability of Building Materials and Components, Lyon, France, 17.–20.4.2005

Köhl, M.; Roos, A.[1]; Persson[1]; Wilson, H.; Platzer, W.
»Energy Efficiency of Switchable Glazing in Office Buildings«, in: Proceedings, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005 pp. 334-337
([1]: Uppsala University, Sweden)

Köhl, M.; Hussong, J.[1]; Schönlein, A.[2]; Schroeder, C.[3]; Scott, K.[4]; Dreiskemper, R.[5]; Ketola, W.[6]; Maybee, J.[7]; Geburtig, A.[8]; Brunhold, S.[9]; Chistiaens, F.[10]
»Comparison of Measurements of Spectral Irradiance (UV/VSI) by an International Round Robin Test«, in: Proceedings, 9th International Conference on Developments and Applications in Optical Radiometry, Davos, Switzerland, 17.–19.10.2005,
([1,2]: ATLAS MTT GmbH, Linsengericht, Germany) ([3]:opto.cal GmbH, Movelier, Switzerland) ([4]:ATLAS MTT LLC, Chicago, USA) ([5]: Heraeus Noblelight GmbH, Hanau, Germany) ([6]: 3M, St.Paul, Minnesota, USA) ([7]: ATLAS DSET Laboratories Inc., Phoenix, Arizona, USA) ([8]: Bundesamt für Materialforschung und -prüfung BAM, Berlin, Germany) ([9]: Institut für Solartechnik, Rapperswil, Switzerland) ([10]: L`Oréal, Clichy, France)

Koschikowski, J.; Wieghaus, M.; Rommel, M.; Basel, S.
»Entwicklung von kompakten, solarthermisch getriebenen Wasserentsalzungsanlagen«, in: Tagungsband, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005

Koschikowski, J.; Wieghaus, M.; Rommel, M.; Basel, S.
»Solarthermal Driven Membrane Distillation for Small-Scale Desalination Plants«, in: Proceedings, International Solar Energy Society ISES World Congress, Orlando, Florida, USA, 6.–12.8.2005

Kray, D.; Baumann, S.; Mayer, K.; Eyer, A.; Willeke, G. P.
»Novel Techniques for Low-Damage Micro- and Macrostructuring of Silicon«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Kray, D.; Baumann, S.; Mayer, K.; Schumann, M.; Bando, M.; Eyer, A.; Willeke, G. P.
»Wafering research at Fraunhofer ISE«, in: Proceedings, 15th Workshop on Crystalline Silicon Solar Cells and Modules: Materials and Processes, Vail, Colorado, USA, 7.–10.8.2005

Kuhn, T.
»Klimafreundliche Wege zu einem freundlichen guten Arbeitsklima«, in: Deutsche Bauzeitung DBZ, September 2004

Kuhn, T.
»Solar Protection and Daylight Utilisation in Modern Office Buildings«, in: Proceedings, Intelligent Building Middle East 2005, Manama, Kingdom Bahrain, 5.–7.12.2005

Lehnert W.[1]; Grünerbel, M.[1]; Mergel, J.[2]; Wippermann, K.[2]; Scharmann, H.[2]; Kulikovsky, A.[2]; Hebling, C.; Wittstadt, U., Smolinka, T.; Gülzow, E.[3]; Schulze, M.; Kaz, T.[3]
»Niedertemperatur-Brennstoffzellen – Stand und Perspektiven der PEMFC«, in: Forschungs-Verbund Sonnenenergie, FVS Themen 2004, pp. 94–100
([1]: Zentrum für Solarenergie- und Wasserstoff-Forschung, Stuttgart, Germany) ([2]: Forschungszentrum Jülich, Germany) ([3]: Deutsches Zentrum für Luft- und Raumfahrt, Germany)

Lerchenmüller, H.; Bett, A. W.; Siefer, G.; Dimroth, F.; Willeke, G.
»FLATCON® Konzentrator-PV-Technologie«, in: Tagungsband, OTTI-Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp. 94-101

Lerchenmüller, H.[1]; Jaus, J.; Willeke, G.; Bett, A. W.
»Cost and Market Perspectives for FLATCON® - Systems«, in: Proceedings, Conference on Solar Concentrators for the Generation of Electricity or Hydrogen, Scottsdale, Arizona, USA, 1.–6.5.2005, NREL CD August 2005
([1]: Concentrix Solar GmbH, Freiburg, Germany)

Löckenhoff, R.; Riesen, v. S.; Meusel, M.; Dimroth, F.; Bett, A. W.
»Large Area Monolithic Interconnected Modules (MIMs) for Compact Concentrator Modules«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Mette, A.; Erath, D.; Ruiz, R.; Emanuel, G.; Kasper, E.[1]; Preu, R.
»Hot Melt Ink for the Front Side Metallisation of Silicon Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 873-876
([1]: Ferro GmbH, Electronic Material System, Hanau, Germany)

Meusel, M.[1]; Baur, C.; Guter, W.; Hermle, M.; Dimroth, F.; Bett, A. W.; Dietrich, R.[1]; Köstler, W.[1]; Kern, R.[1]; Nell, M.[1]; Zimmermann, W.[1]; LaRoche, G.[1]; Strobl, G.[1]; Taylor, S.[2]; Signorini, C.[2]; Hey, G.[3]
»Development Status of European Multi-Junction Space Solar Cells with High Radiation Hardness«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 20-25
([1]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([2]: ESA/ESTEC, Noordwijk, The Netherlands) ([3]: German Aerospace Center DLR, Bonn, Germany)

Miara, M.
»Passivhäuser – praktische Prüfung, Domy pasywne – egzamin praktyszny«, in: Czysta Energia (Reine Energie), 12/2004, pp. 18

Mick, J.[1]; Müller, C.[1]; Gombert, A.; Bläsi, B.
»Maskless Origination of Microstructures with Optical Functions on Large Areas«, in: Proceedings, Microlithography 2005, San Jose, California, USA, 27.2–4.3.2005, pp.1003-1014
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Mick, J.[1]; Bläsi, B.; Gombert, A.; Reinecke, H.[1]; Müller, C.[1]
»Große dreidimensionale Mikrostrukturen mittels Interferenzlithographie«, in: Proceedings, Mikrosystemtechnik Kongress 2005, Freiburg, Germany, 10.–12.10.2005, pp. 283-286
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Mohr, A.; Roth, T.; Epmeier, M.[1]; Glunz, S. W.
»Silicon Concentrator Cells in an One-Axis Tracking Concentrator System with a Concentration Ratio of 300X«, 31st IEEE Photovoltaic Specialist Conference and Exhibition, Orlando, Florida, USA, 3.–7.1.2005, pp. 639-642
([1]: Institut für Mikrosystemtechnik IMTEK, Albert-Ludwigs-Universität Freiburg, Germany)

