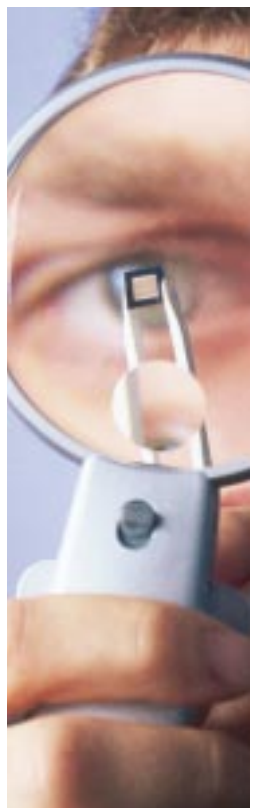
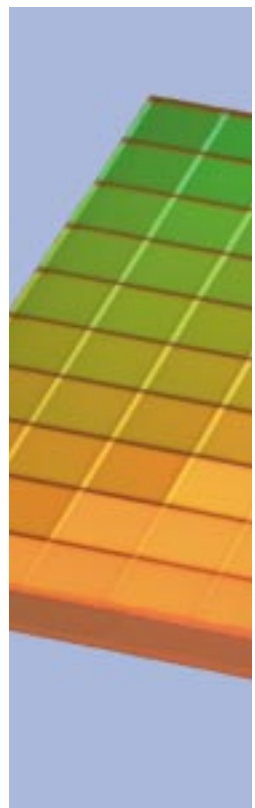
Fraunhofer Institut
Solare Energiesysteme

Annual Report 2003

Achievements and Results


left
Silicon concentrator solar cell for use in a photovoltaic concentrator system: The area needed for the solar cell is greatly reduced and "replaced" by concentrating optics such as lenses or parabolic reflectors. At Fraunhofer ISE, we are developing two-stage optical systems, which achieve relatively high concentration factors exceeding 300 with single-axis tracking (article on p. 37).

centre
Micro-structured polymer substrate produced by interference lithography as the basis for organic lasers: Organic lasers are a novel type of laser. The materials used for them offer the potential for an inexpensive production process. In addition, they can be produced over large areas and on flexible substrates. Within the project on "Tunable Photonic-Crystal Lasers based on Polymers", which is supported by the German Federal Ministry for Research, Fraunhofer ISE is co-operating with working groups at the Universities of Karlsruhe and Kassel to produce novel tunable organic lasers (article on p. 80).

right
Micro-encapsulated phase-change materials: A new class of building materials with micro-encapsulated paraffin drastically increases the thermal storage capacity of indoor plasters and plasterboards for lightweight buildings. A 6 mm thick layer can store as much heat in a daily cycle as a solid brick wall. Micro-encapsulated paraffins integrated into coatings for room walls can serve as a heat-storing building material, particularly for lightweight buildings without active cooling systems (article on p. 23).

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 building services technology, 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

Foreword

It is a pleasure to report that Fraunhofer ISE was able to continue its steady growth also in 2003. This was possible due to a comparatively good stock of industrial research contracts and joint European projects, and a stable amount of public funding. We have used this opportunity to sharpen the profile of some research areas on the one hand, and to further round off our R & D spectrum on the other hand.

We have intensified, reinforced and concentrated our activities on "Heating, Ventilation and Air-Conditioning (HVAC) Technology for Solar Lowest-Energy Buildings" and "Operation Management and Control of Energy Systems". The latter concerns electric and thermal systems primarily for solar and energy-efficient buildings and also decentralised energy supply systems. Our expertise is focussed on model-based procedures and linked control systems. In the HVAC sector, we are dedicating ourselves to customised technology for innovative buildings. The two technological areas are being led with great enthusiasm by Dr Andreas Bühring (HVAC), and Dr Christof Wittwer and Hans-Georg Puls.

In photovoltaics, Fraunhofer ISE has worked on solar cells, solar cell materials and systems technology up to now. Here, we have rounded off our spectrum by increasing our efforts on photovoltaic module technology. Our specific goal is extremely durable modules. Predicting the technical lifetime of such components, based on accelerated ageing tests and modelling, is particularly important.

Dr Helge Schmidhuber is responsible for expanding activities in this field.

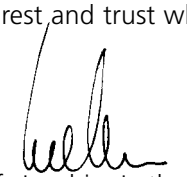
A new law concerning payment for electricity from solar power stations in Spain and numerous project developments in other countries of the "Sunshine Belt" have stimulated new technological developments in this area. Corresponding activities are vigorously supported by R & D projects from the German Federal Ministry for the Environment. Responding to this development, our Institute will intensify its efforts both on photovoltaic power stations and solar-thermal power stations. Whereas we conduct photovoltaic R & D ranging from solar cell development through concentrating optics to the complete system, our focus for the thermal systems is on materials research for optical components, optimisation of the collector optics and the corresponding control concepts. Hansjörg Lerchenmüller is co-ordinating work on this highly interdisciplinary and multi-facetted topic at Fraunhofer ISE.

However, these new or newly concentrated areas of activity represent only a small portion of the R & D spectrum at our Institute. We hope that this Annual Report will give you a good overview of the complete range of our activities. From the diversity of results achieved in 2003, I would like to select three as examples to demonstrate the performance of Fraunhofer ISE in applied and industrially relevant research:

- Development of a new inverter topology, which makes power electronics for photovoltaics feasible with efficiency values exceeding 96 %. The concept has already been transferred to industry.
- Fabrication of the first monolithic quintuple-junction solar cell in the world, based on III-V materials. The cell consists of 34 fully automatically grown epitaxial layers. This work is focussed on space applications.
- Development of novel coatings with a very high thermal storage capacity for building walls. The new building materials contain micro-encapsulated paraffins as an additional storage medium. Resulting products, which have been developed to commercial maturity together with industrial partners, are intended primarily for use in buildings which completely avoid installation of active cooling systems.

Again, this year a leading scientist has left us to accept new responsibilities at a university: Dr Dirk Uwe Sauer became a Junior Professor for "Electrochemical Energy Conversion and Storage System Technology" at the RWTH in Aachen. Fraunhofer ISE owes a great deal to Dr Sauer as a highly innovative and integrative scientist. On behalf of the entire Institute, I would like to thank him sincerely here also for his untiring efforts. Dr Sauer's successor in the areas of "Off-Grid Power Supply" and "Rural Electrification" is Felix Holz, who has been leading this work with verve since autumn, 2003.

It is important to me to emphatically thank all members of the Institute staff here for their achievements in 2003. Their creative, highly motivated and successful work deserves undisguised admiration! I am especially grateful to our clients and supporters in industry, ministries and the European Union. It is ultimately their interest and trust which makes our work possible.



Prof. Joachim Luther

Since 2002, the organisational structure of Fraunhofer ISE has had 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 five business areas the Institute addresses.

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

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

Portraits right, from left to right:
Joachim Luther
Volker Wittwer
Gerhard Willeke
Christopher Hebling

Portraits below, from left to right:
Wolfgang Wissler
Tim Meyer

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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 building services technology, solar cells, off-grid power supplies, grid-connected renewable power generation and hydrogen technology. Further expertise - beyond solar technology - includes micro-structured functional surfaces, seawater desalination and purification of drinking water.

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.

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 Solar Energy Research Association (Forschungsverbund Sonnenenergie) and the European Renewable Energy Centres (EUREC) Agency. There is particularly close co-operation with the Albert Ludwig University in Freiburg.

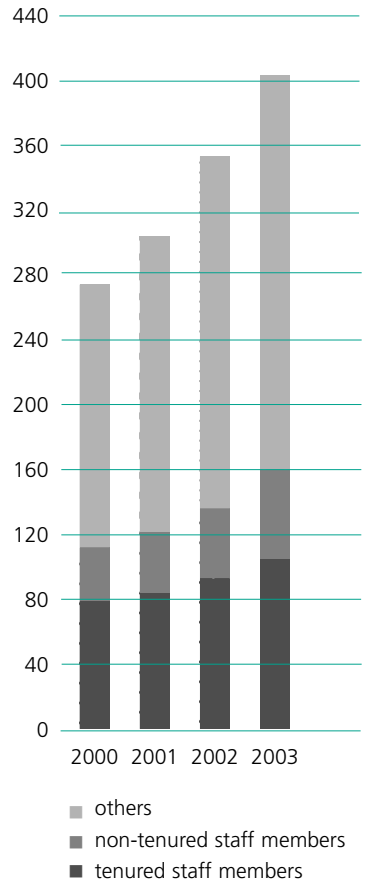
Research and Services Spectrum

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.

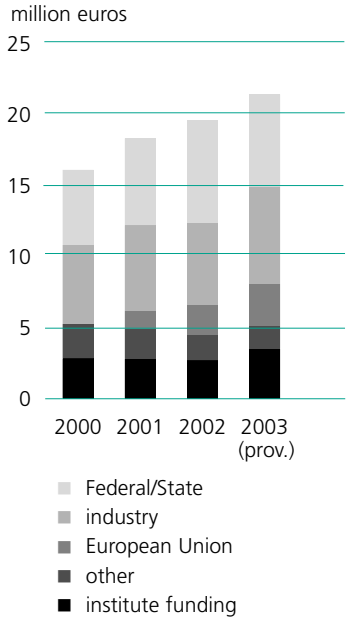
International Clients and Co-operation Partners

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

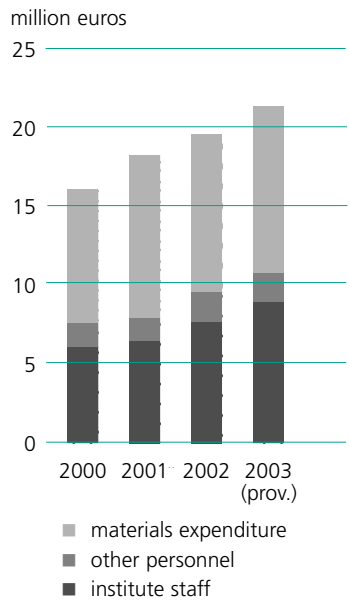
Personnel development



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 2003, 54 doctoral candidates, 75 undergraduate students, 6 apprentices, 107 scientific assistants and 1 other assistant were employed at the Institute. In this way, Fraunhofer ISE provides essential support to the education system.

In addition to the expenditure documented in the graph, the Institute made investments of 2.4 million euros in 2003.

Research and Development

- a heat-storing building material with integrated micro-encapsulated paraffins for use as a coating for room walls - particularly in lightweight buildings without active cooling developed to commercial maturity and successfully tested
- small, compact heating and ventilation units successfully transferred to the practice as excellent technology for heating solar passive houses
- automated interference-lithographic exposure of various 2D photonic crystal structures on a substrate developed
- nanostructured surfaces produced over an area of 60 cm x 80 cm
- evaluation methodology for glare resulting from daylighting systems further developed and tested
- first rolled module for thermal seawater desalination systems successfully tested
- 37 µm thin monocrystalline Si solar cell produced with an area of 2 cm x 2 cm and an efficiency value of 20.2 %, back-surface contacting with laser-fired contact LFC technology
- 17.8 % efficiency value achieved with 2 cm x 2 cm multicrystalline Si solar cell
- 10 cm x 10 cm monocrystalline Si solar cell with screen-printed contacts on the front and LFC (laser fired contacts) on the back achieved an efficiency value of 17 %
- silicon concentrator cell achieved an efficiency value of 24.1 % with an optical concentration factor of 100
- diffusion facility with walking-string transport, a plasma-etching system and nitride sputtering equipment developed on a technological prototype scale
- small module with four cells (10 cm x 10 cm), epitaxial thin-film equivalent-wafer cells on "reclaim wafers", achieved an efficiency value of 12.2 % in outdoor tests
- epitaxial process developed to produce triple-junction cells with an efficiency value of 27 % (AM0) for space applications
- first quintuple-junction solar cell in the world fabricated with 4.8 V cell voltage
- first monolithically integrated module (MIM) cells developed on the basis of GaAs. Ten series-connected cells (10 V), each with an area of 1 cm^2, achieve an efficiency value of 20 % (AM1.5d)
- GaSb cells successfully developed with MOVPE and Zn diffusion
- two new thermographic methods to determine performance losses in solar cells presented, illuminated thermography and emission carrier density imaging (CDI)
- natural gas reformer developed to produce hydrogen with a CO concentration < 10 ppm for application in household energy supplies
- electrolyser with 1 kW electric power at 15 bar successfully investigated in a field test
- methanol-fuelled fuel-cell stack developed with a continuous power of 30 W
- kerosene reformer for use in aeroplanes taken into operation
- "fuel-cell power box" with integrated control electronics and voltage conditioning developed as pre-series prototypes and presented at the Hanover Trade Fair
- fuel-cell power supply developed for professional television camera
- new circuit topology for inverters developed with an efficiency value of up to 96.5 % and successfully transferred to industry
- hybrid PV system, located remote from the grid at the "Rappenecker Hof" hikers' inn, extended with a fuel cell as an auxiliary electricity generator and highly innovative battery systems technology
- comprehensive package of training courses on non-technical aspects of rural electrification developed, first courses conducted with companies and public institutions

University Appointments and Prizes

Dr Karsten Voss became a C3 Professor at the University of Wuppertal, Chair of Building Science and Building Services Technology.

Dr Dirk Uwe Sauer became a Junior Professor for Electrochemical Energy Conversion and Storage System Technology at the Rheinisch-Westfälische Technische Hochschule RWTH in Aachen.

Dr Andreas Gombert declined the invitation to a Chair of Physics (Micro-Optics) at the Technische Fachhochschule of Darmstadt.

At the World Conference on Photovoltaic Energy Conversion (WCPEC) in Osaka, Fraunhofer ISE received awards for a young researcher, a paper and a poster:

WCPEC Young Researcher Award, Osaka, 16th May 2003
S. van Riesen, A.W. Bett, G.P. Willeke
"Accelerated ageing test on III-V solar cells"

WCPEC Paper Award, Osaka, 16th May 2003
S.W. Glunz, E. Schäffer, S. Rein, K. Bothe*, J. Schmidt*
"Analysis of the defect activation in Cz-silicon by temperature-dependent bias-induced degradation of solar cells"
* Institut für Solarforschung Hameln ISFH

WCPEC Poster Award, Osaka, 16th May 2003
S. Rein, P. Lichtner, S.W. Glunz
"Advanced lifetime spectroscopy: unambiguous determination of the electronic properties of the metastable defect in boron-doped Cz-Si"

Dr. Meyer-Struckmann Science Prize 2003 of the Brandenburg Technical University, Cottbus
This prize was awarded to Ralf Preu and Eric Schneiderlöchner for a publication with the title, "Der Laser-gefeuerte Solarzellenrückkontakt: ein innovatives hocheffizientes Verfahren für die industrielle Fertigung". (The laser-fired solar cell back-surface contact: an innovative, highly efficient process for industrial production.)

European Architecture + Technology Award 2003, presented for the first time by Messe Frankfurt within the ISH - Trade Fair for Building and Energy Technology 2003
The first prize was awarded for the Solvis zero-emission factory, for which Fraunhofer ISE had prepared the energy concept.
Special commendation was made of the Danish architectural office, Dissing+Weitling, for the new Institute premises of Fraunhofer ISE.

Innovation Prize R+T 2003 - International Trade Fair for Roller Shutters, Doors/Gates and Sun Protection 2003
One of ten innovation prizes was awarded by R+T 2003 for a transparent sun-shading blind constructed of hollow stainless steel rods, that was developed by Tilmann Kuhn, Fraunhofer ISE together with the company, clauss markisen Projekt GmbH.

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: 31st December, 2003

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Gerhard Warnke
MAICO Ventilatoren, Villingen-Schwenningen

Buildings and
Technical Building Services

Solar Cells

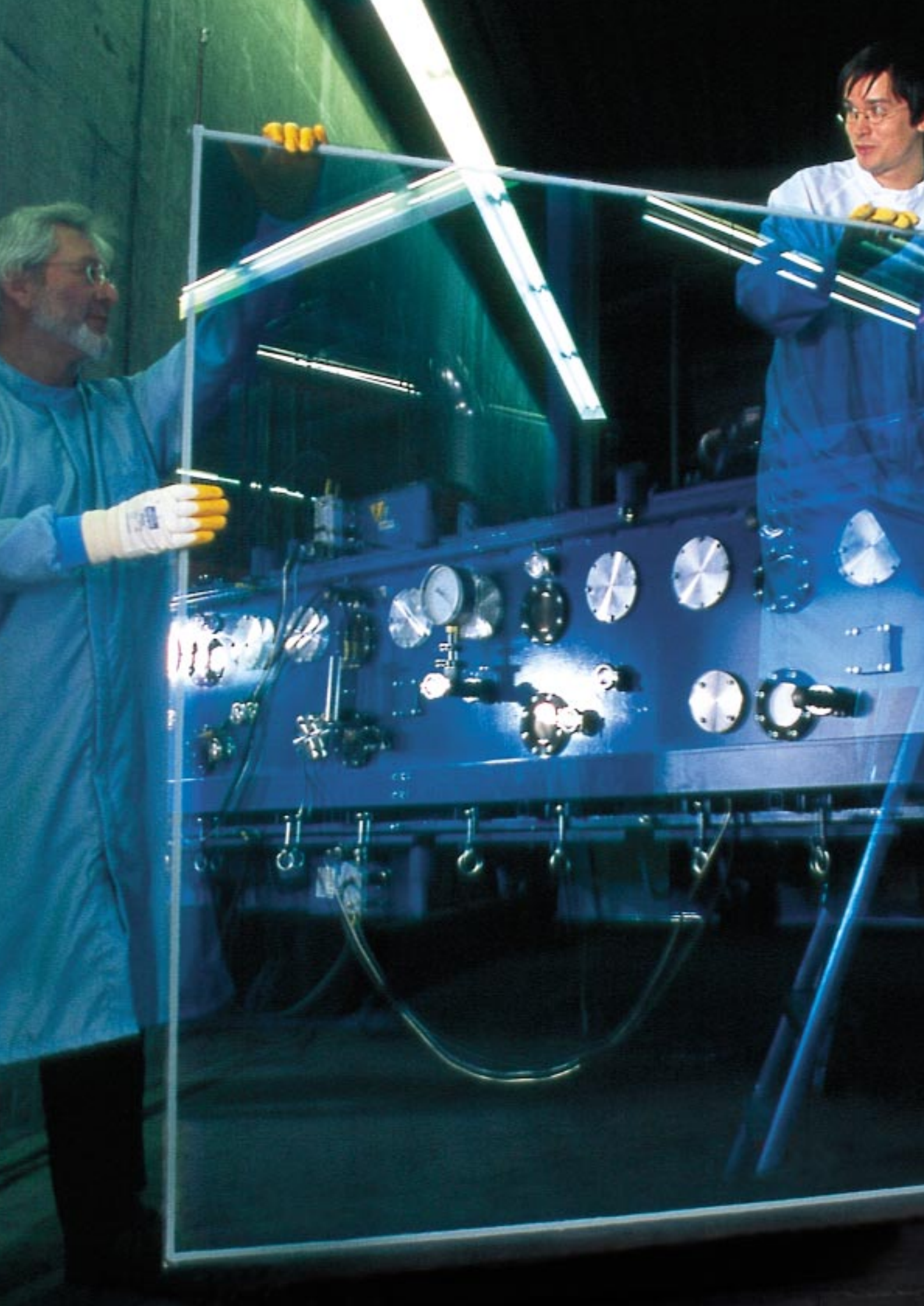
Off-Grid Power Supplies

Grid-Connected Renewable
Power Generation

Hydrogen Technology

Special Areas of Expertise

Service Units



Building efficiently with the sun

Buildings and Technical Building Services

Sustainable buildings not only protect the atmosphere, but are also easier to market. Buyers and tenants can be found more readily for real estate with built-in solar energy features and energy efficiency. This applies equally for new buildings and for building renovation, for commercial buildings and family homes, as energy costs have long since become a "second rent". In addition, sustainable buildings offer more user comfort: an abundance of natural lighting without glare, comfortable temperatures throughout the entire year, fresh air without draughts.