Mohr, A.; Roth, T.; Hermle, M.; Glunz, S. W.
»Rear-Line-Contacted Silicon Concentrator Cells on Highly and Lightly Doped Substrates«, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005, pp. 758-761

Mohr, A.; Siefer, A.; Roth, T.; Sadchikov, N.[1]; Bett, A. W.; Glunz, S. W.; Willeke, G. P.
»Development of FLATCON® Modules«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 507-510
([1]: Ioffe Physico-Technical Institute, St. Petersburg, Russia)

Núñez, T.; Mittelbach, W.[1]; Henning, H.-M.
»Development of an Adsorption System for Heating and Solar Cooling Applications«, in: Proceedings, World Renewable Energy Conference WREC 2005, Aberdeen, U.K., 22.–27.5.2005, CD-ROM, ISBN: 008044671X
([1]: Sortech AG, Halle a.d.S., Germany)

Núñez, T.; Mittelbach, W. [1]; Henning, H.-M.
»Development of a Small Capacity Adsorption System for Heating and Cooling Applications«, in: Proceedings, International Sorption Heat Pump Conference ISHCP 2005, Broomfield, Colorado, USA, 22.–24.6.2005
([1]: Sortech AG, Halle a.d.S., Germany)

Núñez, T.; Hau, M.; Henning, H.-M.
»Simulation based Performance Assessment of a Small Capacity Adsorption System in a Domestic Heating and Cooling Application«, in: Proceedings, 2nd European Solar Thermal Energy Conference estec 2005, Freiburg, Germany, 21./22.6.2005, pp. 52-58

Núñez, T.; Hau, M.; Henning, H.-M.
»Simulation Based Performance Assessment of a Small Capacity Adsorption System in a Domestic Heating and Cooling Application«, in: Proceedings, International Sorption Heat Pump Conference ISHCP 2005, Broomfield, Colorado, USA, 22.–24.6.2005

Núñez, T.; Hau, M.; Henning, H.-M.
»A Small Capacity Adsorption System in a Heating and Cooling Application: The German Field-Test in the MODESTORE Project«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp. 335–340

Oszcipok, M.; Zedda, M.; Hesselmann, J.; Huppmann, M.; Junghardt, M.; Riemann, D.; Hebling, C.
»Portable Fuel Cell Systems for Outdoor Applications«, in: Proceedings, 9th Grove Fuel Cell Symposium, London, United Kingdom, 4.–6.10.2005, p. 5A.5

Oszcipok, M.; Hakenjos, A.; Riemann, D.; Hebling, C.
»Freezing Processes in PEM Fuel Cells«, in: Proceedings, 3rd European PEMFC Forum, 4.-8.7.2005, Lucerne, Switzerland, PA22-066

Pfafferott, J.; Herkel, S.
»Statistical Simulation of User Behaviour in Low-Energy Office Buildings«, in: Proceedings, Passive and Low Energy Cooling for the Built Environment PALENC 2005, Santorini, Greece, 19.–21.5.2005, pp. 721-726

Pfafferott, J.; Herkel, S.; Schiel, S.
»Bauteilkühlung – Messungen und modellbasierte Auswertung«, in: Tagungsband, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005, pp. 422-427

Pfafferott, J.; Herkel, S.
»Kühlen ohne Klimaanlage«, in: Bauen heute, Ausgabe 9/2005, pp. 78/79

Pfafferott, J.; Herkel, S.
»A Preliminary Model of User Behaviour Regarding the Manual Control of Windows in Office Buildings«, in: Proceedings, Clima 2005, Lausanne, Switzerland, 9.–12.10.2005, Nr. 167

Pfafferott, J.; Herkel, S.; Zeuschner, A.
»Thermischer Komfort im Sommer in Bürogebäuden mit passiver Kühlung«, in: Tagungsband, 9th Internationale Passivhaustagung 2005, Ludwigshafen, Germany, 29./30.4.2005, pp. 275-281

Platzer, W.; Simmler, H.[1]; Bryn, I.[2]
»Energy Performance of Facades and Buildings – IEA as Support for the European Directive?«, in: Tagungsband, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005, pp. 578-582
([1]: EMPA Dübendorf, Switzerland)
([2]: Erichsen&Horgen AS, Oslo, Norway)

Platzer, W.; Hube, W.[1]; Adelmann, W.; Crisinel, M.[2]; Vollmar, T.[2]
»Development of a Glass Facade with Internal Fluid Flow«, in: Tagungsband, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005, pp. 303-307
([1]:PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg, Germany) ([2]: EPFL Ecole Polytechnique Fédérale de Lausanne, Switzerland)

Platzer, W.
»Performance Assessment for Solar Shadings – State of the Art«, in: Tagungsband, Glass Processing Days 2005, Tampere, Finland, 16.–20.6.2005, pp. 584-588

Platzer, W.; Stramm C.; Amberg-Schwarb, S.; Köhl, M.;
»Development of Innovative Insulation Systems on the Basis of Vacuum Insulation Panels«, in: Proceedings, 7th International Vacuum Insulation Symposium, Zurich, Switzerland, 28./29.9.2005, pp. 105-112

Platzer, W.
»Steps Towards a Vision – a Multifunctional Glass Facade«, Intelligent Glass Solutions, Issue 2/2005, pp. 54-56

Reber, S.; Eyer, A.; Haas, F.
»High-Throughput Zone-Melting Recrystallization for c-Si Thin-Film Solar Cells«, in: Abstract Book of the 16th American Conference on Crystal Growth and Epitaxy, Montana, USA, 10.–14.7.2005, p. 69

Reber, S.; Eyer, A.; Hurrle, A.; Haas, F.; Schillinger, N.; Janz, S.
»Progress in Crystalline Silicon Thin-Film Solar Cell Work at Fraunhofer ISE«, in: Proceedings of the 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 694-697

Rein, S.; Glunz, S. W.
»Advanced Lifetime Spectroscopy – Defect Parameters of Iron in Silicon and a New Fingerprint«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 753-756

Rentsch, J.; Kohn, N.; Bamberg, F.; Roth, K.[1]; Peters, S.[2]; Lüdemann, R.[2]; Preu, R.
»Isotropic Plasma Texturing of mc-Si for Industrial Solar Cell Fabrication«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005
([1]: Roth&Rau AG, Hohenstein-Ernstthal, Germany) ([2]: Deutsche Cell GmbH, Freiberg, Germany)

Rentsch, J.; Jaus, J.; Preu, R.; Roth, K.[1]
»Economical and Ecological Aspects of Plasma Processing for Industrial Solar Cell Fabrication«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005
([1]: Roth&Rau AG, Hohenstein-Ernstthal, Germany)

Rentsch, J.; Schetter, C.; Schlemm, H.[1]; Roth, K.[1]; Preu, R.
»Industrialisation of Dry Phosphorus Silicate Glass Etching and Edge Isolation for Crystalline Silicon Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([1]: Roth & Rau AG, Hohenstein-Ernstthal, Germany)

Rentsch, J.; Bamberg, F.; Schneiderlöchner, E.; Preu, R.
»Texturisation of Multicrystalline Silicon by Laser Ablation«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Riepe, S.; Lautenschlager, H.; Ghosh, M.[1]; Müller, A.[1]; Warta, W.
»Lifetime Characteristics and Gettering Effects in N-Type Multicrystalline Silicon Block Material«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 713-716
([1]: Deutsche Solar AG, Freiberg, Germany)

Riepe, S.
»Recombination Activity of Crystal Defects in Multicrystalline Silicon after Thermal Oxidation«, in: Proceedings, 11th GADEST 2005, Giens, France, 25.–30.9.2005

Rinio, M.; Zippel, E.; Borchert, D.
»Spatial Redistribution of Recombination Centres by the Solar Cell Process«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Rommel, M.; Zahler, C.[1]; Luginsland, F.[1]; Häberle, A.[1]; Koschikowski, J.
»Fertigung und Installation eines Sonnensimulators für das GREEN Labor an der Pontifíca Universidade«, in: Proceedings, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005, pp. 462–467
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg, Germany)

Rommel, M.;
»Prozesswärmekollektoren. Aktuelle Entwicklungen im Mitteltemperaturbereich bis 250°«,in: Erneuerbare Energie, September 2005, pp.11-14

Rommel, M.; Siems, T.; Schüle, K.; Mehnert, S.; Becker, R.
»Wieviel Dampf produziert ein Kollektor im Stillstandsfall?«, in: Proceedings, OTTI-Energie-Kolleg 15. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 27.–29.4.2005, pp. 49-53

Rommel, M.; Koschikowski, J.; Wieghaus, M.; Basel, S.
»Entwicklung von vollständig solar betriebenen Meerwasserentsalzungssystemen«, in: Erneuerbare Energie (Österreich), February 2005, pp. 11-14

Rommel, M.
»Medium Temperature Collectors for Solar Process Heat up to 250°C«,in: Tagungsband, 2nd European Solar Thermal Energy Conference estec 2005, Freiburg, Germany, 21./22.6.2005, pp. 167-172

Roth, W.; Schüler, K.; Dickert, T.[1]; Fuchs, D. R.[1]; Vielreicher, H.[1]
»Strategie zur erfolgreichen Bewerbung von Unternehmenskonsortien um Projekte internationaler Entwicklungsbanken«, in: Tagungsband, OTTI Energie-Kolleg, 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp.132–137
([1]: Fraunhofer-Gesellschaft, European and International Business Development, München, Germany)

Roth, W.; Dickert, T.[1]; Fuchs, D. R.[1]; Vielreicher, H.[1]
»Erfahrungen aus der Bildung von Unternehmenskonsortien zur Bewerbung um Projekte internationaler Entwicklungsbanken«, in: Tagungsunterlagen, Thüringer Außenwirtschaftstag 2005 – Auftragsbeschaffung durch Beteiligung an internationalen Ausschreibungen, Weimar, Germany, 28.4.2005
([1]: Fraunhofer-Gesellschaft, European and International Business Development, München, Germany)

Roth, W.; Fuchs, D. R.[1]; Vielreicher, H.[1]
»BIKE – Bayerische Initiative zur Konsortialbildung für internationale Entwicklungsprojekte«, in: Veranstaltungsunterlagen, Internationale Aufträge gewinnen! Geschäftschancen in Projekten der Weltbank und anderer internationaler Organisationen, Bayreuth, Germany, 5.7.2005
([1]: Fraunhofer-Gesellschaft, European and International Business Development, München, Germany)

Roth, W.; Fuchs, D. R.[1]; Sellmeier, C.[1]; Vielreicher, H.[1]
»Strategische Maßnahmen zur erfolgreichen Bewerbung von Unternehmenskonsortien um Projekte internationaler Entwicklungsbanken«, in: Tagungsunterlagen, Internationale Ausschreibungen – Chancen nutzen, Leipzig, Germany, 25.10.2005
([1]: Fraunhofer-Gesellschaft, European and International Business Development, München, Germany)

Sastrawan, R.[1]
»Interpretation der Rückwärts-Kennlinien von Farbstoffsolarzellen«, in: Book of Abstracts, Jährliches Kolloquium des Freiburger Materialforschungszentrum FMF, Titisee, Germany, 7./8.10.04
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Sastrawan, R.[1]; Hinsch, A.; Beier, J.[2]; Belledin, U.[1]; Hemming, S.[3], Kern, R .; Vetter, C.[2]
»Upscaling Dye Solar Modules with Durable Glass Frit Sealing«, in: Proceedings, 15th International Science and Engineering Conference, Shanghai, China, 10.–15.10.2005, pp. 756-757
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany)
([3]: PSE GmbH, Forschung, Entwicklung, Marketing Freiburg, Germany)

Sastrawan, R[1].; Renz, J.; Prahl, C.; Beier, J.[2]; Hinsch, A.; Kern, R.
»Interconnecting Dye Solar Cells in Modules – I-V Characteristics under Reverse Bias«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) (2: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany)

Sastrawan, R.[1]; Hinsch, A.; Beier, J.[2]; Belledin, U.[1]; Hemming, S.[3]; Hore, S.[1]; Kern, R.; Prahl, C.; Renz, J.; Vetter, C.[2]; Würfel, U.[1]; Luther, J.; Petrat, F.-M.[4]; Prodi-Schwab, A.[4]
»Towards Manufacturing Dye Solar Cells», in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany)
([3]: Projektgesellschaft Solare Energiesysteme PSE, Freiburg, Germany) ([4]: Degussa AG, Creavis GmbH, Marl, Germany)

Schäffler, H.; Holz, F.
»Kostenstruktur und Anforderungen in der autonomen Stromversorgung«, in: Tagungsband, OTTI Energie-Kolleg 20. Symposium Photovoltaische Solarenergie, Bad Staffelstein, Germany, 9.–11.3.2005, pp. 278-283