Legislation is supporting the trend toward sustainable building. Thus, millions of heating systems in Germany must be renovated in the coming years. An energy passport will make the specific energy consumption of buildings transparent to the general public.

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 demands 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 we have developed ourselves. The topics are treated at all levels, ranging from fundamental development to market introduction of completed systems.

These tasks rely on co-operation between many disciplines: materials research and thin-film development, rational use of energy, simulation, planning, monitoring, development of components such as windows or walls, and of solar systems for heat and electricity. The importance of miniature heat pumps is growing. In future, decentralised energy generators such as small fuel cells will assume a major role as suppliers of heat and electricity in the building sector.

We apply comprehensive measurement technology to characterise materials and systems. Monitoring is used to analyse the practical operating experience in selected buildings, improving our own concepts and those of our clients. We accompany 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. The international boundary conditions for solar air-conditioning, solar building and the long-term durability of components are created within programmes of the International Energy Agency IEA. Our participation in these programmes ensures that we are always informed about the current technical standards. This, together with our international contacts, means that we can support our clients optimally in market introduction.

Our work includes both the further development of simulation programs to optimise materials and systems and also user acceptance studies on architectural innovations.

We are constantly developing our equipment and measurement procedures further. Some examples include:

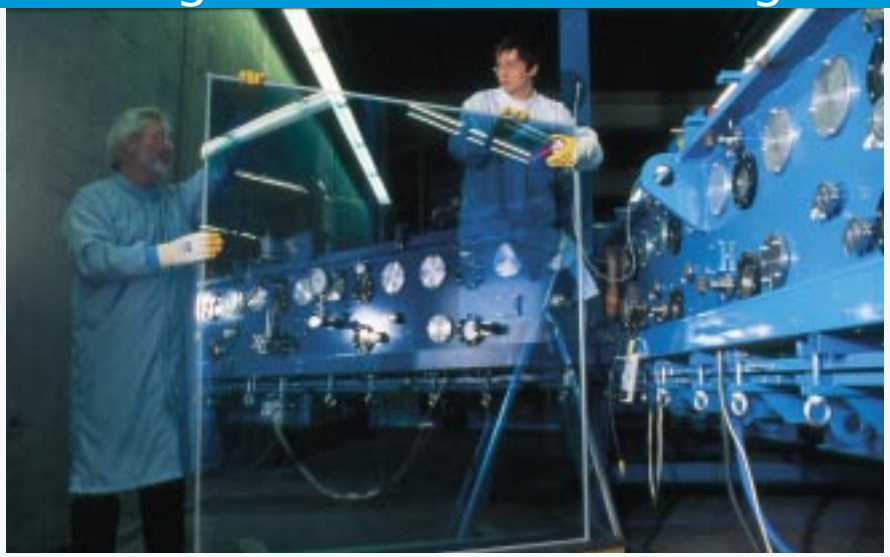
- large laser exposure benches, to produce microstructures over areas of up to 60 cm x 80 cm
- vacuum deposition system for quasi-industrial production of large-area (140 cm x 180 cm), complex coating systems on glass, polymer films and metals
- optical laboratories for characterisation and analysis in materials development
- test laboratories to determine physical and technical properties of collectors, thermal storage tanks, windows and wall systems
- measurement technology for on-site quality control in buildings.

The more complex buildings and systems become, the greater the importance of controls. With the development of our own software and hardware, we are working toward the goal of operating complete systems optimally according to economic and / or ecological criteria.

Fraunhofer SOBIC - Solar Building Innovation Center

The Fraunhofer Solar Building Innovation Center SOBIC will be opened in spring 2004. The demonstration centre for solar building is a joint project between two Fraunhofer Institutes, for Building Physics IBP in Stuttgart and for Solar Energy Systems ISE. Its objective is to transfer research results concerning energy-efficient and solar building rapidly to commercial enterprises and consumers. The Freiburg branch of Fraunhofer SOBIC is located in the "solar info center", a privately operated expertise centre for planning and building with renewable energy. The other branch of Fraunhofer SOBIC is situated in Fellbach.

Buildings and Technical Building Services



Gasochromic glazing unit in front of equipment which is used to develop production procedures for sputtered coatings. Demonstration objects with an area of up to 1.4 m x 1.8 m can be produced with this equipment.

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Passive Cooling of Buildings with Night Ventilation

The summer of 2003 was a severe test for the indoor climate in all buildings - regardless of whether they were residential buildings, production halls or office buildings, with or without air-conditioning units. Measurement campaigns over the summer of 2003 demonstrated that cooling based only on natural heat sinks can also function during heat waves. Where active cooling is needed, the energy demand can be restricted to a minimum, provided that technical building services and architecture are designed to complement each other in all aspects.

Sebastian Herkel, **Jens Pfafferott**, Jan Wienold, Tilmann Kuhn

Fig. 1: In the 17-storey Fraunhofer Haus in Munich, with its large glazed areas, the cooling energy demand for concrete slab cooling can be greatly reduced by use of natural heat sinks (cool night air), as the double-glazed external facade makes natural ventilation feasible, day and night. The photo shows a view along one storey of the double-glazed facade on the south-eastern side.

A cross-sectional comparison of five passively cooled buildings in the long-term monitoring programme shows that - with careful tuning of heat gains, losses and storage - comfortable room temperatures can be achieved without the use of air-conditioners. In the extreme summer of 2003, continually comfortable room temperatures could be maintained only in those buildings in which not only cooler night air but also a further heat sink was available, e.g. an earth-to-air heat exchanger or cooling of a building component.

We design building concepts with passive cooling, paying particular attention to the effect of the user's behaviour and the energy balance for the room. Minimising the heat load, efficient heat removal and use of building components for heat storage are central aspects. We use thermal building energy simulation as a planning tool to optimise the building concept, the technical building services and their operation management. We apply computational fluid dynamics for very detailed analysis of the measured data, to determine air flow patterns in a room or the heat transfer between building components and air.

Measurement data from long-term and short-term measurements (e.g. air exchange measurements, thermography, measurement of comfort indicators, temperatures, meteorology and user behaviour) are used not only to assess implemented concepts, but also to validate the planning tools. This in turn increases the planning certainty.

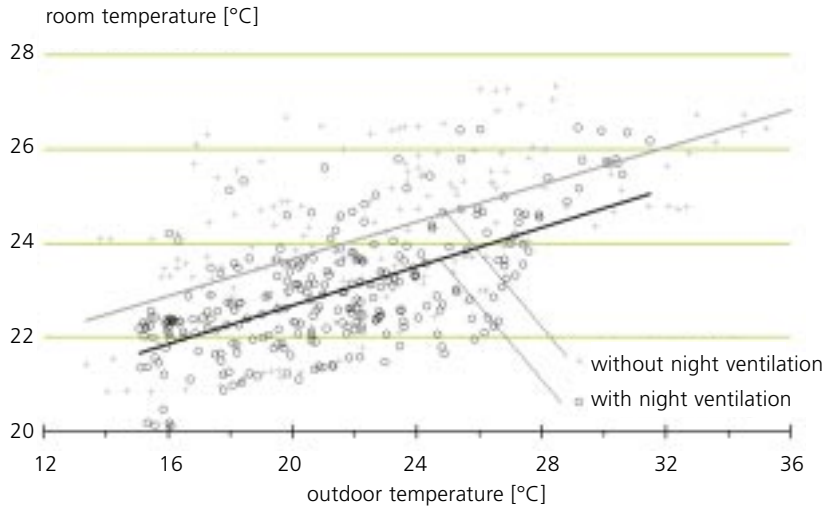

Fig. 2: Measured room air temperatures in an office at Fraunhofer ISE versus outdoor temperatures, during the period from 1st June to 31st August 2002. The night cooling was not operated between 1st June and 14th July, but was operated between 15th July and 31st August. As the fitted lines for both periods indicate, the night cooling lowered the room temperature during the operating period by 1.2 K.

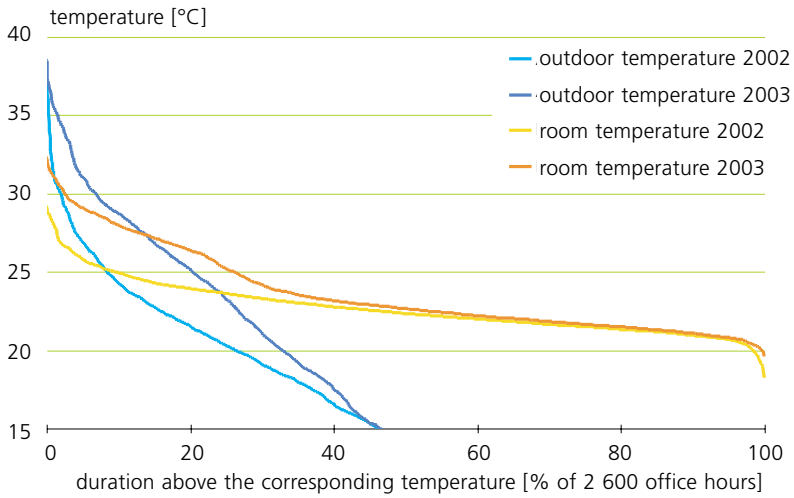

Fig. 3: The summer of 2003 was around 4 °C hotter than that of 2002. Accordingly, the room temperatures in Fraunhofer ISE in summer 2003 were 3 °C higher for several weeks than for summer 2002. The short hot period in 2002 was accommodated well by the building. In the extreme summer of 2003, the night cooling also lowered the room temperature, but could not guarantee continually comfortable room air temperatures due to the high temperatures that still prevailed at night.

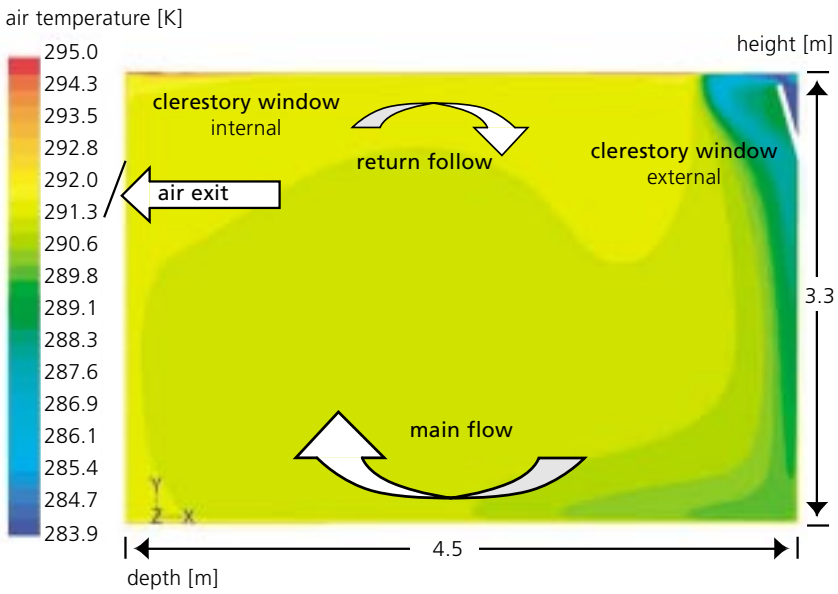

Fig. 4: Temperature field in an office room at 2 a.m. in the morning. The computational fluid dynamic simulation was based on comprehensive model validation using temperature and air exchange measurements. The cool night air enters the top of the room through a clerestory window, falls as a "curtain" with a width of about 80 cm to the floor, is heated and is removed mechanically into the adjoining corridor through a flap above the door opposite the inlet wall. The thermal updraft leads to formation of a convection roll within the room.

Three Examples of Successful Facade Planning

The extremely hot summer of 2003 in Germany presented a major challenge for controlling solar gains to buildings. Thus three buildings, where Fraunhofer ISE had participated in designing the facades, were subjected to a "baptism of fire" during the first summer after occupation. All three buildings, with their individual facade concepts, passed this test successfully.

Tilmann Kuhn, Jan Wienold

Fig. 1: The new high-rise building for the Dresdner Bank in Frankfurt am Main. The single-skin facade allows natural ventilation of the rooms. A single-skin facade is economic, not only because of the investment costs, but also because more space is available for leasing due to the thinner external walls.

Fig. 2: The "Messeturm" (trade fair tower) in Basel, Switzerland. In the highest building in Switzerland, the exhaust air is removed from the rooms via the intermediate space in the facade. This air flows past the sun-shading units, cooling them and the intermediate space. The photo shows the installation of the facade elements.

Fig. 3: The Fraunhofer Haus in Munich. The double-skin facade is part of the ventilation concept for the offices.

Gallileo, Frankfurt am Main: The high-rise building for the Dresdner Bank has a single-skin, fully glazed facade with internal sun-shading units and windows which can be opened by being pushed outward (parallel stays). The building has both thermally activated ceilings and air conditioning (heating + cooling). The main goal was to design the facade to be "robust" against so-called "faulty operation". To achieve this, we used a newly developed methodology to analyse the effect of diverse types of usage on the solar control performance for several facade variations. In addition, we tested the g value of several facade variants in our laboratory.

Messeturm Basel, Switzerland: We co-operated with Bug AluTechnic to develop the facade concept for the Messeturm Basel. The air conditions within the building are regulated and the fully glazed facade forms part of the ventilation concept. In this mechanically ventilated double-skin facade, the exhaust air from the offices is removed through the gap between the inner and outer double-glazings. The exhaust air cools the sun-shading units, which are located in this gap. In this way, extremely low g values of 0.06 ± 0.02 (venetian blinds closed) and 0.10 ± 0.02 (venetian blind slats in operating position) were achieved and demonstrated in laboratory tests.

Fraunhofer Haus, Munich: The central issue for the new headquarters of the Fraunhofer Gesellschaft, a 17-storey building with a double-skin facade, was natural ventilation and cooling without mechanical ventilation technology or a chiller. Fraunhofer ISE was responsible for the energy concept, and the optimisation of the facade. On the basis of measurements and simulation, we optimised not only the flow patterns for inlet air and the air flowing behind the facade, but also the sun-shading devices and the internal heat sources (e.g. use of energy-saving PC's and TFT monitors, central printers). To prevent overheating, thermally activated ceilings are used, which operate with the surrounding, naturally cool night air by using a cooling tower. Satisfied users and measurements during the summer of 2003 demonstrated that the specified comfort criteria were met.

Optimisation of Control Strategies for Facade Systems

Solar control and glare protection systems are usually set or adjusted by the user according to visual criteria. To determine an optimised switching point for an automated gasochromic system, the amount of daylight and particularly the luminance of the facade should be taken into account. Within the EU-funded SWIFT project, we have developed a procedure that allows widely differing control strategies to be evaluated under realistic conditions.

Jan Wienold, Werner Platzer

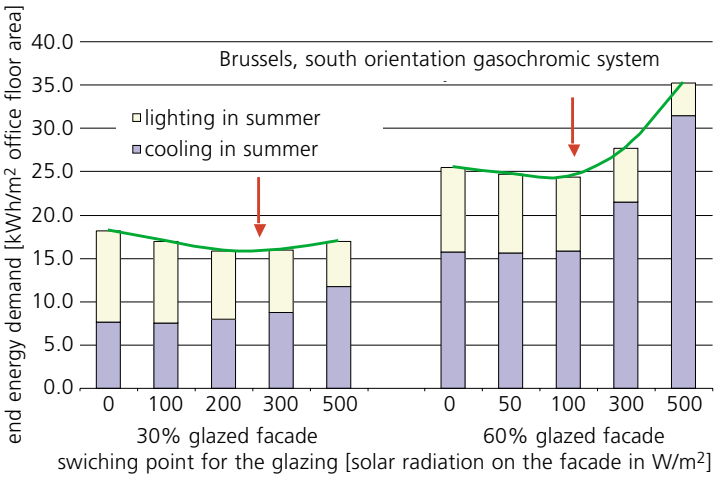

Fig. 1: Results of the coupled thermal and daylighting simulations. Minimisation of the total energy for cooling and lighting identifies the optimal switching point for the switchable glazing. Results for two glazing variants and a Central European climate (Brussels) are shown. For a facade glazing fraction of 30 %, the optimal switching point is at about 250 Wm^{-2} solar radiation in the facade plane; for a fraction of 60 %, it is at about 100 Wm^{-2}.

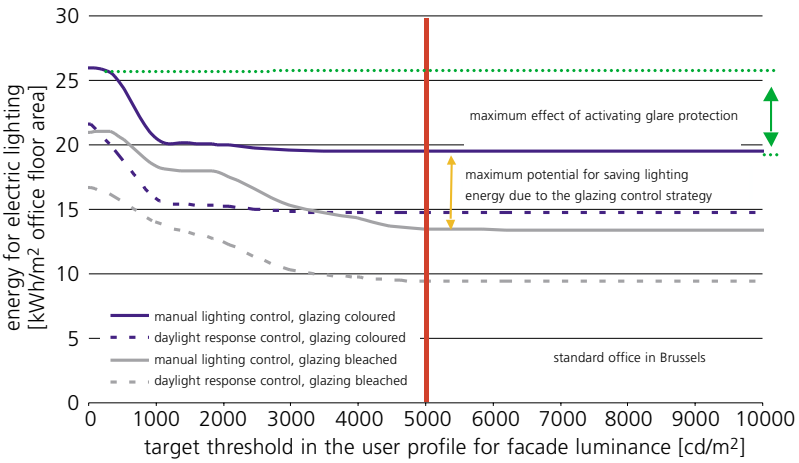

Fig. 2: The applied user profile assumes that glare protection is activated to prevent the viewed facade luminance from exceeding a certain threshold. The graph shows the effect of choosing different luminance thresholds on the electricity demand for the artificial lighting. The red line marks the maximum facade luminance of 5000 cdm^{-2}, which was determined in user studies and then applied in all following simulations. Also shown is the maximum possible influence of a control strategy on the lighting energy, both for the switchable glazing and for operation of the glare-protection device.