Schindler, R.; Gremmelspacher, M.[1]; Hermle, M.; Kleer, G.[1]; Reis, I.; Willeke, G.
»Thin Large Area Crystalline Silicon Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005
([1]: Fraunhofer-Institut für Werkstoffmechanik IWM, Freiburg, Germany)

Schlegl, T. [1]; Abbott, P.; Aicher, T.; Dimroth, F.; Siefer, G.; Szolak, R.; Bett, A. W.
»GaSb Based PV Modules for a TPV Generator System«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 258-261
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Schmich, E.; Reber, S.; Willeke, G.
»In-Situ HCl Etching for Optical Confinement in Crystalline Silicon Thin-Film Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 1383-1386

Schmidt, F. P.; Henninger, S.[1]; Stach, H.[2]; Jänchen, J.[2]; Henning, H.-M.
»Novel Adsorbents for Solar Cooling Applications«, in: Proceedings, International Conference Solar Air-Conditioning, OTTI-Technologie-Kolleg, Staffelstein, 6/7.10.2005, pp. 39-44
([1]: Albert-Ludwigs-Universität Freiburg, Freiburger Materialforschungszentrum FMF, Germany)
([2]: ZeoSys GmbH, Berlin, Germany)

Schmitz, A.; Tranitz, M.; Eccarius, S.; Hebling; C.
»Spatial Characterisation of Planar Air-Breathing PEMFC«, in: Proceedings, 3rd European Polymer Electrolyte Fuel Cell Forum PEFC, Lucerne, Switzerland, 4.–8.7.2005

Schmidhuber, H.; Klappert, S.; Stollhof, J.; Erfurt, G.; Preu, R.
»Laser Soldering – a Technology for Better Contacts?«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Schnabel, L.; Henning, H.-M.
»Experimental and Simulation Study on the Kinetics of Water Vapour Adsorption on Different Kinds of Adsorptive Material Matrices«, in: Proceedings, International Sorption Heat Pump Conference ISHCP 2005, Broomfield, Colorado, USA, 22.–24.6.2005

Schnabel, L.; Henning, H.-M.; Henninger, S.[1]; Spreemann, D.
»Simulation Study on the Kinetics of Water Vapour Adsorption on Different Kinds of Adsorptive Materials«, in: Proceedings, International Sorption Heat Pump Conference ISHCP 2005, Broomfield, Colorado, USA, 22.–24.6.2005
([1]: Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität Freiburg, Germany)

Schnabel, L.; Henning, H. M.
»Simulation Study on the Kinetics of Water Vapour Adsorption«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp. 46-51

Schnabel, L.; Henning, H. M.; Munz, G.
»Experimental Study on the Kinetics of Water Vapour Adsorption«, in: Proceedings, International Conference Solar Air Conditioning, Bad Staffelstein, Germany, 6./7.10.2005, pp. 52-57

Schneiderlöchner, E.; Grohe, A.; Hofmann, M.; Preu, R.; Glunz, S. W.; Willeke, G. W.
»Current Status and Challenges in Transferring the Laser-Fired Contact Technology to Screen-Printed Silicon Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 785-788

Schossig, P.; Henning, H.-M.; Gschwander, S.; Haussmann, T.[1]
»Phase Change Materials as an Approach to Energy Efficient Buildings«, in: Proceedings, World Renewable Energy Conference WREC 2005, Aberdeen, Scotland, U.K., 22.–27.5.2005, pp. 970-975, CD-ROM, ISBN: 008044671X
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg, Germany)

Schossig, P.; Tamme, R.[1]; Göttsche, J.[2]; Huenges, E.[3]; Drück, H.[4]; Kabus, F.[5]; Dötsch, C.[6]
»Thermische Speicher für die Hausenergieversorgung«, ForschungsVerbund Sonnenenergie FVS Jahrestagung, Köln, Germany, 22./23.9.2005
([1]:Deutsches Zentrum für Luft- und Raumfahrttechnik, Köln, Germany) ([2]: Solar Institut Jülich)
([3]: GeoForschungsZentrum Potsdam, Germany)
([4]: ITW Morlock GmbH Germany)
([5]: GTN) ([6]: Fraunhofer UMSICHT, Oberhausen, Germany)

Schubert, M. C.[1]; Isenberg, J.; Warta, W.
»Injection Dependent Carrier Density Imaging Measurements Including Correction for Trapping Effects«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)
Schubert, M. C.[1]; Isenberg, J.; Rein, S.; Warta, W.
»Ortsaufgelöste temperaturabhängige Lebensdauerspektroskopie mit Carrier Density Imaging«, in: Proceedings, Workshop Silicon Forest 2005, Falkau, Altglashütten, Germany, 27.2.–2.3.2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Schubert, M. C.[1]; Isenberg, J.[1]; Rein, J.; Bermejo, S.[2]; Glunz, S. W.; Warta, W.
»Injection Dependent Carrier Density Imaging Measurements Including Correction for Trapping Effects«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: on leave from Universitat Politecnica de Catalunya UPC, Barcelona, Spain)

Schultz, O.; Hofmann, M.; Glunz, S. W.; Willeke, G.
»Silicon Oxide / Silicon Nitride Stack System for 20% Efficient Silicon Solar Cells«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005, pp. 872-876

Schultz, O.; Glunz, S. W.; Kray, D.; Dhamrin, M.[1]; Yamaga, I.[2]; Saitoh, T.[1]; Willeke, G. P.
»High-Efficiency Multicrystalline Silicon Solar Cells on Gallium-Doped Substrate«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, pp. 741-744
([1]: Tokyo University of Agriculture and Technology, Koganei, Tokyo, Japan) ([2]: Dai-ichi Kiden Co., Tokyo, Japan)

Schumacher, J.; Ziegler, C.; Philipps, S.; Niemeyer, J.; Schumacher, J. O.
»A Dynamic PEM Fuel Cell Stack Model for System Simulation«, in: Proceedings 3rd European Fuel Cell Forum , Lucerne, Switzerland, 4.–8.7.2005

Schumacher, J.; Gerteisen, D.; Hakenjos, A.; Schumacher, J.O.
»Model-Based Analysis of the Current Interrupt Technique for the Characterisation of Porous Gas Diffusion Electrodes in PEM Fuel Cells», in: Proceedings 3rd European Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005

Schumacher, J.; Tranitz, M.; Schumacher, J.O.
»A Model for Planar Self-Breathing Proton Exchange Membrane Fuel Cells in FEMLAB«, in: Konferenzband, FEMLAB Konferenz 2005, Frankfurt, Germany, 2.–4.11.2005

Sicre, B.; Bühring, A.; Platzer, B.[1]
»Energy and Financial Performance of Micro-CHP in connection with High-Performance Buildings«, in: Proceedings, The 9th International Building Performance Simulation, Montreal, Canada, 15.–18.8.2005,
([1]: Technische Universität Chemnitz, Germany)

Sicre, B.; Platzer, B.; Hoffmann, K. H.
»Energy and Cost Assessment of Micro-CHP Plants in High-Performance Residential Buildings«, in: Proceedings, 18th International Conference on Efficiency, Optimization, Simulation and Environmental Impact of Energy Systems ECOS 2005, Trondheim, Norway, 20.–23.6.2005

Siefer, G.; Bett, A. W.
»Experimental Comparison Between the Power Outputs of FLATCON® Modules and Silicon Flat Plate Modules«, in: Proceedings, 31st IEEE Photovoltaic Specialists Conference, Orlando, Florida, USA, 3.–7.1.2005

Siefer, G.; Abbott, P.; Baur, C.; Schlegl, T.; Bett, A. W.
»Determination of the Temperature Coefficients of Various III-V Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005

Smolinka, T.; Wittstadt, U.; Grünerbel, M.[1]; Lehnert, W.[1]
»Performance and Endurance of PEFC Single Cells and Stacks Fed Hydrogen and Reformate«, in: Proceedings, 3rd European Polymer Electrolyte Fuel Cell Forum, Lucerne, Switzerland, 4.–8.7.2005, pp. B035
([1]: Zentrum für Sonnenenergie- und Wasserstoffforschung ZSW, Stuttgart, Germany)

Specht, M.[1]; Zuberbühler, U.[1]; Wittstadt, U.
»Regenerativer Wasserstoff – Erzeugung, Nutzung und Syntheserohstoff«, in Forschungs-Verbund Sonnenenergie FVS Themen 2004, pp. 33–40
([1]: Zentrum für Sonnenenergie- und Wasserstoffforschung ZSW, Stuttgart, Germany)

Strobl, G.[1]; Dietrich, R.[1]; Hilgarth, J.[1]; Kern, R.[1]; Köstler, W.[1]; LaRoche, G.[1]; Meusel, M.[1]; Poeck, D.[1]; Rasch, K. D.[1]; Zimmermann, W.[1]; Bett, A.W.; Dimroth, F.; Taylor, S.[2]; Signorini, C.[2]; Schuelke, P.[3]; Hey, G.[3]
»Evolution of Fully European Triple GaAs Solar Cells«, in: Proceedings, 7th European Space Power Conference, Stresa, Italy, 9.–13.5.2005, pp. ESA SP-589
([1]: RWE Space Solar Power GmbH, Heilbronn, Germany) ([2]: ESA/ESTEC, Noordwijk, The Netherlands) ([3]: Deutsches Zentrum für Luft- und Raumfahrt DLR, Bonn, Germany)

Thoma, M.; Mienski, R.; Wasiak, I.; Pawelek, R.; Gburczyk, P.; Thoma, M. C.; Foote, C.; Morini, A.
»A Power Quality Management Algorithm for Low Voltage Grids with Distributed Resources«, in: Dispower. Project Highlight no. 17, 13.6.2005

Tiedtke, Y.;
»Concept for Solar Assisted Air-Conditioning of a Mushroom Farm in Windhoek/Namibia«, in:Tagungsband, International Conference Solar Air-Conditioning, Bad Staffelstein, Germany, 7./8.10.2005

Voyer, C.; Biro, D.; Wagner, K.; Preu, R.; Koriath, J.[1]; Heintze, M.[1]; Wanka, H. N.[1]
»Progress in the Use of Sprayed Phosphoric Acid as an Inexpensive Dopant Source for Industrial Solar Cells«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005, ([1]: Centrotherm Photovoltaics GmbH+Co. KG, Blaubeuren, Germany)

Went, J.; Seibert, U.; Herold, S., Holz, F.
»High-Intensity Ultrasonic Fields: A Promising Antifouling Strategy for UF Membranes in Decentralized Drinking Water Treatment Plants», in: Proceedings, International Conference and Exhibition for Filtration and Separation Technology FILTECH, Wiesbaden, Germany, 11.–13.10.2005, pp. II-570-579

Went, J.; Seibert, U.; Herold, S., Holz, F.
»Hochintensive Ultraschallfelder: Eine vielversprechende Strategie gegen Fouling für UF-Membranen in dezentralen Trinkwasseraufbereitungsanlagen», in: Tagungsband, 6. Aachener Tagung Siedlungswasserwirtschaft und Verfahrenstechnik ATSV, Aachen, Germany, 26.–17.10.2005, pp. P10-1-9

Wienold, J.;Christoffersen, J.;
»Towards a New Daylight Glare Rating«, in: Proceedings, Luxeuropa 2005, Berlin, Germany, 19.–21.9.2005

Wolke, W.; Preu, R.; Catoir, J.; Emanuel, G.; Ruske, M.[1]; Liu, J.[1]
»Surface Passivation for Solar Cells by Large Scale Inline Sputtering of SiN:H«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([1]: Applied Films GmbH, Alzenau, Germany)

Würfel, U.[1]; Peters, M.[1]; Hinsch, A.; Kern, R.
»Incorporating a Secondary Electrode in the Dye Solar Cell: Measuring the Internal Voltage«, in: Proceedings, 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6.–10.6.2005,
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Ziegler, C.; Schmitz, A.; Schumacher, J. O.; Tranitz, M.; Fontes, E.; Hebling, C.
»Modelling Approach for Planar Self-Breathing PEMFC and Comparison with Experimental Results«, in: Fuel Cells – From Fundamentals to Systems, Vol. 4, Issue 4, December 2004

Zimmermann, B.; Mingirulli, N.; Glatthaar, M.; Niggemann, M.; Riede, M.; Hinsch, A.
»Influence of Electrode Material on the Built-In Potential and Photovoltaic Performance of Organic Bulk-Heterojunction Solar Cells«, in: Proceedings, European Materials Research Society EMRS Spring Meeting 2005, Strasbourg, France, 31.5.–3.6.2005

Publications in Reviewed Journals

Aicher; T.; Lenz, B.
»Catalytic Autothermal Reforming of Jet Fuel«, in: Journal of Power Sources, Vol 149C, February 2005, pp. 44-52

Burmeister, F.[1]; Schäffer, E.[1]; Kleer, G.[1]; Döll, W.[1]; Bläsi, B.; Gombert, A.
»Investigation of structured TiAlN- and TiO_2-coatings with moth-eye like surface morphologies«, Surface and Coatings Technology, Vol. 200, Issue 1-4, pp. 1088–1092 (2005)
([1]: Fraunhofer IWM, Freiburg, Germany)

Fath, E. S.; El-Shall, F. M.; Vogt, G.; Seibert, U.
»A Stand Alone Complex for the Production of Water, Food, Electrical Power and Salts for the Sustainable Development of Small Communities in Remote Areas«, Desalination, 183(1-3) 2005, pp. 13-22.