To evaluate control strategies for facade systems in advance by simulation, it is essential to run coupled thermal and daylighting simulations. The distinguishing feature of our newly developed method compared to existing ones is the use of realistic user profiles, which were identified within research projects. These profiles reflect the fact that users also adjust glare protection according to visual comfort criteria, e.g. facade luminance and the potential penetration of direct sunlight onto the user's face and working area. As well as taking the optimised slat position of e.g. venetian blinds into account, the profile also reflects a typical feature of user behaviour, that the blinds are not readjusted unless conditions change drastically. In addition, the calculation method used allows any other type of control strategy to be investigated without needing time-consuming new simulations. All data required are determined in the initial simulation step and can then be evaluated with the help of control algorithms.

The results of the daylighting simulations are load profiles for the artificial lighting, which take account of realistic operation of the solar-control and glare-protection devices. These load profiles are used as inputs for the thermal simulations to calculate the indoor climate conditions. We have applied this to gasochromic facade systems to determine optimised switching points for different combinations of climatic zone, orientation, glazing fraction and horizon obstruction. The switching point was defined as the solar radiation intensity (in Wm^{-2}) on the facade plane which resulted in a minimal energy demand total for lighting and cooling. The results of our simulation study have been presented in design guidelines for switchable facade systems. With this new method, we can quantify the effect of different solar-control units and control strategies on the lighting and cooling demand and on thermal and visual comfort.

Integration and Evaluation of Switchable Units in Facades

Electrochromic and gasochromic glazing units dynamically control the amount of light and energy passing through the facade. To support the practical integration of this new technology into buildings, we have developed methods and a data base for the planning process. The potential for saving the primary energy needed for artificial lighting, cooling and heating was investigated, while thermal and visual comfort were simultaneously optimised.

Markus Heck, Michael Köhl, Florian Pfeifer, **Werner Platzer**, Jan Wienold, Helen Rose Wilson*

* Interpane Entwicklungs- und Beratungsgesellschaft mbH, Lauenförde

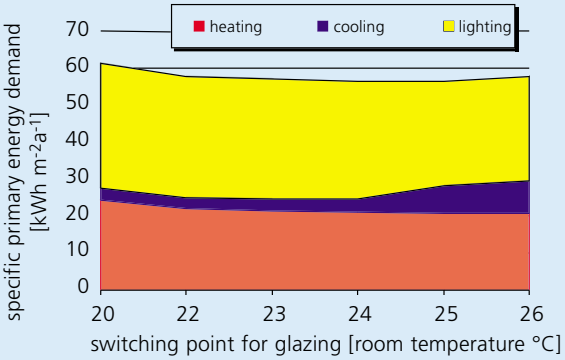

Fig. 1: Primary-energy optimisation of the switching point of a control strategy based on room temperature. In the example, a model office building located in Brussels, with offices oriented to the south and the north, is equipped with an additional blind for glare protection, to ensure visual comfort. The switching point of the facade should be 2 K below the threshold for active cooling (26 °C), as the cooling energy demand increases strongly otherwise (twice as high with 26 °C instead of 24 °C). The primary energy factor of three for artificial lighting means that it represents the dominant share of the annual energy demand.

Fig. 2: View out of a Fraunhofer ISE office equipped with switchable glazing. The right-hand window has been coloured blue, the left-hand window is open. The view through the window is retained even when it is in a deeply coloured state with a total solar energy transmittance of around 15 %.

The dynamic optical and thermal properties of switchable facades were tested in the laboratory and measured for long periods in test facades. In order to simulate the facade behaviour for different climatic zones, usage profiles and building types, we derived simulation models for the facades from the measured data and validated them. Durability and stability were investigated with accelerated ageing tests and long-term exposure to outdoor weathering. The new features of the systems meant that existing testing procedures had to be adapted and further developed appropriately.

Evaluation of the control strategy for switchable elements depends on the specified goals: Thermal and visual user comfort compete with minimisation of the primary energy consumption for lighting, cooling and heating. Different control strategies have been tested by simulation, using a reference office that we developed in international co-operation within the IEA-SHC Task 27, "Performance of solar facade components". This means that we can now quantify the effect of various control options for sun-shading devices and switchable glazing on the primary energy consumption and comfort. Minimisation of the primary energy consumption was the main object of the simulation illustrated in fig. 1. In another investigation (see p. 21), the control strategy was optimised according to visual criteria. In both cases, we used coupled thermal and daylighting simulations with realistic user profiles.

The results of simulation studies, user questionnaires and technical investigations formed the input for a planning manual on switchable facade systems.

The work was financially supported by the EU within the SWIFT project. The planning manual and further information can be found under: www.eu-swift.de

Temperature Control with Micro-Encapsulated Phase Change Materials

The heat capacity of many different materials can be drastically increased by introducing phase change materials (PCM). Micro-encapsulation of PCM's makes it feasible to add them to conventional building materials. This increased heat capacity is desirable in lightweight buildings to buffer the peak thermal loads that occur on hot summer days. This reduces the need for air-conditioning and increases user comfort. Heat transfer fluids can also be optimised by these additives.

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

Fig. 1: Application of the PCM plaster in the new premises of the badenova utility in Offenburg. The material can be handled on the building site in exactly the same way as conventional plaster.

With the goal of quantifying the PCM effect exactly with measurements, we thoroughly instrumented two identical lightweight test cells and equipped them with PCM products for several test series. For our current measurement series, we covered the test cell walls with 12 mm thick plaster from the maxit company. Our measurements revealed a temperature difference of up to 4 K in the wall and 3 K in the air. The number of hours with temperatures exceeding 26 °C in the PCM cell was significantly reduced. Despite this, use of sun-shading blinds is still recommended. Similarly, it is essential to operate controlled night ventilation to discharge the storage elements overnight. The data we measured with the test stand, even during the record summer of 2003, clearly show the potential of building materials containing PCM. The need for air-conditioning sinks and the indoor comfort level rises.

The first products containing PCM became commercially available at the beginning of 2003. They have already been used in reference buildings. For instance, the badenova utility equipped its new offices in Offenburg with PCM plaster and decided against installing an air-conditioning unit.

Our partners in the project, which is funded by BMWi (German Federal Ministry of Economics and Technology), are BASF, DAW, maxit and Sto.

If micro-encapsulated PCM's are added to heat transfer fluids, their heat capacity can also be increased in the desired temperature range. This reduces both the pump energy required and thermal losses in the distribution circuit. The capacity of existing circuits can be increased by introducing PCM fluids.

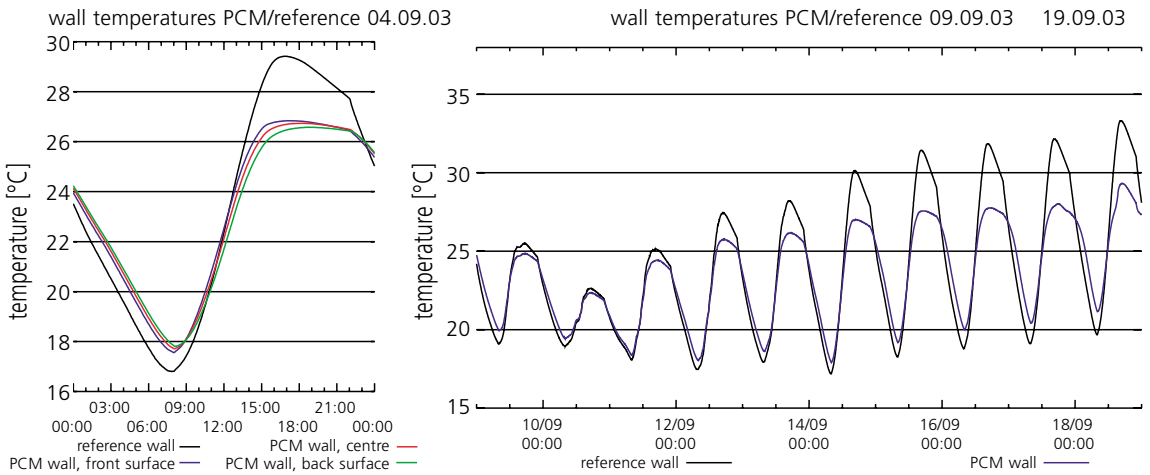

Fig. 2: Wall temperatures of the PCM cell (blue) and the conventional reference cell (black) during a period of three weeks. It is clear that the wall temperature of the PCM cell is regularly about 3 - 4 K lower than that of the reference cell. In the melting range of the PCM (24 - 27 °C), the temperature of the PCM wall rises significantly more slowly than that of the conventional wall. In addition, the temperature maximum is shifted due to the PCM by about 1 - 2 hours to about 6 p.m. in the evening, make it particularly attractive for office buildings.

Planning Tools for Solar Air-Conditioning

Summer air-conditioning is a promising application for thermal use of solar energy in buildings. However, to date there has been a lack of standardised concepts for system design. Within various projects over the past few years, we at Fraunhofer ISE have developed a range of planning tools with varying levels of detail, which can be applied as appropriate to the project phase.

Hans-Martin Henning, Edo Wiemken, Carsten Hindenburg, Lena Schnabel, Mario Motta, Tim Selke

Fig. 1: Cover of the handbook, "Solar-Assisted Air-Conditioning in Buildings - A Handbook for Planners" (Springer-Verlag Vienna, ISBN 3-211-00647-8)

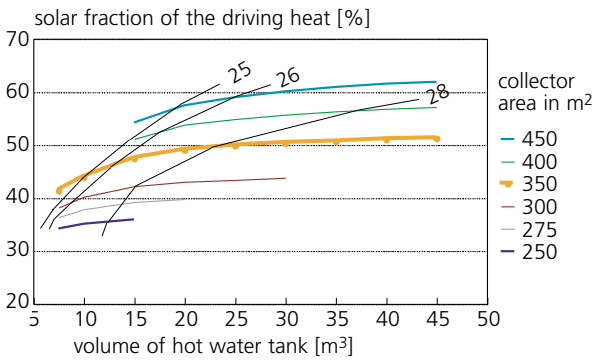

Fig. 2: Solar fraction of room cooling energy as a function of the volume of the buffer tank for different collector areas. The system is to be installed at the Umweltbundesamt UBA (German Federal Environmental Office) in Dessau. The solar fraction is defined as the fraction of the total driving energy for the chiller which is provided by the solar thermal system. The lines marked with numbers (25, 26, 28) are iso-lines for the annual net collector efficiency: e.g. the value of 25 means that the annual net collector efficiency value is 25 %. The annual collector efficiency is the ratio of the solar driving heat that can be used for cooling, and the annual solar radiation total on the solar system.

Under the leadership of Fraunhofer ISE, a handbook for planners has been produced within the IEA-SHC Task 25 on "Solar Assisted Air-Conditioning of Buildings". It gives an overview of the most important types of technology and recommendations for planning (fig. 1).

A simple design program produces preliminary drafts for the solar system in solar-assisted air-conditioning systems. The program was developed within the EU-funded project, "SACE - Solar Air Conditioning in Europe" and is freely available: www.ocp.tudelft.nl/ev/res/sace.htm

Detailed planning of systems for solar air-conditioning often still requires extensive system simulation, as the planning engineer cannot draw on much practical experience yet. Therefore, we have developed special computer programs at Fraunhofer ISE which can be used to carry out detailed system simulations in a relatively short time. At the same time, we have written special subprograms for the TRNSYS software, which is widely used for solar-thermal system technology, to model the cooling and air-conditioning components and have applied them in various studies to support system planning. As an example, fig. 2 shows results from different designs for the solar-thermal air-conditioning system for the computer rooms in the new building of the Umweltbundesamt UBA (German Federal Environmental Office) in Dessau. The system is combined with a solar-assisted adsorption chiller.

Monitoring – Energy Evaluation of the Heating Technology in Passive Houses

This monitoring programme is designed to investigate the energy efficiency of heating technology for passive houses. Its main emphasis is on evaluating the integrated heating system with exhaust-air heat pumps in combination with thermal solar systems. The monitoring results on heating passive houses with extremely small heat pump systems confirm the intended energy efficiency and user comfort.

Andreas Bühring, Christel Russ,
Benoit Sicre, Marek Miara

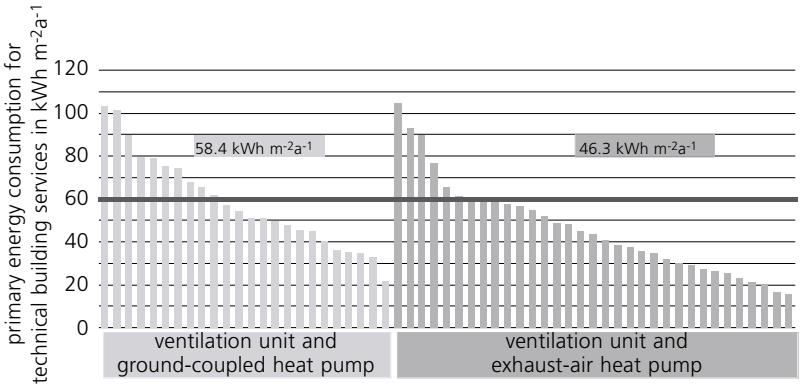

Fig. 2: The specific primary energy consumption for 2002 was determined for space heating and domestic hot water, as well as for ventilation in passive houses with modular ground-coupled heat-pump systems and ventilation units with exhaust-air heat pumps or compact ventilation units. The heating energy per heated useful floor area was even lower than the target value of 60 kWh m^{-2} per annum for most passive houses. Only a few buildings have a higher primary energy consumption. The energy consumption in these buildings can still be reduced by optimising the control systems.

We are investigating heating systems with heat pumps in passive houses (fig. 1) in numerous monitoring projects, with the aim of quality assurance for the systems and the buildings. In more than 65 % of all the evaluated single-family homes and blocks of flats, we have determined a primary energy consumption of less than 60 kWh m^{-2} a^{-1} (fig. 2). We revealed that the primary energy demand in buildings with well-tuned controls technology for the different heating system components is so low that it is only a quarter of the threshold specified in the energy-saving regulation, EnEV 2002.

The heating systems in the passive houses that were investigated within the monitoring programme include:

- modular systems with a ventilation unit, ground-coupled heat pump and solar collector
- compact ventilation units (ventilation with heat recovery and exhaust-air heat pump) and solar collectors
- central heating with a heat pump or district heating supply in combination with a solar system and ventilation systems with heat recovery for the whole building or individual flats

Information about weak points in the heating technology identified during the energy analysis is valuable for the planners and equipment manufacturers.

We were able to carry out this extensive monitoring programme for quality assurance of heating technology with heat pumps in passive houses thanks to financial support by the utility EnBW Energie Baden-Württemberg, the Stiftung Energieforschung Baden-Württemberg (Foundation for Energy Research) and the Deutsche Bundesstiftung Umwelt (German Federal Foundation for the Environment).

Fig. 1: Passive houses from the monitoring programme of the utility, EnBW Energie Baden-Württemberg AG. Heating system with ground-coupled heat pumps, ventilation units with heat recovery or compact ventilation units and thermal solar systems.

Testing of Compact Ventilation Units

Compact ventilation units with integrated exhaust-air heat pumps represent a very efficient solution for supplying heat to passive houses. While the equipment is being developed, high-quality measurements of prototypes and experimental systems are important for the optimisation process. To support development, we have set up a test rig in which we can measure our clients' equipment according to the measurement standards, but also under individually specified stationary and dynamic conditions.

Andreas Bühring, Sebastian Bundy, Wolfgang Guter, Jan van Wersch, Martina Jäschke, Michael Schossow, Michael Krieg

Fig. 1: Compact ventilation units during measurement on the test rig. The unit on the top is specially designed for use in passive blocks of flats and has a small, integrated drinking water tank with a capacity of 200 l. The unit below, with an integrated solar hot-water tank of 240 l, can use an additional outdoor air current as a further heat source, and can also be used in summer to cool the inlet air.

Our test rig for compact ventilation units is used to test the efficiency and operating safety of equipment for our clients. In doing so, we can set fixed boundary conditions for usage over a wide range or specify dynamic load profiles as required.

The test specifications according to the standard, EN 255 Parts 2 and 3, make special demands. A test cycle lasting several days is run for the water heating, in which the test rig controls continually check the measured values and must react to the operating states of the compressor. We have fully automated this measurement procedure and also offer it for additional operating points. This also applies for coupled operation of a heat pump for space heating and domestic hot water.

We have set up two equivalent measurement facilities to allow measurements to be completed quickly. While measurements on one compact ventilation unit are running, we can simultaneously install a second one and equip it with sensors. The system allows rapid alternation between the two measurement facilities. In this way, we have completed measurements and

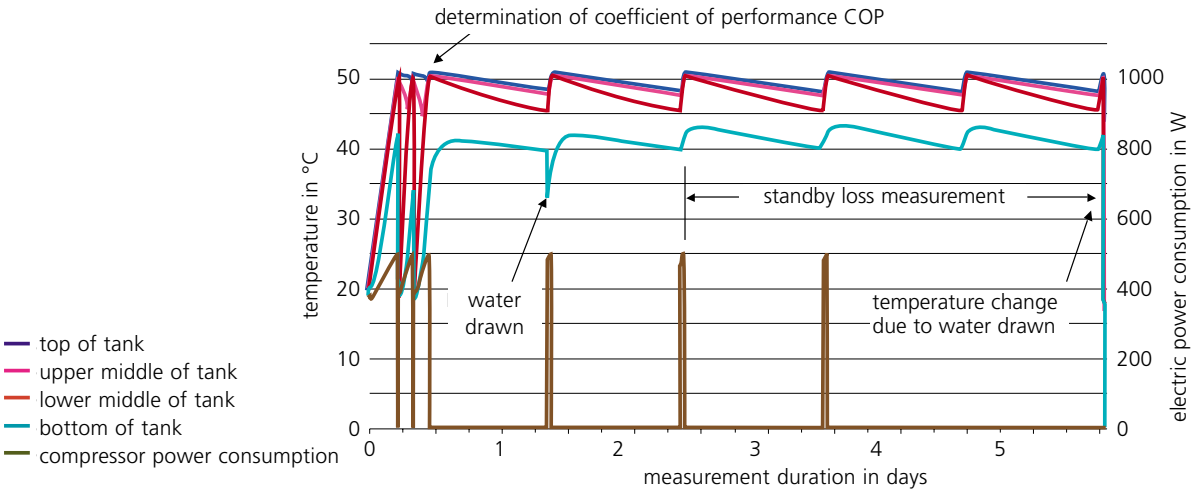

Fig. 2: Tank temperatures and compressor power consumption for the integrated exhaust-air heat pump in a measured compact ventilation unit. The measurement conforming to EN 255-3 lasts several days and determines several specifications of the equipment. In the start-up phase, after initial heating, half of the tank content is withdrawn and the tank is re-heated several times. During this phase, the coefficient of performance (COP) for the heat pump is determined. Subsequently, the amount of water which can be drawn at 40 °C is determined, as is the average power consumption for the heat pump to cover the heat losses from the tank during periods when the system is idle.

analyses for several different manufacturers of compact ventilation units with exhaust-air heat pumps this year.