Glatthaar M.[1]; Niggemann, M.; Zimmermann, B.; Lever, P.; Riede, M.; Hinsch, A.; Luther, J.
»Organic Solar Cells Using Inverted Layer Sequence«, in: Thin Solid Films, Vol. 491, Issues 1-2, 22.11.2005, pp. 298-300
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Glatthaar, M.[1]; Mingirulli, N.; Zimmermann, B.[1]; Ziegler, T.; Kern, R.; Niggemann, M.; Hinsch, A.; Gombert, A.
»Impedance Spectroscopy on Organic Bulk-Heterojunction Solar Cells« in: Physica Status Solidi (a), Issue 11, R125-R127 (2005)
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Gschwander, S.; Schossig, P.; Henning, H.-M.
»Micro-encapsulated paraffin in phase-change slurries«, in: Solar Energy Materials and Solar Cells 89, special issue Eurosun 2004, May 2005, pp. 307-315

Hakenjos, A.; Zobel, M.; Hebling, C.
»Spatially Resolved Measurement of PEM Fuel Cells«, in: Journal of Power Sources, Vol. 145, Issue 2, 18.8.2005, pp. 307-311

Hore, S.[1]; Palomares, E.[2]; Smit, H.[3]; Bakker, N. J.[3]; Comte, P.[4]; Liska, P.[4]; Thampi, K. R.[4]; Kroon, J. M.[3]; Hinsch, A.[1]; Durrant, J. R.[2]
»Acid versus Base Peptization of Mesoporous Nanocrystalline TiO_2 Films: Functional Studies in Dye Sensitized Solar Cells«, in: Journal of Material Chemistry, 2005, (3), p. 412
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Centre for Electronic Materials and Devices, Imperial College, Department of Chemistry, London, UK)
([3]: ECN Solar Energy, Petten, The Netherlands)
([4]: Laboratory for Photonics and Interfaces, Swiss Federal Institute of Technology, Lausanne, Switzerland)

Hore, S.[1]; Vetter, C. ; Kern, R.[1]; Smit, H.[2]; Hinsch, A.[1]
»Influence of Scattering Layers on Efficiency of Dye Solar Cells«, in: Solar Energy Materials and Solar Cells, In Press, Corrected Proof, Available online 19 August 2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Energy Research Center ECN, Solar Energy, Petten, The Netherlands)

Hore, S.[1]; Cameron, P. J.[2]; Peter, L. M.[2]
»How Important is the Back Reaction of Electrons via the Substrate in Dye-Sensitized Nanocrystalline Solar Cells?«, in: Journal of Physical Chemistry B, 2005; 109(2); pp. 930-936
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Department of Chemistry, University of Bath, United Kingdom)

Hore, S.[1]; Nitz, P.; Vetter, C.; Prahl, C.; Niggemann, M.; Kern, R.[1]
»Scattering Spherical Voids in Nanocrystalline TiO_2 – Enhancement of Efficiency in Dye Solar Cells«, in: Chemical Communications, 2005, (15), pp. 2011-2013
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Isenberg, J.; van der Heide, A. S. H.[1]; Warta, W.
»Investigation of Series Resistance Losses by Illuminated Lock-In Thermography«, in: Progress in Photovoltaics,Vol 138 (2005), pp. 697-703
([1]: ECN Solar Energy, LE Petten, the Netherlands)

Isenberg, J.; Buonassisi, T.[1]; Pickett, M. D.[1]; Marcus, M. A.[1]; Istratov, A. A.[1]; Hahn, G.[2]; Ciszek, T. F.[3]; Riepe, S.; Isenberg, J.; Warta, W.; Schindler, R.; Willeke, G.; Weber, E. R.[4]
»Quantifying the Effect of Metal-Rich Precipitates on Minority Carrier Diffusion Length in Multicrystalline Silicon Using Synchrotron-Based Spectrally-Resolved X-ray Beam Induced Current«, in: Applied Physics Letters, Vol. 87, (2005), pp. 044101
([1]: Lawrence Berkeley National Laboratory, Berkeley, CA, USA) ([2]: Universität Konstanz, Department of Physics, Konstanz, Germany) ([3]: National Renewable Energy Laboratory, Golden, CO, USA) ([4]: Department of Materials Science and Engineering, Berkeley, CA, USA)

Kaiser, R.; Baring-Gould, I[1].; Liaw, B. Y.[2]; Lundsager, P.[3]; Manwell, J.[4]; Ruddell, A.[5]; Svoboda, V.; Wenzel, H.[6]
»Life Prediction of Batteries for Selecting the Technically Most Suitable and Cost Effective Battery«, in: Journal of Power Sources, Vol. 144, Issue 2, 15.6.2005, pp.373-384
([1]: National Renewable Energy Laboratory, Golden, USA) ([2]: Electrochemical Power Systems Laboratory, Hawaii Natural Energy Institute, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, USA) ([3]: Risoe National Laboratory, Roskilde, Denmark) ([4]: University of Massachusetts, Amherst, USA) ([5]: Council for the Central Laboratory of the Research Councils, Rutherford Appleton Laboratory, Energy Research Unit, Chilton, UK) ([6]: Beratung für Batterien und Energietechnik, Osterode, Germany)

Köhl, M; Jorgensen, G.[1]; Brunold, S.[2]; Carlsson, B.[3]; Heck, M.; Möller, K.[3]
»Durability of Polymeric Glazing Materials for Solar Applications«, in: Solar Energy, Vol. 79, Issue 6 , December 2005, pp. 618-623
([1]: National Renewable Energy Laboratory, Golden, Colorado, USA) ([2]: Institut für Solartechnik Prüfung Forschung SPF, Rapperswil, Switzerland) ([3]: Swedish National Testing and Research Institute, Boras, Sweden)