Our work concentrates on supporting our clients in the further development of their equipment. We measure prototypes or zero-series units and determine the potential for improvement. This also includes customised optimisation of commercially available equipment.

Heat for Passive Houses - Development of a New Compact Ventilation Unit with Exhaust-Air Heat and Inlet-Air Heating

New residential buildings are characterised by increasing energy efficiency and a low heating consumption. Passive and zero-emission houses impose different demands on the supply technology and open up new possibilities. We co-operate with our clients to develop technology that is optimised for this purpose. The focus is on further development of compact ventilation units for passive houses, technology which allows our clients to penetrate new markets.

Andreas Bühring, Christian Bichler*, Jeannette Wapler**, Wolfgang Guter

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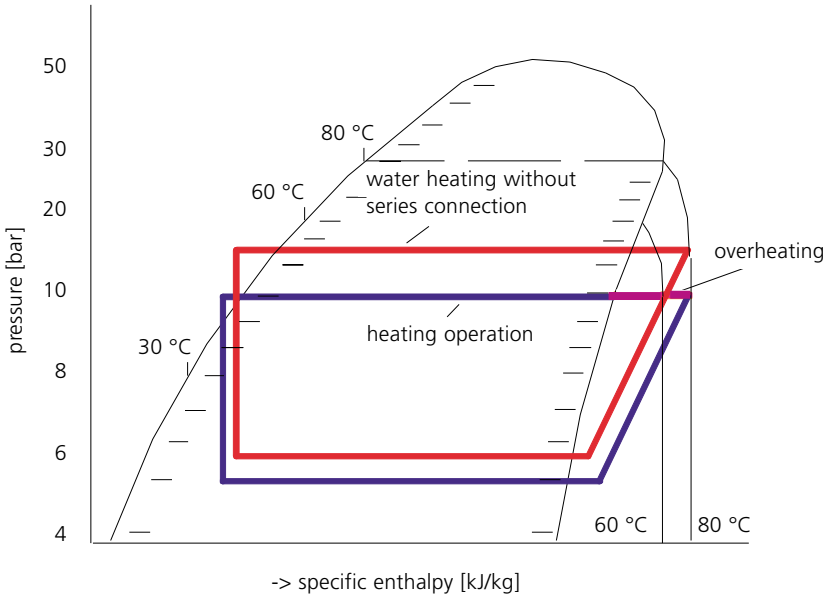


Fig. 1: States of the cooling medium cycle for the new heat pump in a pressure-enthalpy diagram. The red curve shows a typical process during domestic hot water heating. For the temperatures needed, a high pressure is needed in the cycle, which must be generated with a large amount of electrical energy. During the heating phase (blue curve), only lower pressure values are needed, and thus less electricity. Nevertheless, the new series connection means that some of the energy (purple) at the high temperature can be used for domestic water heating, without increasing the pressure. As a result, the coefficient of performance (COP) for the heat pump increases, and the electricity consumption decreases.

Together with our industrial partners, we are further developing the technology of compact ventilation units with integrated exhaust-air heat pumps. These units provide ventilation, space heating and domestic hot water particularly for passive houses, i.e. highly energy-efficient residential buildings. In a compact ventilation unit, an air-to-air heat exchanger and a subsequent heat pump remove so much energy from the exhaust air that it can meet the heating demand of the building and its occupants.

Our current work concentrates on the development of a particularly efficient heat pump for a new generation of equipment. It implements a series connection for the cooling medium cycle that was developed at the Institute (and has been patented). A pure hydrocarbon is used instead of the fluorohydrocarbons that are still mostly used, despite their harmful effect on global warming. In addition, the new unit will include the option for passive cooling of the building.

In developing optimised units, we carry out simulation studies, give advice on the selection of components, and implement system configurations and experimental units. Our services also include the development of controls and tests of prototypes on our test rig (see p. 26) and in field tests. Obviously we pay particular attention to high energy efficiency, user friendliness and low production costs, and the possibility of combination with solar technology.

The work is being carried out within the BMWA-funded strategic project on "New Integrated Energy Concepts for Buildings - NEGEV", on commission to and in co-operation with the companies, Maico in Villingen-Schwenningen, Solvis in Braunschweig and Resol in Hattingen.

Combined Heat and Power reconciled with Solar Heating

Thermal solar systems and decentralised combined heat and power (CHP) systems are currently competing to displace each other in the same share of the market. On commission to the German Federal Ministry for the Environment, we have investigated how slight changes to the existing support instruments could prevent these negative effects. By slightly changing the time-dependent profile for the currently paid CHP bonus for electricity exported to the grid, the displacement mechanisms could be largely eliminated without the need for additional funding.

Andreas Bühring, Werner Hube*, Benoit Sicre, Matthias Vetter

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Decentralised systems for combined heat and power (CHP) generation (e.g. fuel-cell household energy supplies) are competing with and displacing thermal solar systems under the currently prevailing boundary conditions. This affects both investment decisions and the operating mode in coupled applications. We have conducted simulation studies to study this problem in greater detail and have proposed measures to solve it.

To achieve high financial gains from selling electricity to the grid, there is considerable interest in long periods of CHP operation. However, the operating period is reduced if heat is supplied by solar energy, so that an economic disadvantage results that may cause an investor to decide against installing a solar collector. In coupled operation, it may cause displacement of potential solar gains by the CHP system, e.g. if this heats the storage tank so much that the solar collector can hardly input any gains at all.

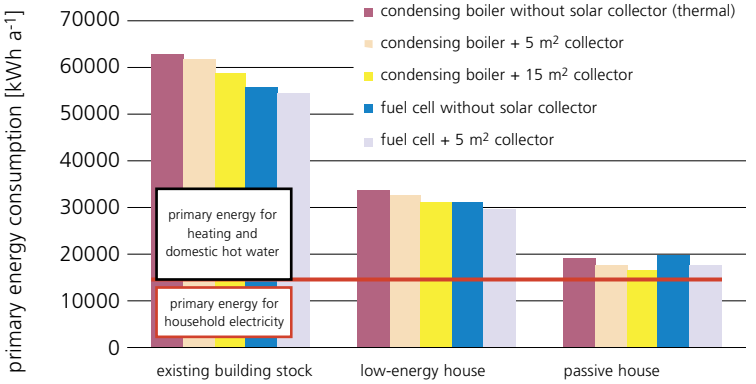


Fig. 1: Primary energy consumption of different types of building technical services for different insulation standards. A PEM fuel-cell household energy supply with 1 kW_{el} has been assumed for the passive house, and one with 2 kW_{el} for the other two buildings. The boundary conditions are: an electric efficiency value of 30 %, a thermal efficiency value of 50 % and an efficiency value for the public electricity grid of 39 %, household electricity consumption of 5500 kWh a^{-1}, domestic hot water consumption 2600 kWh a^{-1}. Significantly more energy can be saved with the improved building standard than with systems technology. If the insulation standard is high, a solar system can achieve greater savings than a household energy supply based on a fuel cell.

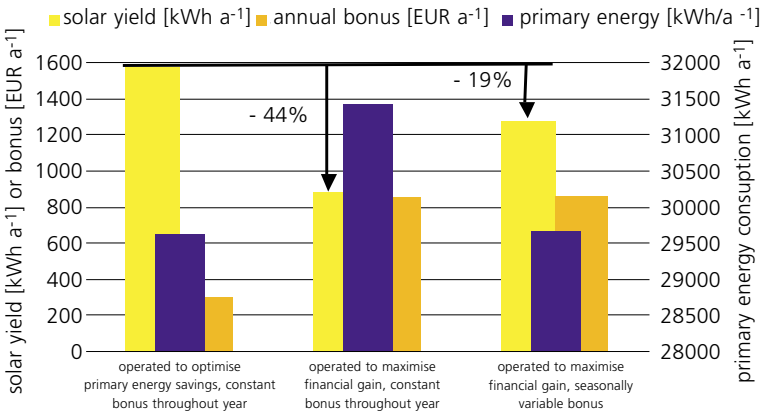


Fig. 2: If a variable price based on spot market prices is paid for electricity exported to the grid, and the operating mode is oriented toward financial gains, there is a strong displacement of solar yields. A seasonally dependent CHP bonus, which is paid in winter but not in summer, alleviates this effect and reduces the primary energy consumption, without increasing the annual subsidy (total price paid for electricity exported to the grid).

We have formulated the proposal for a seasonally dependent option for the CHP bonus, which is currently constant at 5.11 cent/kWh throughout the year. This means that there would be no bonus in the summer months, but it would be increased for the remaining months of the year such that the CHP bonus averaged over the whole year would remain the same. This simple change to the existing scheme to support CHP systems would effectively remove the motivation to replace solar gains in summer by the CHP system.

The work was carried out within the joint project on "Environmental impacts, boundary conditions and market potentials of decentralised, stationary fuel-cell systems", which was supported by the BMU (German Federal Ministry for the Environment).

Coloured Solar Collectors

The aesthetic effect of relatively large black surfaces has repeatedly acted as a deterrent to the integration of solar collectors into building facades. This can be countered by coloured, selective absorber coatings. We are accompanying relevant development projects with our specific competence in optical characterisation and durability tests of functional coatings.

Michael Köhl, Stefan Brachmann, Franz Brucker, Markus Heck, Sebastian Herkel

Fig. 1: Design study on coloured facade collectors (source: AEE Intec).

Two approaches are being followed in the development of coloured, selective absorber coatings. In selective coatings that are produced by physical vapour deposition (PVD), the colour of the reflected light can be modified by varying the coating thickness of the upper layer. Unfortunately, these interference colours depend on the viewing angle of the observer, but their optical properties are excellent, i.e. a high solar absorptance and a low thermal emittance.

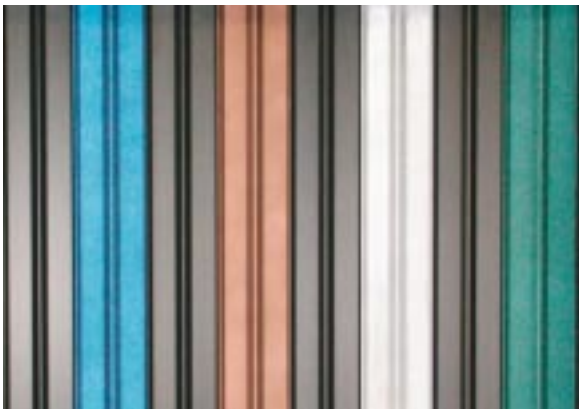


Fig. 2: Sample of an absorber for flat-plate collectors, consisting of pressed strips of aluminium profiles, which are alternately coated with conventional black paint and coloured, selective solar paints.

The second approach is the development of coloured, selective solar paints. Here, selectivity is achieved by adding infrared-reflective pigments, usually aluminium flakes. The colour is then determined by the addition of appropriate pigments. Although the emissive and absorptive properties cannot compete with those of PVD coatings on the market, the advantage is that they can be applied directly by the collector manufacturer.

We have tested the durability of facade coatings developed by our project partners to weathering, and have investigated building science aspects of integrating the collectors into buildings. The positive results led to construction of glazed solar facades within pilot projects. Both the development work and the pilot projects are funded by the EU. Solar facades without cover glazing are subject to significantly harsher weathering conditions. Within a further EU project, Fraunhofer ISE is co-ordinating the development of selective paints and facade collectors for steel facades without protective glazing.

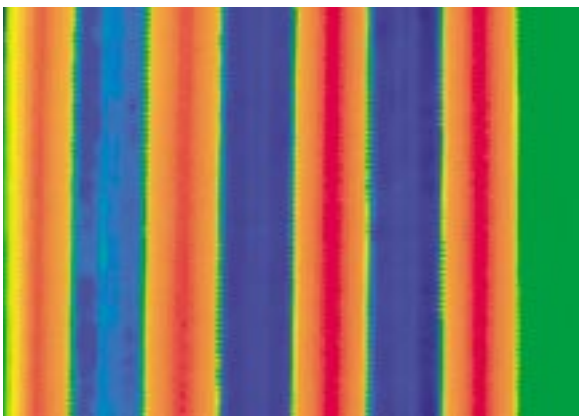


Fig. 3: Thermograph of the absorber in fig. 2, taken while fluid flowed through the absorber piping at a constant temperature of 80 °C. The selective colours (ε_{blue} = 0.43, ε_{red} = 0.36, ε_{grey} = 0.17, ε_{green} = 0.45) show much less emission of thermal radiation than the black solar paint (ε_{black} = 0.95).

Development of a New, Double-Glazed Flat-Plate Collector with Anti-Reflective Glass

Current research work reveals new possibilities for developing double-glazed flat-plate collectors with anti-reflective (AR) glass. This applies particularly for applications in the temperature range between 80 and 120 °C for collectors with two AR glass covers. In order to tap this potential, we are making the necessary adaptations to the complete collector construction.

Matthias Rommel, Arim Schäfer, Thorsten Siems

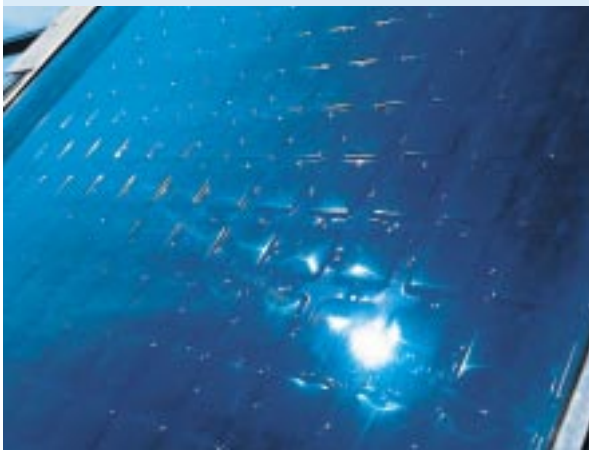


Fig. 1: Flat-plate collector with a selective absorber and a glass cover with AR coatings on both surfaces.

Up to now, the assumption that a flat-plate collector with a good selective absorber does not require double glazing has remained unchallenged. However, the conditions for making such an assumption have changed fundamentally: Successful research and development work has resulted in anti-reflective coatings which reduce the reflection losses from a glass pane for solar radiation from about 8 % to 3 %.

Figure 2 shows a comparison of efficiency characteristic curves for a standard flat-plate collector with single, double and triple glazing consisting of AR coated panes. We were able to verify the assumed parameters with measurements of test collectors. Our investigations show that there is a large development potential for AR double-glazed collectors, particularly for applications in the temperature range between 80 and 120 °C. In order to tap this potential, the complete collector construction must be adapted. In doing so, we are paying particular attention to the raised temperature loads for the collector components. Similarly, in selecting the materials, the release of volatile substances by thermal insulation materials and sealants also plays an important role.

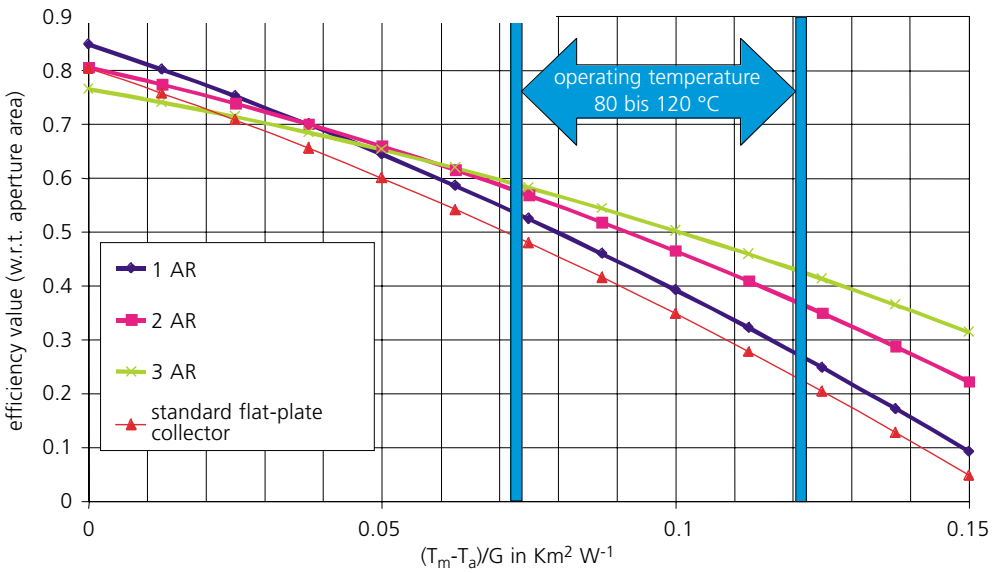


Fig. 2: Comparison of the efficiency characteristic curves of a standard flat-plate collector with covers of conventional solar glass (single-glazed), and single, double and triple glazing using panes with AR coatings on both surfaces. The parameter, $(T_m-T_a)/G$ describes the operating conditions for the collector:
T_m = mean fluid temperature [K],
T_a = ambient air temperature [K],
G = global radiation in the collector plane [W m^{-2}].

Photoelectrochromic Windows with a Solid Ion Conductor

The optical transmission of photoelectrochromic window systems can be switched. Sunlight provides the energy needed for colouring. We have succeeded in developing a system that consists solely of solid components. In particular, the ion conductor in this system can also be solid, a polymer. Potential applications of the window system are as protection against overheating or glare, e.g. in buildings or vehicles.

Andreas Georg, Anneke Georg, Wolfgang Graf, Volker Wittwer

A photoelectrochromic systems is a combination of an electrochromic cell and an electrochemical solar cell, the so-called dye solar cell. When illuminated, a dye-coated, porous titanium dioxide layer injects electrons into a porous electrochromic tungsten oxide layer, which then changes colour from transparent to blue. Charge equilibrium is maintained by a redox salt (lithium iodide), that is dissolved in an ion conductor. The rapid bleaching process is made feasible by a thin catalyst layer of platinum, which is deposited on the counter-electrode. By electrically connecting and disconnecting the oxide layers to the counter-electrode, the system can be coloured during illumination and bleached at any time.

The ion conductor must both penetrate the pores in the oxide layers and fill the gap to the counter-electrode. We met this requirement with an ormosilane, an organically modified silane polymer. The use of ormosilane and improved sealing considerably improved the stability.

The system does not require an external voltage supply. It can be switched manually, but can also be operated in an automatic mode. This automatically adapts the coloration depth according to the light intensity. If required, the glazing can also be switched with the help of an external voltage, independent of the lighting intensity.

The specific configuration of the layers in the photoelectrochromic window element makes the switching time independent of the area, in contrast to conventional electrochromic systems.

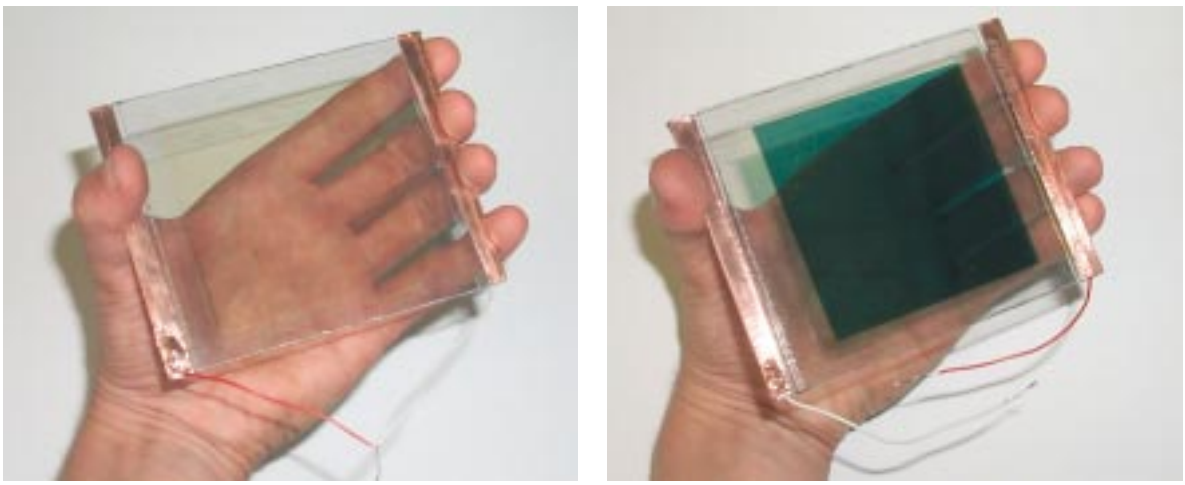


Fig. 1: Photoelectrochromic window element with a polymer ion conductor: in the bleached state, when the two electrodes are short-circuited (left) and in the coloured state after illumination with a solar simulator (open circuit, right). The visible transmittance of a typical sample switches in about 15 minutes from 62 % to 1.6 % and the solar transmittance from 41 % to 0.8 %.

Solar Cells

Photovoltaics is experiencing a real boom all over the world, with annual growth rates of about 30 %. In Germany, the renewable energy law and the 100,000 Roofs Programme led to the new installation of around 80 MW power in 2002 alone –only a few years ago, this was the size of the entire global market.

More than 90 % of solar cells are made 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.

In order to reduce consumption of the expensive raw material, the silicon wafers are becoming thinner and thinner. Despite this, we still achieve constantly high 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 wafers 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-junktion cells for extraterrestrial applications. For terrestrial use, we are developing concentrator cells for the highest optical concentration factors.

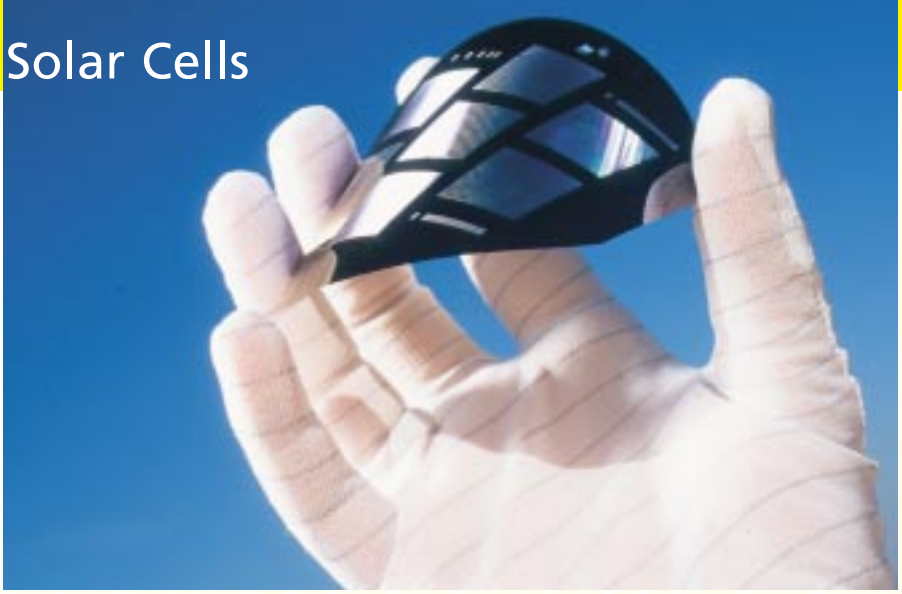
Dye and organic solar cells represent a third class of materials. In particular, the technology for dye solar cells has developed well beyond the laboratory scale over the last few years. However, long-term stability and the upscaling of this technology to module areas exceeding 0.5 m^2 must still be demonstrated. Organic solar cells are currently at the stage of application-oriented basic research.

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. Here, we are working on more stable polymers and new module concepts which completely avoid the use of polymers.

In the "Solar Cells" sector, we support materials developers, system manufacturers and producers of solar cells and modules in the following areas:
- development of new cell structures
- evaluation of novel processing sequences
- optimisation of production procedures for solar cell materials and modules
- production of small series of high-performance solar modules and customised test objects
- characterisation of semiconductor materials and solar cells
- development of semiconductor characterisation procedures
- conduction of photovoltaic studies

We use the following facilities for our work:
- clean-room laboratory for Si and III-V semiconductors
- standard solar cell technology
- industrially relevant production line for crystalline silicon (screen-printing, pad-printing, in-line RTP oven, in-line RTP diffusion oven)
- chemical vapour deposition of Si, RTCVD
- MOVPE for III-V epitaxy
- semi-automated production of dye solar cells and modules
- plasma etching system
- optical heating systems for silicon production and processing
- thin-film technology: plasma deposition, evaporation, galvanisation, contacting
- characterisation of materials: X-ray diffraction, charge carrier lifetime measurements, photoluminescence, ellipsometer, IR Fourier spectrometer, glow discharge mass spectrometer, scanning electron microscope with EBIC, ECV profiling, MW-PCD, MFCA, DLTS, CDI, CV, SPV, sheet resistance mapping, stripping Hall, SRP
- characterisation of solar cells: I-V characteristic curve measurement, SR, LBIC, PCVD, MSC, diffusion length mapping, shunt analysis

Solar Cells



Paper-thin crystalline silicon solar cell with industrially relevant cell structure (laser-fired back-surface contact points). Although the cell is less than 50 µm thick, its efficiency value exceeds 20 %.

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Highly Efficient Silicon Solar Cells on Thin Wafers

A perceptive observer of current photovoltaic conferences, press releases and exhibitions will have noticed that the use of thinner wafers and continuous increases in efficiency are the central issues for the photovoltaic industry today. The demand for both goals arises from the relatively high costs of the silicon wafer itself. To support this trend, we have developed a cell structure which makes very high efficiency values feasible for very thin wafers.

Sybille Baumann, **Stefan Glunz,**
Andreas Grohe, Franz J. Kamerewerd,
Henner Kampwerth, Joachim Knobloch,
Daniel Kray, Ji Youn Lee, Antonio Leimenstoll,
Daniela Oßwald, Ralf Preu, Elisabeth Schäffer,
Eric Schneiderlöchner, Oliver Schultz,
Siwita Wassie, Gerhard Willeke

Fig. 1: Highly efficient solar cells on an extremely thin and flexible wafer (40 µm thick). The cells were produced with the LFC (laser-fired contacts) technique, an economic production method which permits very high efficiency values even on thin wafers (20 % for this example).

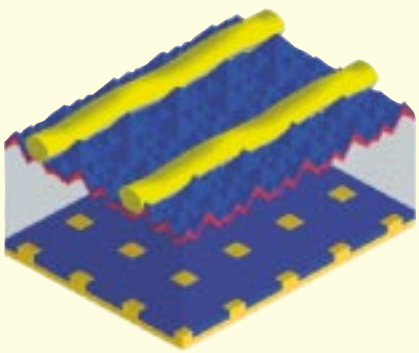

Fig. 2: The illustration shows the corresponding cell structure. The local contacts on the back surface are a characteristic feature. Only 1 % of the area is contacted with metal, whereas the rest is covered with a layer of silicon dioxide or silicon nitride. This sophisticated contact structure is produced simply and elegantly with the LFC technique, by locally firing the back-surface aluminium layer through the passivation layer with a laser.

Increasing the solar cell efficiency and reducing the cell thickness are aspects that are closely related to each other. When the cell thickness is reduced, the efficiency value for simple cell structures usually suffers strongly. However, cell structures have been developed for some time in the laboratory, which demonstrate high efficiency values both on thick and thin wafers. They are characterised by a strong reduction of the unwanted charge carrier recombination on the cell surface by dielectric layers such as silicon dioxide or silicon nitride. However, to date it had always been very complicated and expensive to produce these cell structures, preventing their transfer to industrial cell production.

Our newly developed LFC (laser-fired contacts) cell offers the ideal opportunity to combine the potential for high efficiency with low production costs. To produce it, first the dielectric passivation layer is deposited onto the back surface of the cell. In previous laboratory procedures, the next, complicated step was to open up small holes in this insulating layer, and then to deposit the aluminium back-surface electrode by evaporation. In LFC processing, we evaporate the aluminium layer directly onto the passivation layer and then fire it through the passivation layer with a laser into the underlying silicon to form the local contacts. This patented process is extremely rapid (1 second per cell) and inexpensive. Despite this, we have achieved the same efficiency values for normally doped silicon as with conventional laboratory processing (21.5 % for 0.5 Ω cm). For wafers with low doping concentrations, the comparison is even more favourable (20 % for 100 Ω cm). A particularly pleasing result is that we have achieved very high efficiency values exceeding 20 % with extremely thin (40 µm) and flexible wafers.

Silicon Concentrator Solar Cells for Two-Stage Optical Concentrator Systems

Photovoltaic concentrator systems offer the interesting option to significantly reduce the area of actual solar cells and "replace" it with concentrating optics such as lenses or parabolic reflectors. Two-stage systems represent an elegant variant, which achieve relatively high concentration factors exceeding 300, although only single-axis tracking is applied. We are currently developing such a system at Fraunhofer ISE, including the appropriate high-efficiency silicon concentrator cells.

Andreas Bett, Armin Bösch, **Stefan Glunz,** Gerrit Lange, Andreas Mohr, Thomas Roth, Gerhard Willeke

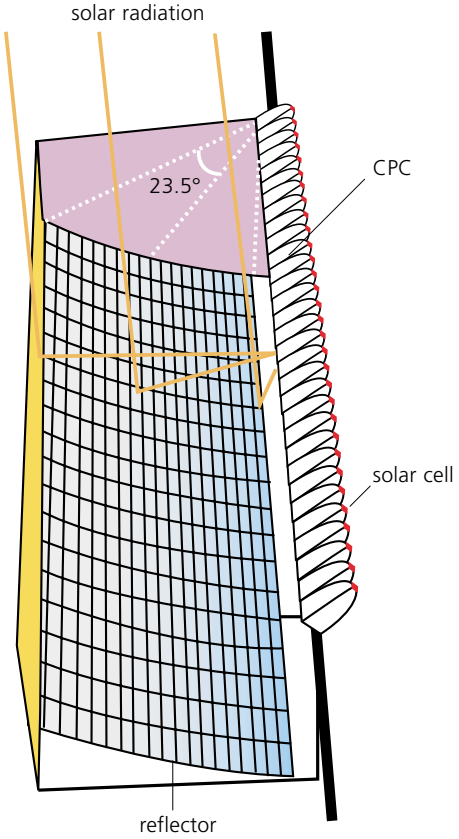

Fig. 1: Two-stage photovoltaic concentrator system. Despite single-axis tracking, a geometric concentration factor exceeding 300 is achieved. The second concentrator stage (compound parabolic concentrator - CPC) adheres directly to the silicon concentrator cells, that were developed specifically for this purpose (see photo). The cells, each with an area of only 4.5 mm x 4.5 mm, have an efficiency value of 24 % for an illumination of 100 suns.

An important precondition for an economic optical concentrator system is that the concentrating optics and the motor unit for tracking the sun are inexpensive and reliable. Highly concentrating, two-stage systems, which require only single-axis tracking, represent a promising approach.

In the system developed at Fraunhofer ISE, a parabolic trough reflector achieves a concentration factor of about 40. The concentrated light is incident on a second concentrator stage, a solid, parabolically tapered polymer body, a so-called compound parabolic concentrator (CPC), which increases the concentration due to total internal reflection by a further factor of 7.7. In this way, concentration factors exceeding 300 can be achieved. This range is very suitable for silicon solar cells. However, the cells must be specially optimised for these high concentration values, causing higher production costs than for standard cells. Nevertheless, these additional costs are more than compensated by the extremely small cell area that is needed. Of course, the system costs for the optics and the tracking mechanism must also be kept as low as possible so that the total electricity generation costs are reduced.

As the solar cells are mounted directly onto the back surface of the CPC, it is appropriate to position both the n and the p contacts on the rear of the cell. This offers the additional advantage that the contacts do not cause any shading. We developed our so-called rear line contact cells (RLCC) according to these criteria. These cells, with an area of only 4.5 mm x 4.5 mm, are currently characterised by an efficiency value of 24 % at 100 suns, i.e. when the radiation intensity is 100 x higher than solar radiation. The cells are electrically contacted with a specially adapted technique. In developing it, we ensured that the heat resulting from the high concentration is effectively transferred to a heat sink on the back surface, so that the cells show excellent performance in our concentrator system, even with simple passive air cooling.

Analysis of Metastable Defects in Boron-Doped Czochralski Silicon

More than 40 % of all solar cells are manufactured of monocrystalline Czochralski silicon. On illumination, the efficiency value of these cells initially decreases by 5 - 10 % relative to the original value, until it reaches a stable final value after about one day. If the number of manufactured cells is considered, an investigation of the underlying defect is not only of scientific but also strong economic interest.

Stephan Diez, **Stefan Glunz,** Stefan Rein, Wilhelm Warta

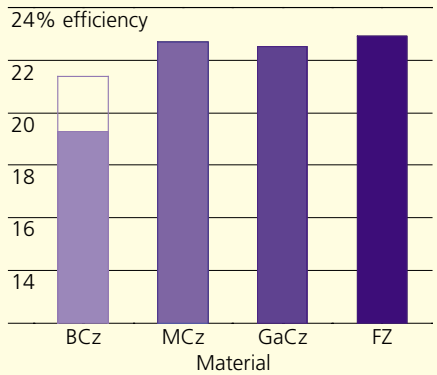

Fig. 1: Efficiency value of solar cells on different types of Czochralski (Cz) silicon and float-zone (FZ) silicon before and after illumination for 24 h. Whereas the efficiency value of boron-doped Cz silicon (BCz) decreases strongly due to light-induced degradation, a stable value is maintained by oxygen-depleted magnetic Cz silicon (MCz) and gallium-doped Cz silicon (GaCz), which is comparable to that on extremely pure FZ silicon.

Within several scientific studies, it was proven that the main components of the underlying metastable defects are oxygen and boron. Both elements are present in large quantities in standard Czochralski (Cz) silicon. Although this defect has such a strong effect on the solar cell, it cannot be detected with classic characterisation methods such as deep-level transient spectroscopy (DLTS). The most important method for our analysis was thus temperature-dependent lifetime spectroscopy. With this new and sensitive method, we succeeded in determining the exact electronic position of the defect (E_c-E_t = 0.41 eV) in the band gap, and thus in identifying the most important "fingerprint" of the defect. Another important result of our investigations is that the defect is activated by electric recombination processes and not directly by irradiation with light.

Apart from these scientifically interesting results, which are very important for microscopic decoding of the defect structure, the central question was how to avoid this defect. To this purpose, we have developed several different strategies and implemented them technologically. On the one hand, it is possible to replace the boron dopant by gallium. Despite the oxygen present in this material, these cells indeed show very high efficiency values and no degradation. A second option is to significantly reduce the oxygen content in Cz silicon, which can be achieved in so-called MCz by applying a strong magnetic field while the crystal is grown. We were able to obtain very high and stable efficiency values with this material also. Further, it is possible to reduce the defect concentration significantly by applying high-temperature processing steps that were optimised at Fraunhofer ISE, and thus achieve good results even with standard Czochralski silicon.

Higher Material Yields for Block-Crystallised Silicon due to Improved Solar Cell Processes

The yield of silicon wafers from a silicon block can be increased appreciably by appropriately adapting the solar cell technology with optimised diffusion steps.

Harald Lautenschlager, Stephan Riepe, **Roland Schindler,** Wilhelm Warta

After crystallisation, the edge zones of a silicon block are characterised by lower minority charge carrier lifetimes than in the main core of the block. Therefore, they are not used for producing solar cells. However, the economic feasibility of a specific crystallisation procedure is partly determined by the total yield of silicon wafers that can be used for solar cell production.

In the production of solar cells, the minority charge carrier lifetime is lengthened by the phosphorous diffusion gettering step, which is normally included in the solar cell process. This has only a very limited effect on the edge zone of the block, so that the material yield from the block remains restricted.

By optimising the integrated gettering step in producing solar cells, we considerably increased the minority charge carrier lifetime for wafers from the edge zone. This can be seen in figures 1 and 2. The changes in the minority charge carrier lifetime due to different diffusion and gettering steps were investigated with vertically cut silicon wafers taken from the top and the bottom of a block. We demonstrated that an additional 4 cm in the block height, taken from the top and the bottom zones, can be used for solar cell production with the optimised processing procedure. With common wafer areas and block dimensions, this corresponds to a gain of almost 3 kWp in solar cell power.