Luque, A.[1]; Marty, A.[1]; Bett, A.; Andreev,V.[2]; Jaussaud,C.[3]; van Roosmalen, J.[4]; Alonso, J.[5]; Räuber, A.[6]; Strobl, G.[7]; Stolz, W.[8]; Algora,C.[1]; Bitnar, B.[9]; Gombert, A.; Stanley, C.[10]; Wahnon, P.[1]; Conesa, J.[11]; van Sark, W.[12]; Meijerink, A.[13]; van Klink, G.[14]; Barnham, K.[15]; Danz,R.[16]; Meyer, T.[17]; Luque-Heredia, I.[18]; Kenny, R.[19]; Christodes, C.[20]; Sala, G.[1]; Benítez, P.[1]
»FULLSPECTRUM: a New PV Wave Making More Efficient Use of the Solar Spectrum«, in: Solar Energy Materials and Solar Cells, 2005 vol. 87, pp. 467–479
([1]: Instituto de Energia Solar-Universidad Politécnica, Madrid, Spain) ([2]: Ioffe Physico-Technical Institute, St. Petersburg, Russia) ([3]: Commissariat à l´Energie Atmoique, Grenoble, France) ([4]: Energy Research Center of the Netherlands, Petten, Netherlands) ([5]: Isofotón S.A., Málaga, Spain) ([6]: PSE Projektgesellschaft Solare Energiesyteme mbH, Freiburg, Germany) ([7]: RWE Space Solar Power, Heilbronn, Germany) ([8]: Phillips Universität, Marburg, Germany) ([9]: Paul Scherrer Institut PSI, Villigen, Switzerland) ([10]: University of Glasgow, Scotland) ([11]: Instituto de Catálisis y Petroleoquímica, Madrid, Spain) ([12]: Department of Science, Technology and Society, Copernicus Institute, Utrecht, The Netherlands) ([13]: Department of Chemistry of Condensed Matter, Deby Institute, Utrecht, The Netherlands) ([14]: Department of Homogeneous Catalysis and Metal-Mediated Synthesis, Deby Institute, Utrecht, The Netherlands) ([15]: Imperial College of Science, Medicine and Technology, London, UK) ([16]: Fraunhofer Institut für Angewandte Polymerforschung, Potsdam, Germany) ([17]: Solarnoix SA, Aubonne, Switzlerand) ([18]: Inspira S.L., Madrid, Spain) ([19]: Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy) ([20]: Department of Physics, University of Cyprus, Nicosia, Cyprus)

Macdonald, D.[1]; Roth, T.; Deenapanray, P.N.K.[1]; Bothe, K.[2]; Pohl, P.[2]; Schmidt, J.[2]
»Formation Rates of Iron-Acceptor Pairs in Crystalline Silicon«,
in: Journal of Applied Physics, Vol. 98 (8) 083509 (2005)
([1]: Australian National University, Canberra, Australia) ([2]: Institut für Solarenergieforschung, Hameln, Germany)

Nitz, P.; Hartwig, H.[1]
»Solar Control with Thermotropic Layers«, in: Solar Energy Journal, Vol. 79, Issue 6, December. 2005
([1]: Technische Universität München, Germany)

Núñez, T.; Mittelbach, W.[1]; Henning, H.-M.
»Development of a Small Capacity Adsorption System for Heating and Cooling Applications«, in: International Journal of HVAC&R Research, USA, in press; received 24 February 2005; accepted 25 July 2005, available online 13 September 2005
([1]: Sortech AG, Halle, Germany)

Oszcipok, M.; Riemann, D.; Kronenwett, U.; Kreideweis, M.; Zedda, M.
»Statistic Analysis of Operational Influences on the Cold Start Behaviour of PEM Fuel Cells«, in: Journal of Power Sources, special issue February 2005, Vol. 149C, pp. 44-52

Papapetrou, M.; Epp, C.; Teksoy, S.; Sözen, S.; Ortin, V.; Seibert, U.; Vogt, G.
»Market Analysis for Autonomous Desalination Systems Powered by Renewable Energy in Southern Mediterranean Countries. Case study on Turkey«, in: Desalination, 183(1-3), pp. 29-40

Peharz, G.; Dimroth, F.
»Energy Payback Time of the High-Concentration PV System FLATCON,«, in: Progress in Photovoltaics: Research and Applications, 13, 2005, pp. 627-634

Pfafferott, J.; Herkel, S.; Wapler, J.
»Thermal Building Behaviour in Summer: Long-term Data Evaluation Using Simplified Models«, in: Energy and Building, 8/2005, Vol. 37, pp. 844–852

Reber, S.; Hurrle, A.; Eyer, A.; Willeke, G.
»Crystalline Silicon Thin-Film Solar Cells – Recent Results at Fraunhofer ISE«, in: Solar Energy, Vol. 77, December 2004, pp. 865–875

Rein, S.; Glunz, S. W.
»Electronic Properties Of Interstitial Iron And Iron-Boron Pairs Determined By Means Of Advanced Lifetime Spectroscopy«, in: Journal of Applied Physics, Vol. 98, Dez. 2005, pp. 113711

Riepe, S.; Buonassisi, T.[1]; Istratov, A.[1]; Peters, S., Ballif, C.[2]; Isenberg, J.; Warta, W.; Schindler, R.; Cai, Z.[3]; Lai, B.[3]; Weber, E. R.[4]
»Impact of Metal Silicide Precipitate Dissolution During Rapid Thermal Processing«, in: Applied Physics Letters, Vol. 87 (2005), p. 121918
([1]: University of California and Lawrence Berkeley National Laboratory, Berkeley, USA) ([2]: Institut of Microtechnology University Neuchâtel, France) ([3]: Advanced Photon Source, Argonne, USA) ([4]: Department of Materials Science and Engineering, University of California, Berkeley, USA)

van Riesen, S.; Bett, A.W.
»Degradation Study of III-V Solar Cells for Concentrator Applications«,in:
Progress in Photovoltaics: Research and Applications, Vol. 13, (2005), pp.369-380

Sastrawan, R[1].; Renz, J.; Prahl, C.; Beier, J.[2]; Hinsch, A.; Kern, R.
»Interconnecting Dye Solar Cells in Modules – I-V Characteristics Under Reverse Bias«, in: Journal of Photochemistry and Photobiology A: Chemistry, in press, corrected proof, available online 26 July 2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) (2: 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[5], F.M.; Prodi-Schwab, A.[5]; Lechner, P.[6]; Hoffmann, W.[6]
»A Glass Frit Sealed Dye Solar Cell Module with Integrated Series Connections«, in: Solar Energy Materials and Solar Cells, in press, corrected proof, available online 8 November 2005
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany) ([2]: Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany) ([3]: PSE GmbH Forschung, Entwicklung, Marketing), Freiburg, Germany) ([5]:Degussa AG, Creavis, Marl, Germany) ([6]:RWE Schott Solar GmbH, Alzenau, Germany)

Schossig, P.; Henning, H.-M.; Gschwander, S.; Haussmann, T.[1]
»Microencapsulated PCM Integrated into Construction Materials«, in: Solar Energy Materials and Solar Cells, special issue Eurosun 2004, pp. 297-306
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg, Germany)

Schultz, O.; Glunz, S. W.; Willeke, G. P.
»Multicrystalline Silicon Solar Cells Exceeding 20% Efficiency«, in: Progress in Photovoltaics: Res. Appl., Vol. 12, November 2004, pp. 553–558

Smolinka, T.; Hainen, M.[1]; Chen, X. Y.[1]; Jusys, Z.[1]; Lehnert, W.[2]; Behm, R. J.[1]
»CO_2 Reduction on Pt Electrocatalysts and its Impact on H_2 Oxidation in CO_2 Containing Fuel Cell Feed Gas – A Combined In-Situ Infrared Spectroscopy, Mass Spectrometry and Fuel Cell Performance Study«, in: Electrochimica Acta, ISE 2004 Special Issue, Vol. 50 (2005), pp. 5189–5199
([1]: Universität Ulm, Abteilung Oberflächenchemie und Katalyse, Germany) ([2]: Zentrum für Solarenergie- und Wasserstoff-Forschung, Germany)

Szolak, R.; Aicher, T.; Ivers-Tiffée, E.[1]; Weber, A.[1]; König, P.[1]; Jörissen, L[2].; Kaczerowski, J.[2]; Lewald, N.[3]; Brendel, M.[3]
»Testing and Model-Aided Analysis of a 2kW$_{el}$ PEMFC CHP-System«, in: Journal of Power Sources, 145/2 (2005), pp. 327-335
([1]: IWE, Universität Karlsruhe, Germany) ([2]: Zentrum für Sonnenenergie- und Wasserstoffforschung, Ulm, Germany) ([3]: Stadtwerke Karlsruhe, Germany)

Vetter, M.
»Erdgasbetriebene Brennstoffzellen-Blockheizkraftwerke im Einfamilienhaus – Simulationsbasierte Entwicklung von Regelstrategien«, in: H2-Tec, August 2005, pp. 7-10

Walze, G.; Nitz, P.; Ell, J.; Georg, A.; Gombert, A.; Hossfeld, W.
»Combination of Microstructures and Optically Functional Coatings for Solar Control Glazing«, in: Solar Energy Materials & Solar Cells, Vol. 89, pp. 233-248

Warta, W.; Green, M. A.; Emery, K.; King, D. L.; Igari, S.
»Solar Cell Efficiency Tables (Version 25)«, in: Progress in Photovoltaics, Vol. 13, January 2005, pp. 49–54

Wittstadt, U.; Wagner, E.; Jungmann, T.
»Membrane Electrode Assemblies for Unitised Regenerative Polymer Electrolyte Fuel Cells«, in: Journal of Power Sources, Vol. 145 (2005), pp. 555–562

Würfel, U.[1]; Wagner, J.; Hinsch, A.
»The Spatial Electron Distribution and its Origin in the Nanoporous TiO_2-Network of a Dye Solar Cell«, in: Journal of Physical Chemistry B, Vol. 109 (2005), pp. 20444-20448
([1]: Freiburger Materialforschungszentrum FMF, Freiburg, Germany)

Ziegler, C.; Yu, H.M.; Schumacher, J. O.
»Two-phase Dynamic Modeling of PEMFCs and simulation of cyclo-voltammograms«, in: Journal Electrochemical Society; soc.152 (2005), pp. A1555-A1567

Books and Contributions to Books

Goetzberger, A.; Hoffmann, V. U.
»Photovoltaic Solar Energy Generation«, Springer, Berlin, Heidelberg, New York, 2005
ISBN 3–540-23676-7

Herkel, S.; Wienold, J.; Faasch, T.; Pfafferott, J.; Kuhn, T.; Platzer, W.; Schossig, P.; Nitz, P.; Bühring, A.; Gossauer, E.; Reise, C.; Henning, H-M ; Wambsganß, M.[1]; Voss, K.[2]; Löhnert, G.[3]; Wagner, A.[4] .
»Bürogebäude mit Zukunft. Konzepte, Analyse, Erfahrungen«, März 2005 Bestell-Nr. 90883, TÜV-Verlag GmbH
ISBN 3-8249-0883-2
([1]: ip5 Ingenieurpartnerschaft, Karlsruhe), ([2]: Bergische Universität Wuppertal), ([3]: solidar Planungswerkstatt, Berlin), ([4]: Universität Karlsruhe)

Hebling, C.; Yu, H.
»Fuel Cells: Microsystems«, in: Encyclopedia of Materials: Science and Technology, 2005 Elsevier Ltd, pp.1-13
ISBN 0-08-043152-6

Núñez, T.
»Silica Gel/Water Adsorption Heat Pump for Heating and Cooling«, in: International Energy Agency, IEA-Task 32 Handbook, Chapter 3.7.4.5 Sorption, Closed Systems

Núñez, T.
»Closed System: Silica Gel/Water Adsorption Heat Pump for Heating and Cooling«, in: IEA-Task 32 Handbook Thermal Energy Storage for Solar and Low Energy Buildings, State of the Art«, J-C. Hadorn (ed.), Chapter 12.4.5 Sorption and Thermo-Chemical Storage,
ISBN 84-8409-877-X 149-155

Rein, S.
»Lifetime Spectroscopy – A Method of Defect Characterization in Silicon for PV Applications«, in: Springer Series in Materials Science, Volume 85, 489 p., 153 illus., June 2005
ISBN 3-540-25303-3

Reise, Ch.
Kurseinheit »Einführung zu regenerativen Energiequellen«, Lehrbrief für den Weiterbildenden Fernstudiengang Energiemanagement, Universität Koblenz-Landau, 2005

Reise, Ch.
Kurseinheit »Photovoltaik«, Lehrbrief für den Weiterbildenden Fernstudiengang Energiemanagement, Universität Koblenz-Landau, 2005

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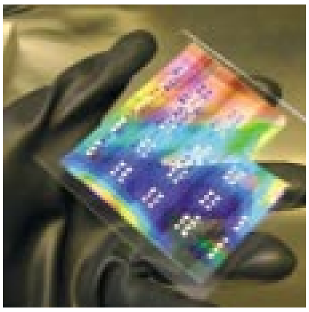



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