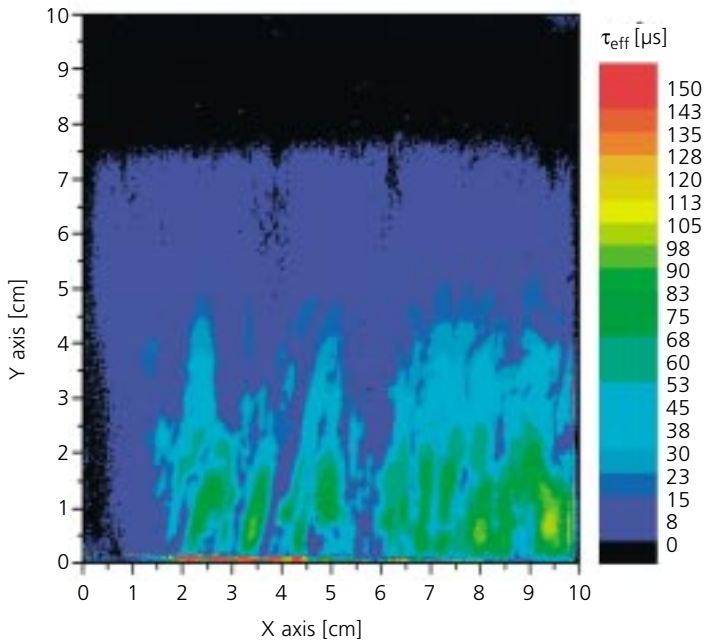

Fig. 1: Initial distribution of minority charge carrier lifetimes in vertically cut wafers near the top of a silicon block (vertical cross-section).

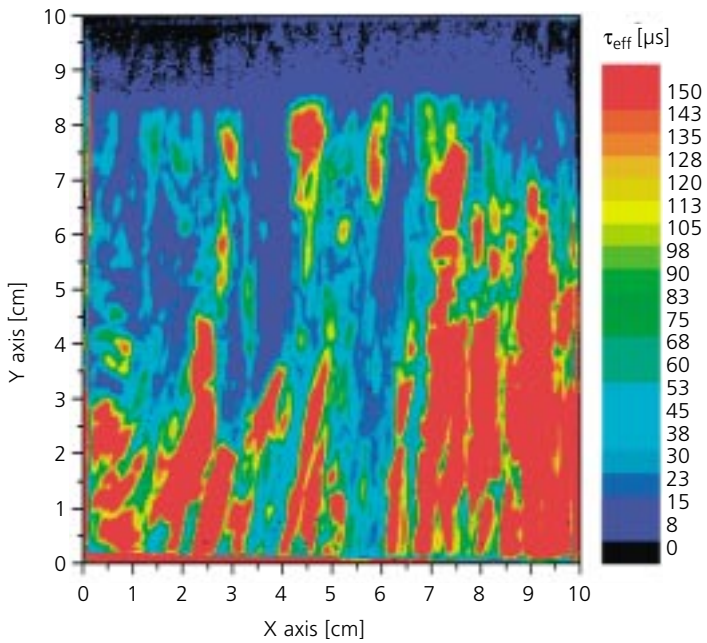

Fig. 2: Distribution of minority charge carrier lifetimes near the top of a silicon block (vertical cross-section) after optimised diffusion.

ZMR400 - A Processor for Zone-Melting Recrystallisation of Large-Area Silicon Films

For a possible application in producing thin-film solar cells and semiconductor components, we have constructed a processor of the next generation for samples with areas up to 400 mm x 400 mm. The ZMR400 uses linear halogen lamps to heat the samples homogeneously in an extremely clean environment up to 1300 °C, and recrystallises the thin silicon layers on diverse substrate materials with focussed lamp radiation in a fully automated, controlled zone-melting process.

Achim Eyer, Fridolin Haas, Thomas Kieliba

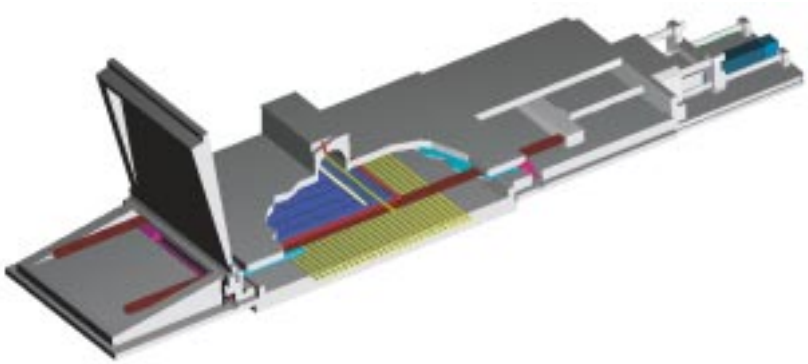

Fig. 1: Three-dimensional computer simulation of the ZMR400: to the left the loading tray, in the centre the reaction chamber with zone heating above and large-area heating below, and to the right the linear drive outside the reaction chamber (lamps yellow, sample blue).

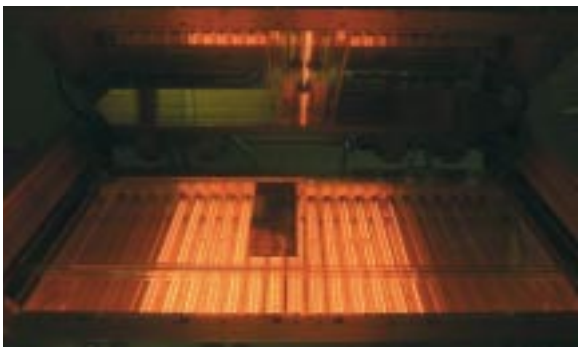

Fig. 2: Reaction chamber of the ZMR400 with a silicon sample measuring 100 mm x 400 mm; the upper cover of the chamber with the zone heating has been tilted up. 28 of the 48 lamps for the large-area heating are active with minimal power. They are reflected in the upper cover.

Zone-melting recrystallisation (ZMR) is applied in the production of semiconductor components in so-called SOI technology (silicon on insulator) and in the manufacturing of crystalline silicon thin-film solar cells. In both technological processes, the properties of thin silicon films on diverse substrate materials are significantly improved by the ZMR step. The aim is to process large areas. Based on our experience with smaller processors, we have developed the ZMR400 for substrate areas of up to 400 mm x 400 mm.

Using linear halogen lamps for heating makes it feasible to heat up and cool down very rapidly if required. A large-area heating array with 48 lamps à 8 kW below the substrate allows it to be heated homogeneously up to approximately 1300 °C. The linear melting zone above the sample surface is generated by focussing the radiation from a single lamp with an elliptically curved cylindrical reflector. A linear drive moves the substrate such that the melting zone passes over the entire surface. The process takes place in an extremely clean atmosphere in an aluminium, cold-wall reactor. The reactor is loaded manually but the entire process is controlled fully automatically with a PC. Video cameras monitor the melting zone, and the signal is also used to control the zone heating, so that the width of the molten zone remains constant at 1.5 mm with an accuracy of 5 %. This constancy is decisive for the quality of the recrystallised silicon films.

Using this procedure, we have produced thin-film solar cells with efficiency values of up to 13.5 % on mc Si and 10.7 % on SiC ceramic substrates, each with a SiO_2 intermediate layer. As substrates with an area of 400 mm x 400 mm were not available, we demonstrated the performance of the processor by placing several smaller substrates next to each other.

Highest-Efficiency Photovoltaic Cells based on III-V Semiconductors

We produce tandem concentrator solar cells with efficiency values of 30 % on the basis of III-V semiconductor materials. The first PV cells with 5 pn junctions are available. Laser power cells and thermophotovoltaic (TPV) cells are developed according to clients' specifications. FLATCON™ modules reach efficiency values exceeding 22.7 % in outdoor tests.

Carsten Baur, **Andreas Bett,** Armin Bösch, Marc Chenot, **Frank Dimroth,** Ines Druschke, Gerrit Lange, Gergö Létay, Rüdiger Löckenhoff, Astrid Ohm, Matthias Meusel, Sascha van Riesen, Gerald Siefer, Thomas Schlegl, Sivita Wassie

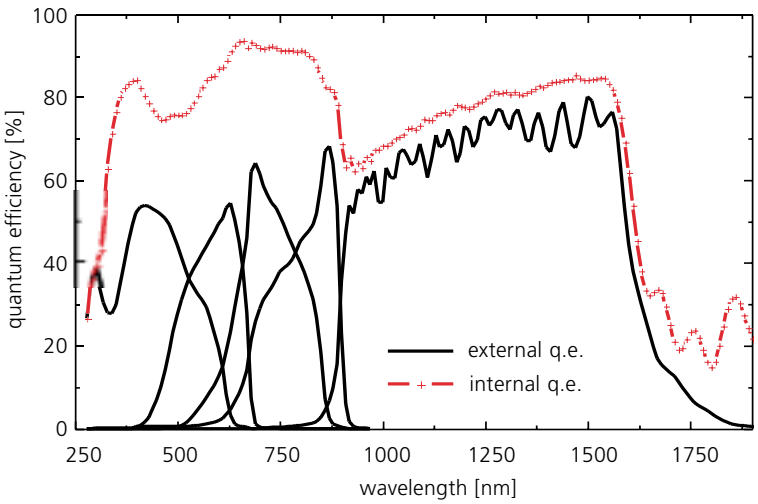

Fig. 1: Internal and external quantum efficiency of the first quintuple-junction solar cell in the world. The external quantum efficiency of the individual subcells can be clearly recognised (black lines). These subcells are internally connected in series via tunnel diodes, so that a quintuple-junction cell cannot be distinguished from a standard cell from the outside. Measurements as illustrated here are complicated but are available to our clients as a service. The internal quantum efficiency of the complete cell is shown in red.

III-V semiconductor materials form the basis for solar cells with the highest efficiency values that have been achieved. We take advantage of the fact that the band gap can be deliberately adjusted in these materials. This makes it feasible to produce so-called multi-junction cells. These are photovoltaic cells in which several pn junctions, that are created in different materials, are stacked on top of each other. This means that the energy of the solar spectrum can be used better. We apply metal organic vapour phase epitaxy (MOVPE) to produce the necessary solar cell structures. Using our industrial deposition facility, we optimise not only the layer sequence but also the deposition conditions for triple-junction solar cells on germanium substrates. We transfer the results directly to our clients. A climax of our work has been the development of the first quintuple-junction solar cell in the world. Figure 1 indicates that we have also succeeded in determining the external quantum efficiency of such a cell.

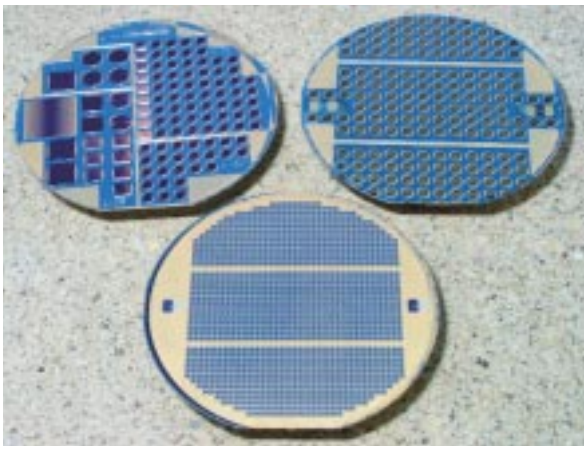

Fig. 2: Examples of the development of customised concentrator solar cells on 2" substrates. Upper left: Test structures of different sizes and concentration factors. Upper right: 165 cells, each with an area of 3.53 mm^2, for an optical concentration factor of 500. Lower centre: 1280 cells, each with an area of 0.67 mm^2, for an optical concentration factor of 1000.

Multi-junction solar cells are also attracting increasing interest for terrestrial applications. Nevertheless, these cells can operate economically only under concentrated light. For our clients, we are developing tandem cells with efficiency values around 30 % at a concentration of up to 1000 suns (fig. 2). To this purpose, we produce customised front contact structures. Wireless energy transfer systems represent a further application field for our III-V PV cells. They convert monochromatic light into electricity with an efficiency value exceeding 45 %. Our infrared-sensitive PV cells based on GaSb find their application in thermophotovoltaics.

Dye and Organic Solar Cells

Dye and organic solar cells are based on new technology with the potential for particularly economic production. Before commercial products can be fabricated, important issues such as long-term stability, efficiency value and production techniques need to be clarified. In co-operation with the industry and other research institutes, we are working on solutions to pave the way to commercial maturity.

Udo Belledin, Markus Glatthaar, **Andreas Hinsch,** Sarmimala Hore, Rainer Kern, Michael Niggemann, Moritz Riede, Ronald Sastrawan*, Uli Würfel, Jochen Wagner, Birger Zimmermann

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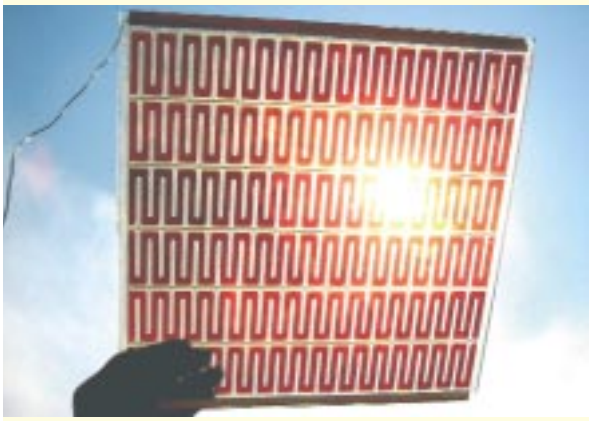


Fig. 1: Photo taken toward the sun through a 30 cm x 30 cm module of dye solar cells. The module was sealed with a thermal procedure developed at Fraunhofer ISE, in which glass solder is applied by screen-printing.

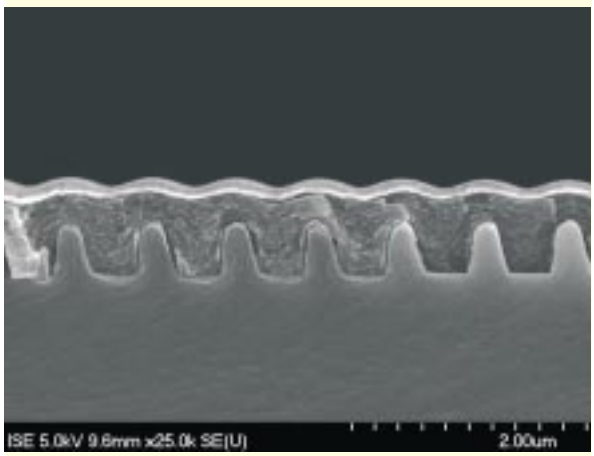


Fig. 2: Cross-section through an organic solar cell, built up on a nano-structured substrate film (scanning electron micrograph). The side flanks of the vertical structures are selectively evaporated with a metal and form the front contact. The gaps are filled with organic, photovoltaically active material. Finally, a back-surface electrode is evaporated over the whole surface.

In the dye solar cell sector, Fraunhofer ISE has special expertise in key technological aspects such as sealing methods using glass solder and synthesis of nanocrystalline oxides. All of the screen-printing pastes needed to produce test cells (masterplates) and complete modules (30 cm x 30 cm) are developed at the Institute. Furthermore, we have considerable experience in characterising and modelling dye solar cells.

With test cells, we have reproducibly achieved a solar efficiency value of 7 % for dye solar cells. We have successfully developed a thermal procedure for hermetically sealing the cells, an important step in module production.

Concerning organic solar cells, the Institute has established competence in fabricating test cells under a protective gas atmosphere and producing microstructured and nanostructured substrates. The structures serve to improve light coupling into the cell and to optimise charge transport in the thin organic absorber layer. The structures are generated in an embossing procedure, which can be easily upscaled. Further, for the first time we have developed inverted and wrapped-through cell concepts for organic cells and experimentally proven their feasibility.

At present, the solar efficiency value of our organic solar cells is about 2.5 %. As part of our substrate development, we have made initial experiments with transparent silver-based coatings, produced at the Institute by large-area sputtering on glass and polymer film substrates. The results indicate an economic approach to replace the expensive, currently used substrates coated with indium tin oxide. This is an important step toward commercialisation of organic solar cells.

Thermographic Methods for Solar Cell Characterisation

Whereas thermographic methods are widely used in materials testing, their development for applications in solar cell development and production is only just starting. At Fraunhofer ISE, we have developed new procedures to image the density of free charge carriers, using the infrared radiation emitted by free charge carriers (emission CDI - carrier density imaging). With another new thermographic method, we can represent local power losses of a solar cell under operating conditions.

Jörg Isenberg, Stephan Riepe, Martin Schubert, **Wilhelm Warta**

Thermography measurements have been used for years to characterise leakage currents (shunts) in solar cells in the laboratory. A (dark) current is electrically injected, and the local heating indicates the position and structure of the losses. In order to achieve the extremely high temperature resolution required (10 µK), digital lock-in techniques were applied. Up to now, a voltage applied to the solar cell was modulated for this purpose. In the illuminated-thermography method that we have developed, the solar cell is illuminated with modulated light instead. This means that a lock-in thermographic image can be obtained under the operating conditions of the solar cell. One advantage of this procedure is the possibility to analyse the significant power losses quantitatively as they occur in operation. Another advantage is that the sensitivity is improved considerably. Thus, illuminated thermography made the losses at individual grain boundaries in multicrystalline solar cells visible for the first time (fig. 1). Figure 2 shows an example of different loss mechanisms within a single cell.

We succeeded in developing a new variant of the carrier density imaging (CDI) technique, emission CDI. Up to now, the absorption by free charge carriers was used to image the density of optically generated charge carriers and determine the distribution of charge carrier lifetimes. With our new procedure, we extract the same information from the enhanced emission by free charge carriers when the wafer is heated. Again, the decisive advantage is an appreciable increase in sensitivity (fig. 3). With this development, the CDI method becomes more widely applicable, particularly for industrially relevant silicon samples.

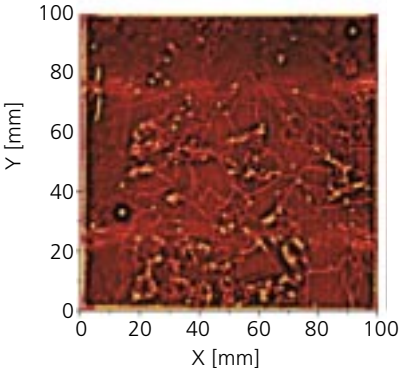


Fig. 1: The new illuminated-thermography method allows the electric losses at grain boundaries of a multicrystalline silicon solar cell to be represented for the first time. The camera signal is plotted in arbitrary units. Bright lines indicate large power losses.

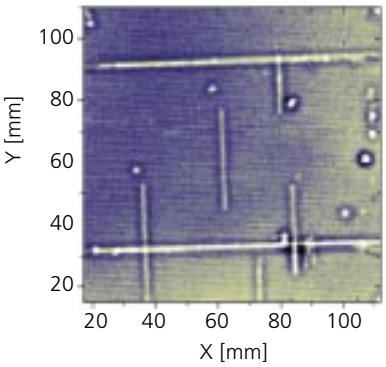


Fig. 2: The illuminated-thermography image of a monocrystalline silicon solar cell produced with an industrially utilisable process reveals losses of widely varying origin: The broad horizontal stripes show the recombination losses under the metal contacts. The vertical lines correlate with cracks that resulted from mechanical damage to the cell. The heat-source spots represent local short circuits of the emitter. The weak horizontal lines show the losses at the back-surface contacts, which were laser-fired along lines in this example. The image was made under open-circuit conditions; the losses along the contact lines are no longer evident at the maximum power point. Bright areas indicate large power losses.

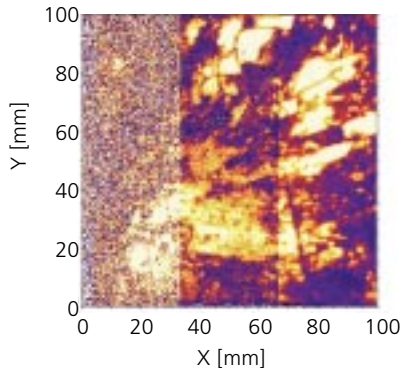


Fig. 3: Images of the infrared emission of optically generated free charge carriers. The sample temperature increases in the three strips from left to right from 40 °C, through 59 °C, to 100 °C. The improved resolution of the crystal structure from strip to strip is clearly evident. Within each strip, the signal is normalised to the average signal for that strip.

New Processing Technology for Crystalline Silicon Solar Cells

Our goal is to produce highly efficient cell structures for thin silicon wafers with economic technology that can be adopted by the industry. To pursue it, we develop and evaluate processes and equipment up to the demonstration stage in close co-operation with industrial partners.

Frederik Bamberg, Faramarz Binaie, Daniel Biro, Ingo Brucker, Gernot Emanuel, Andreas Grohe, Günther Grupp, Marc Hoffmann, Dominik Huljic, **Ralf Preu,** Isolde Reis, Jochen Rentsch, Christian Schetter, Eric Schneiderlöchner, Wolfram Sparber, Catherine Voyer, Dimitri Weilert, Winfried Wolke

We investigate technology that allows us to produce highly efficient solar cell structures economically, i.e. rapidly, in fully automated processes and with minimal usage of expensive materials. In industrial solar cell production, with a throughput of more than 1000 cells per hour, a rational material flow is particularly important. Thus, we mainly concentrate on so-called in-line processes, in which the wafers are transported continuously in a horizontal position through the individual processing zones. The associated gentle treatment means that thin silicon wafers can be processed in industrial facilities in future, opening the way for major cost-saving.

For us, it is essential that we accompany the industry along the entire route from a laboratory process to a production procedure. To allow this, we have set up a demonstration laboratory, in which we carry out process development on equipment in the pilot phase. We are supported in our research and development work by our industrial partners and the BMU (German Federal Ministry for the Environment).

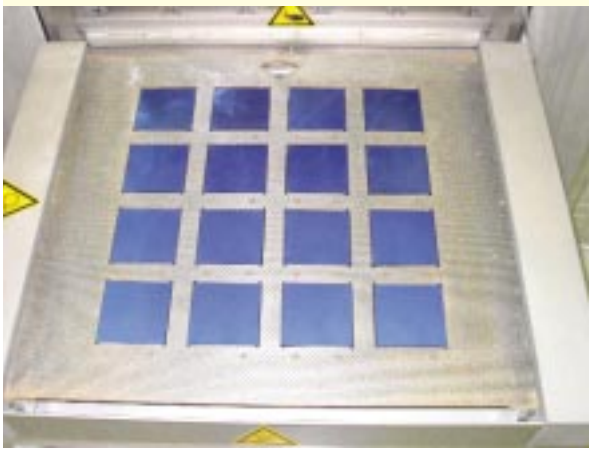


Fig. 1: These wafers were coated with an anti-reflective layer of silicon nitride in our in-line sputtering unit. This technology allows a particularly homogeneous distribution of the coating thickness over large areas. The unit was developed in co-operation with the Applied Films company in Alzenau.

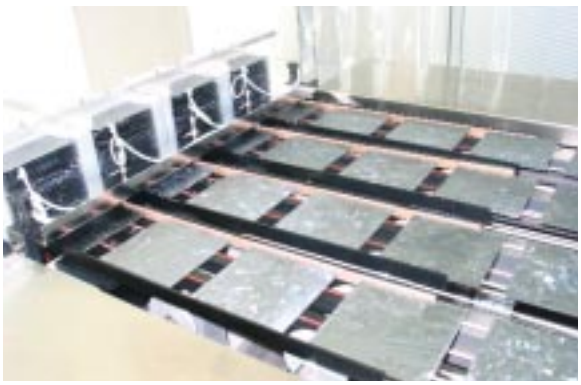


Fig. 2: Four-track walking-string transport. The patented transport system was developed in co-operation with the centrotherm company in Blaubeuren. The system allows silicon wafers to be transported through a high-temperature zone with negligible risk of contamination.

Fig. 3: In-line vacuum equipment for plasma-etching of silicon and thin dielectric films. The equipment was designed and processes were developed in co-operation with the Roth&Rau company in Wüstenbrand.

Laboratory and Service Centre, Gelsenkirchen

In our Laboratory and Service Centre in Gelsenkirchen, we carry out research and development "on site", which allows us e.g. to reproduce and improve solar cell manufacturing processes in the laboratory, without the risk of interrupting production.

Nico Ackermann, Mohammed Abusnina, Christoph Ballif, **Dietmar Borchert,** Markus Dabruck, Andreas Gronbach, Martin Hosenberg, Ali Kenanoglu, Stefan Müller, Stefan Peters, Markus Rinio, Björn Schäfer, Mark Scholz, Thomas Zerres, Gerhard Willeke

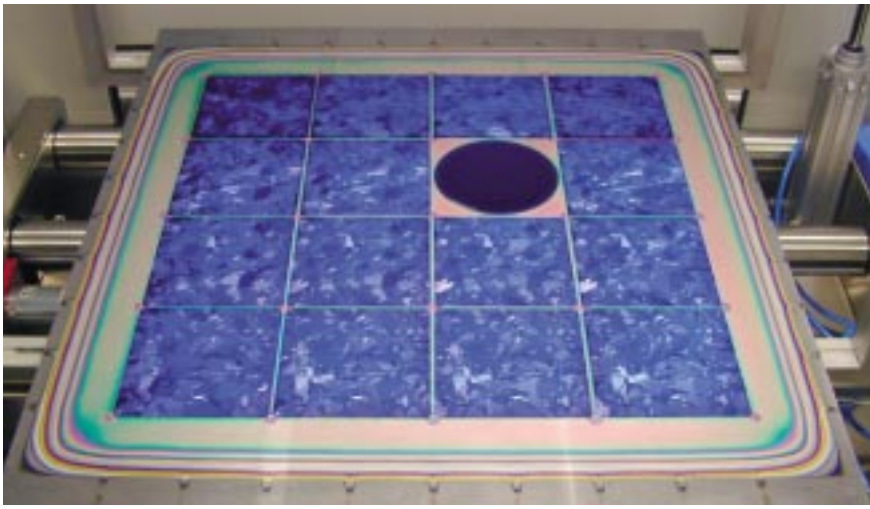


Fig. 1: Graphite tray for the in-line plasma unit, loaded with one monocrystalline and 15 multicrystalline silicon wafers that have been coated with silicon nitride.

Optimisation of the production process in our in-line pilot facility for multicrystalline silicon has now resulted in efficiency values of 15.2 % for 10 cm x 10 cm cells. Filling factors for the screen-printed contacts reached 79.2 % on multicrystalline silicon and 80.5 % on monocrystalline silicon. This means that we have a high-performance reference process available, particularly for materials investigations.

Another focus of our work was to accelerate the diffusion process in in-line production facilities. We have set up diffusion processes with diffusion times of 40 s to 5 minutes for our in-line diffusion ovens with walking-string transport. In a test with two different substrates using the production line of a solar cell manufacturer, we were able to demonstrate that our 5-minute diffusion process results in the same efficiency values as the longer reference process of the solar cell manufacturer.

The effect of processing steps on the material quality is usually characterised by minority charge carrier lifetime measurements of substrates coated with silicon nitride (fig. 1). We have developed a passivation process for our in-line plasma unit, with which we achieve a surface recombination velocity of 10 cm s^{-1} for a deposition temperature of 375 °C. With a throughput of up to 15 wafers measuring 10 cm x 10 cm per deposition run, we are now able to carry out sophisticated investigations on changes in the material quality during the production processes in a much shorter time.

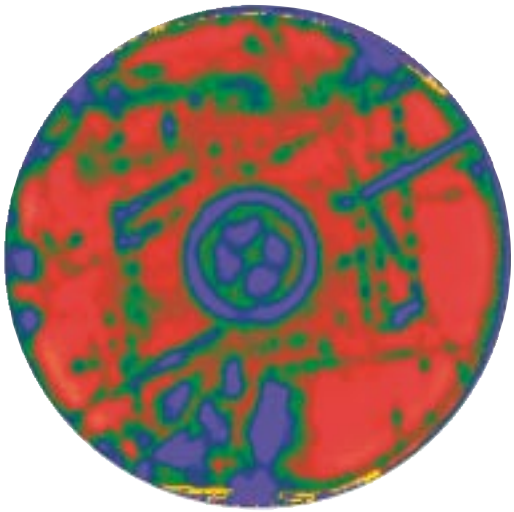


Fig. 2: Spatially resolved measurement of the minority charge carrier lifetime in a monocrystalline FZ silicon wafer coated on both sides with amorphous silicon. The red areas are those with a long lifetime of 350 µs, whereas the lifetime in the blue areas is around 140 µs. The round structure in the centre of the wafer was caused by a contaminated transport system.

As an alternative to passivation with silicon nitride, we have developed a passivation process in which we coat the substrates at 180 °C with an undoped layer of amorphous silicon on both sides. With this, we also achieve surface recombination speeds of less than 10 cm s^{-1}, both on p-type and n-type material. As an example, fig. 2 shows the results of a lifetime measurement on a monocrystalline silicon wafer coated on both sides with amorphous silicon.

Innovative and Rational Production Procedures for Silicon Photovoltaic Modules - SOLPRO IV

Close co-operation between the industry and research institutes forms the basis for progress in the industrial production of solar cells and photovoltaic modules. Within the SOLPRO expert consortium, Fraunhofer IPT and we jointly co-ordinate the co-operation between 13 industrial enterprises in the photovoltaic production sector. In SOLPRO IV, again many innovative production procedures were identified, evaluated and adopted.

Daniel Biro, Gernot Emanuel, Dominik Huljic, **Ralf Preu,** Eric Schneiderlöchner, Catherine Voyer, Dimitri Weilert, Winfried Wolke

Fig. 1: SOLPRO expert consortium. The following enterprises are participating: ACR GmbH, Niedereschach; Applied Films GmbH & Co. KG, Alzenau; centrotherm GmbH, Blaubeuren; Deutsche Cell GmbH, Freiberg/Sachsen; EKRA GmbH, Bönnigheim; ErSol Solar Energy AG, Erfurt; Ferro AG, Hanau; m+w zander Facility Engineering GmbH, Stuttgart; RENA Sondermaschinen GmbH, Gütenbach; Roth&Rau Oberflächen GmbH, Wüstenbrand; RWE Schott Solar GmbH, Alzenau; SGG Saint-Gobain Glass Solar, Aachen; TRUMPF Laser GmbH + Co. KG, Schramberg and the two Fraunhofer Institutes, for Production Technology IPT and Solar Energy Systems ISE.

The potential to reduce costs in photovoltaics is mainly concentrated in the production of solar cells and modules. Against this background, we prepare, test and evaluate rational and innovative production concepts in an expert consortium. The aim of SOLPRO is to identify new technological approaches with a high potential for cost reduction, and to promote their adoption. The consortium consists of wafer, cell and module producers, and manufacturers of machines, production facilities and components. Together with colleagues from Fraunhofer IPT, we co-ordinate the project following a well-tried method. Each year, two conferences are held, in which we present current trends in research and development against the background of the photovoltaic market, and discuss these with the project partners. Three topics are selected, which are addressed by project teams consisting of experts in the relevant fields. For the following six months, we investigate the topic with literature searches, experiments, simulations and cost analyses, so that we can conclude with a well-founded evaluation of the technology in question. This then forms the basis for subsequent research projects. As an example, in SOLPRO IV we identified an alternative to the industrially established edge insulation process with plasma etching, and investigated it experimentally. Among other results, we have determined that a significantly improved material flow in production is obtained with an optimised laser process, and the same or even better cell performance characteristics than with the conventional plasma procedure.

The unique approach in photovoltaic R&D taken by SOLPRO was supported by the industrial partners and the BMU (German Federal Ministry for the Environment). SOLPRO IV was successfully completed on 31.12.2003. More information can be found under: www.solpro.de

New Encapsulation Materials for Photovoltaic Modules

Module fabrication accounts for 30 to 40 % of the total costs of producing a photovoltaic module. At the same time, the quality of the solar cell encapsulation in the module laminate is decisive for the lifetime of a PV system. Thus, there is considerable potential specifically in the module sector for reducing costs and raising quality. In our work on photovoltaic modules, we are investigating new materials and concepts with respect to their applicability and durability in PV modules.

Georg Bahr*, Dietmar Borchert, Stefan Brachmann, Wolfgang Graf, Stefan Gschwander, Markus Heck, Michael Köhl, **Helge Schmidhuber**

* INAP Institut für Angewandte Photovoltaik GmbH

Solar cells must be encapsulated to protect them against the environment. Glass, ethylene vinyl acetate (EVA) and a back-surface film consisting of polyvinyl fluoride (PVF) and polyethylene terephthalate (PET) or aluminium are used for this in standard solar modules. Despite extensive developmental work by the industry and research institutes, EVA is not sufficiently stable to UV radiation and oxidation to guarantee long-term durability for the PV module in regions with high solar radiation intensity, as we have proven in climatic chamber tests (fig. 1).

As an alternative to further development of EVA, we are investigating materials used in vehicular and architectural glazing. Thus, we have improved the adhesion between glass and the polymer by using polyvinyl butyral (PVB) instead of EVA. To apply it, we co-operated with an industrial partner to develop a process to handle PVB in a standard laminator. PVB is used as the laminating film in laminated safety glass and has advantages compared to EVA: Its adhesive power can be varied over a wide range, it is authorised without restrictions for use in overhead installations, and it is inexpensive. In addition to PVB, we are also investigating other materials such as polyurethane and ethylene copolymers with regard to their applicability and durability in PV modules (fig. 2).

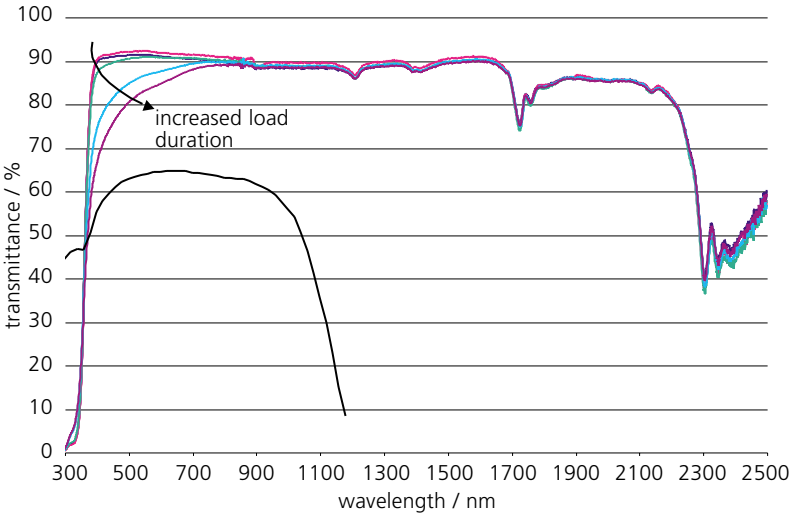
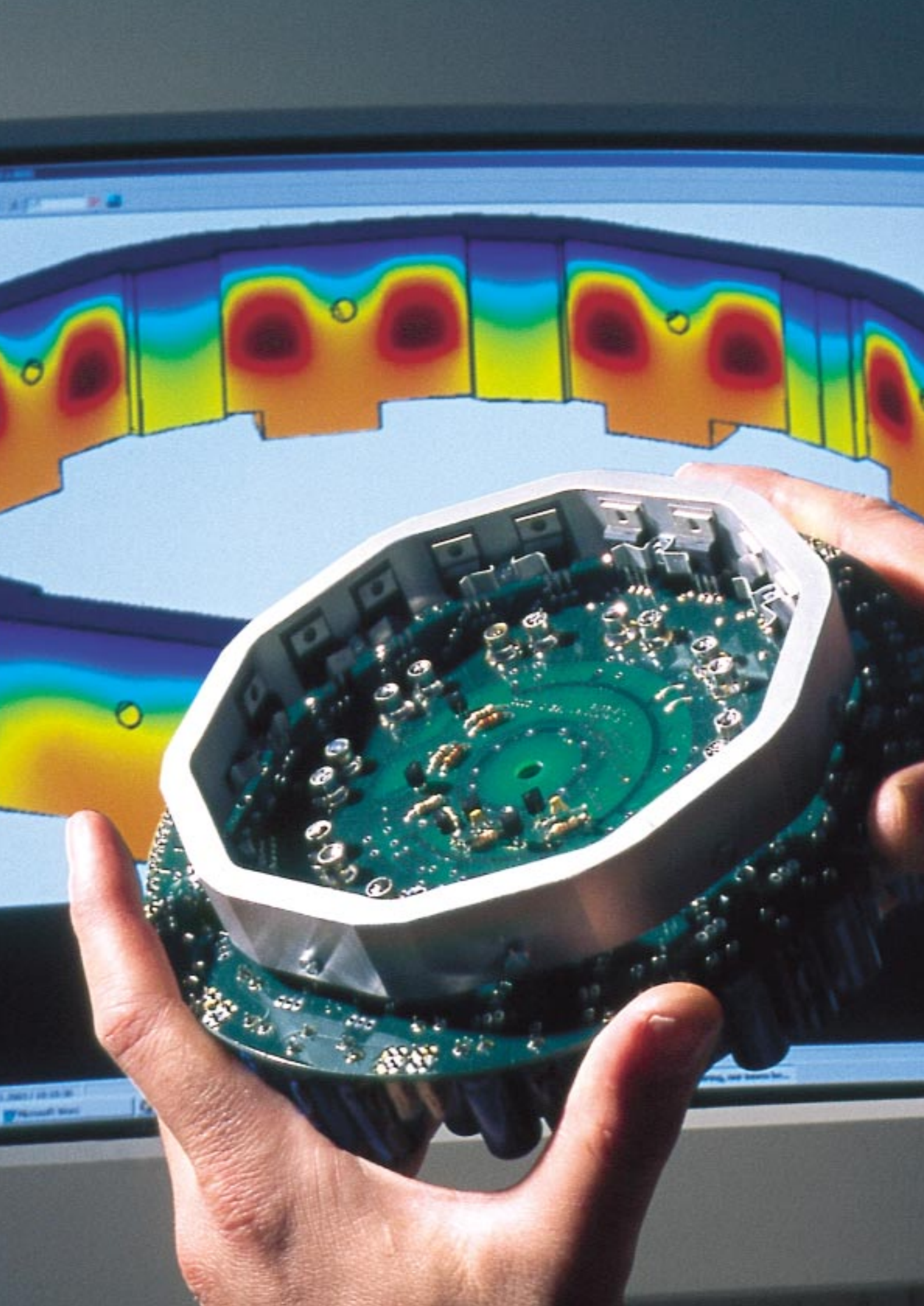


Fig. 1: Transmittance spectrum of a commercially available EVA film. The film was laminated between two low-Fe glass panes and exposed for 70 days to UV radiation and elevated temperatures in a climatic chamber. After periods of 7, 20 and 49 days, samples were taken out of the chamber, to document the ageing process. A decrease in the transmittance can be observed in the spectral range between 370 and 780 nm. This was also evident as yellowing of the EVA film. Depending on the site, the investigated 70 days correspond to outdoor exposure for 7 to 15 years. For orientation, the external quantum efficiency of a monocrystalline solar cell is also plotted (black line).

Fig. 2: Double climatic chamber to test windows, solar facades and solar modules at Fraunhofer ISE. The effect of temperature or humidity gradients across the building envelope can be tested in the chamber under controlled and accelerated conditions.

We are developing new module concepts, with the aim of completely avoiding the use of polymers for module encapsulation. The solar cells are hermetically sealed within a type of glass container. With modules produced in this way, we expect a technical lifetime of about 40 years.



Off-Grid Power Supplies

Two thousand million people without electricity, a multitude of technical power supplies for telematics, telecommunications or environmental measurement technology, and four thousand million portable electronic appliances in the industrialised countries all have one feature in common: They all require off-grid electricity. This is supplied in the required amounts by regenerative energy sources or innovative energy converters like fuel cells. About 30 % of the photovoltaic modules sold world-wide are thus used in off-grid power supplies. This application currently offers the largest natural markets for photovoltaic systems, which are often already more economic today than 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.

The quality of the components and the system design for both rural electrification and technical power supplies has improved notably over the last few years. However, the quality or cost of the power supply is often still unacceptable. Thus, increasing attention is being paid to careful planning, high-quality components and sophisticated operation management. We offer our clients the specific know-how needed for penetrating rural electrification markets. This includes analysis of the boundary conditions, development of power and control electronics, battery models, charging strategies, system operation management, energy management, system simulation and issues concerning the socio-economic environment.

Fuel cells have a high potential as off-grid power supplies - particularly as miniature fuel cells in portable appliances. Their decisive advantage is the high energy density which can be achieved in the storage units for hydrogen or methanol, compared to today's secondary batteries. This can significantly lengthen the operating time for the appliances, while the volume or mass remains unchanged.

New business models and appropriate market penetration strategies are 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. Anyone who wishes to access the markets for rural electrification must therefore include socio-economic methods and knowledge in business planning and product design.

We support component manufacturers, system integrators, planners and service companies in the off-grid power supply sector with our expertise in the following areas:
- electronics development
- battery modelling
- small fuel cells
- system dimensioning and optimisation
- system operation management and energy management systems
- water treatment systems and technology for drinking and other water supplies
- socio-economics

The following facilities are available to us for our development work:
- 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
- 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
- parallel Linux farm for optimisation calculations of complex systems

Off-Grid Power Supplies

Battery management system for optimal operation of series-connected batteries. The monitor shows the results of a finite-element calculation for the heat distribution in the cooling element of the power component.

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Fuel Cells for Distributed Power Supply in Hybrid Photovoltaic Systems

For the first time, a fuel cell has been used under real operating conditions in a hybrid photovoltaic system, for a hikers' inn located some distance from the public electricity grid. The experience from this system provides valuable input for the development of future hybrid PV systems with a fuel cell. At the same time, the project is an important stimulant for further dissemination of fuel-cell technology.

Andreas Steinhüser, Rudi Kaiser, Dirk Uwe Sauer

Fig. 1: The "Rappenecker Hof" with the solar generator (centre) and next to it the storage room to house the gas cylinders for the fuel cell (on the left).

Up to now, hybrid photovoltaic systems have usually included a diesel generator as the auxiliary generator. Now, for the first time, we have integrated a fuel cell into the stand-alone power supply for an inn. On the medium term, it is intended to completely replace the diesel generator in its role as the auxiliary power source. The "Rappenecker Hof", a hikers' inn on the Schauinsland mountain near Freiburg, Germany, was the first solar-powered inn in Europe. A hybrid system consisting of photovoltaics, a wind turbine and a diesel generator has supplied electricity since 1987. Technical progress in systems technology and an increased energy consumption resulting from changes in the inn's catering concept have made it necessary to modernise the system.

The starting point in planning the new power supply concept was the decision to continue and reinforce the "Rappenecker Hof's" character as a pioneering system for stand-alone power supplies. For this reason, a fuel cell was chosen as the auxiliary power supply for the "Rappenecker Hof". The photovoltaic generator and the wind turbine will continue to supply around 70 % of the annual energy consumption. A 48 V battery will compensate for fluctuations in supply and demand. The fuel cell will guarantee a reliable power supply during times when the contribution from the renewable energy sources is too low.

To ensure that the system can supply electricity reliably at all times, the existing diesel generator was integrated into the power supply concept. If insufficient power is available or the fuel cell should break down, the diesel generator will ensure that the battery can be recharged.

A hydrogen-fuelled polymer-electrolyte-membrane (PEM) fuel cell, with a power rating of 1.2 kW, has been used. The fuel cell system was supplied by a project partner, Phocos, and is based on a Ballard fuel cell.

The PEM fuel cell requires pure hydrogen and atmospheric oxygen for operation. Initially, the gas for the "Rappenecker Hof" is being supplied from commercial gas cylinders. However, the flexible system concept allows for later inclusion of a reformer, which produces hydrogen from fuels containing carbon compounds (natural gas, methane, biogas, ethanol, etc.).

As well as modernising the power supply for the "Rappenecker Hof", another goal of this project is to use and demonstrate fuel cells in off-grid systems. It is important now that fuel cells be applied in real systems under field test conditions. In this sense, the "Rappenecker Hof" is functioning as a pilot project.

Together with the first case of a fuel cell integrated into a hybrid PV system, we have introduced an innovative battery management system at the "Rappenecker Hof". The battery consists of four strings, of which one is new and the others have already been operating for three years. The individual strings can be charged and discharged separately, so that they can be deliberately charged for maintenance purposes. We assume that this will significantly increase the available capacity of the older batteries again.

In addition, we expect that this new technology will clearly lengthen the battery lifetime.

Modernisation of the power supply for the "Rappenecker Hof" was possible as a result of funding from the innovation fund for atmospheric and water conservation of the utility, badenova AG & Co. KG in Freiburg. The project partners, the Riesterer family from Oberried, Phocos AG-Deutschland from Illerkirchberg and the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg also contributed with substantial sums toward the financing of this project.

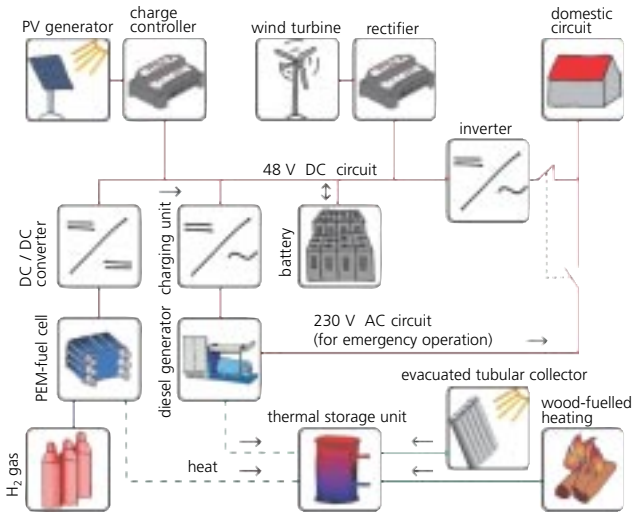


Fig. 2: Block circuit diagram of the energy supply concept for the "Rappenecker Hof". Usage of waste heat from the fuel cell and the diesel generator has already been planned, but not yet implemented.

Fig. 3: A hydrogen-fuelled, polymer-electrolyte-membrane (PEM) fuel cell with a power rating of 1.2 kW is being operated at the "Rappenecker Hof". The PEM fuel cell (its stacks can be seen in the background) requires pure hydrogen and atmospheric oxygen for operation.

Fig. 4: Control panels for the entire household power supply.

Technology for Operation Management of Stand-Alone Power Supplies

UESP (Universal Energy Supply Protocol) simplifies the planning and installation of hybrid photovoltaic systems and simultaneously results in cost-optimised and reliable operation of the system. The basis of this concept is a central energy management system EMS, that communicates with the system components using standardised protocols. The central EMS can operate together with any combination of electricity generators, energy storage units and loads, without requiring any configuration or programming effort.

Jochen Benz, **Felix Holz,** Tim Meyer, Werner Roth

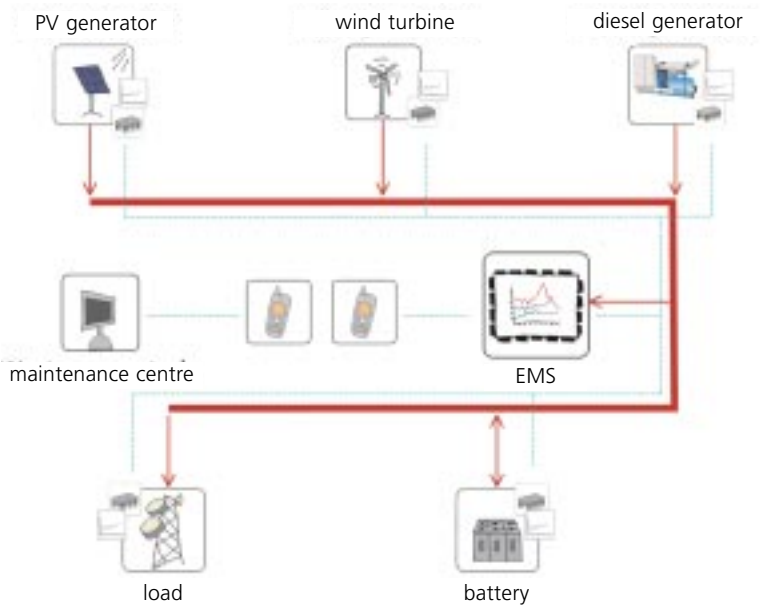


Fig. 1: The energy management system EMS balances electricity generation and consumption, receives status messages and monitors the components. In addition, it continually determines the most economic operating mode for the system. To allow this, the components send information to the EMS on quantities such as the instantaneous and future tariffs for providing or consuming electricity. These are calculated from all cost factors concerning operation and the predicted availability of energy (sun, wind, diesel fuel-tank level, etc.). In a type of electricity stock exchange, a price is determined, which is used to define the contributions to be delivered by the individual components.

Today, stand-alone power supplies are typically designed and constructed individually for each specific site and task. This demands considerable planning effort, as the system components and the parameters for operation management must be adapted anew each time. The results are high planning costs and often also reduced system lifetime and reliability. UESP represents a new system philosophy, which significantly simplifies the planning and operation management of stand-alone power supplies. The key is the distribution of intelligence and component-specific information within the system. A central EMS is connected with the system components via standardised communications interfaces. Similarly, standards are defined for the functionality and the interface of components to be integrated into such a system. The central EMS fetches specific information such as operating parameters, availability and instantaneous costs for the corresponding form of electricity generation from the components, and then optimises operation management without the need for special adaptation.

For the system designer and operator, the UESP acts as a "plug and play" system, that can be flexibly installed and extended. The system data are continuously monitored, evaluated and sent to a maintenance centre if desired. There, service plans can be prepared, for example. The new concept thus allows e.g. the operators of telecommunications facilities to operate economic and reliable power supplies at sites remote from the grid.

We co-operate with eight industrial partners on this work within a project that is funded by BMU (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety).

New Distribution Approach for Photovoltaic Village Power Supplies

To ensure that electricity is distributed fairly within off-grid photovoltaic power supplies, we have developed an "Energy Dispenser" together with the Spanish company, TramaTecnoAmbiental. This prevents uncontrolled - usually excessive - power consumption, user dissatisfaction with the power limits and a resulting unwillingness to pay, and makes a reliable power supply feasible.

Georg Bopp, **Sebastian Gölz,** Claudia Rittner, Gisela Vogt

Installation of photovoltaic systems for a centralised village power supply in regions remote from the public electricity grid has been a controversial issue due to the typical risks of excessive power consumption by the end users, dissatisfaction concerning limits on power availability and poor payment morale. Together with the Spanish company, TramaTecnoAmbiental, we have developed a technical component, which not only reacts to the users' demands for flexibility but also makes technically reliable operation and a lasting payment system feasible.

Central concept of the "Energy Dispenser": The customer selects and pays for a certain tariff class, which guarantees that a specified amount of energy and power will be supplied. Introducing the tariff systems means that the photovoltaic system can be dimensioned accurately. Bonuses and penalty rates motivate the user to control his/her own electricity consumption and thus make optimal use of the available solar energy.

The "Energy Dispenser" was installed within an EU project in demonstration systems in Spain and Ecuador. Detailed measurement data from a Spanish village show that the users are very satisfied with the distribution and financing concept. By taking advantage of the bonuses, some customers are able to use more electricity than agreed in the contract, without incurring higher costs or adversely affecting the supply reliability for others.

Fig. 1: The "Energy Dispenser" guarantees a certain amount of electricity each day, depending on the tariff class. Up to a certain limit, electricity that the user has not consumed is recorded as a bonus. If plenty of energy is available to the system (e.g. during long sunny periods), the customers can consume twice as much energy for the same price. In the opposite case (e.g. during the night, when the battery is almost flat), only half as much electricity is delivered for the same price. Further flexibility is offered by an electronic key, which "opens up" the energy bonus and can also be used in other households.

Demand-Oriented Training for Sustainable Success in Rural Electrification

The introduction of new technology in rural areas requires considerable technical, social and economic competence. An interdisciplinary team from Fraunhofer ISE has prepared training courses on various topics within different projects, and has already run them successfully. The training courses, which are specially tailored to clients' needs, make successful project planning and implementation feasible.

Georg Bopp, Dorika Fleißner, Sebastian Gölz, Werner Roth, Dirk Uwe Sauer, Mark Ullrich
Gisela Vogt

Fig. 1: Training course at Fraunhofer ISE on the integration of social aspects into projects on rural electrification, June 2003.

Topic	Learning Target
Preparation Phase	
Analysis and assessment of regional and local context	➲ Analysis of energy needs ➲ Survey of social and socio-economic data ➲ Transfer of local cultural information into a code of practice
Construction of a financial concept	➲ Design of transparent payment schemes that will be accepted by the users ➲ The match of payment schemes with organisation for operation ➲ Awareness of organisational problems concerning regular payments
Installation & Operation Phase	
Promotion/ Introduction concept	➲ Improvement of promotional activities ➲ Planning of promotion strategies ➲ Optimal communication policy
Training for end users & local technicians	➲ Practice of pedagogical methods ➲ Development of training conception for illiterate people ➲ Handling of cultural problems
Monitoring and Evaluation Phase	
Monitoring and Evaluation	➲ Monitoring & evaluation of the projects' progress and results ➲ Assessment of non-technical parameters e.g. user satisfaction ➲ The application of monitoring and evaluation results for optimisation

Fig. 2: The table shows a list of relevant topics that can be included in a training course on the integration of social aspects. The topics represent essential areas of competence for rural electrification projects to be successful. The core topics are correlated to the individual project phases and important learning targets are defined.

To ensure that projects are sustainable and that markets can be developed in the rural electrification sector, a broad knowledge base is needed, which extends beyond the purely technical aspects of photovoltaics. Thus, demand-oriented education in various aspects, not only the technical ones, is very useful for companies, organisations and users involved in rural electrification projects.

Within our work on off-grid power supply, we develop concepts and materials for technical and non-technical training courses on different subjects. We have already successfully applied and evaluated some of these concepts. The complete training packet, prepared and taught by interdisciplinary teams, includes both awareness-raising seminars for politicians, funding agencies and decision makers and also theoretical and practical seminars to train technical personnel. Training sessions for end users on day-to-day handling of the systems are also part of the programme.

The training courses are specifically designed and adapted to the needs of the target group. In the first phase of the training concept, we determine the training expectations of the course participants by analysing their areas of responsibility and the associated problems. Based on this information, we then select and present the course contents in agreement with the participants. In order to continually improve our offer, we evaluate each training course according to previously defined learning targets, and carry out a comprehensive evaluation process.

The work is carried out within the EU-funded projects, "SOPRA-RE" and "Soltrain", as well as in co-operation with several European partners.

Intelligent Battery Storage Units for Autonomous Power Supply Systems

Throughout the world, batteries provide most of the storage capacity for autonomous power supply systems. However, considerable stresses associated with partial cycling operation and the lack of complete charging processes mean that the battery lifetime is much lower than that of the other system components. To fully exploit the features of modern batteries and lengthen their lifetime, we have developed an intelligent battery bank which convincingly meets these requirements.

Georg Bopp, **Rudi Kaiser,** Dirk Uwe Sauer

Autonomous or off-grid power supplies impose a wide range of demands on the battery storage unit, which cannot be met optimally by a single battery type. If a single storage battery is selected and used, compromises must always be made, which negatively affect the lifetime. The use of different types of battery technology or different types of lead-acid batteries presents a suitable solution to this problem.

We have developed a battery storage unit which meets the differing demands by including different storage batteries. The system intelligently connects different battery types such that batteries designed for cycling operation are responsible for the daily turnover, and batteries with low self-discharge rates serve as long-term storage units (fig. 2). As the internal connection between the batteries is based on a universal configuration, the system can be operated in special modes that are not possible in conventional systems.

Precise algorithms in the battery management system (BMS) determine not only the state of charge (SOC) but also the state of health (SOH) for the individual batteries. This occurs during normal operation, without wasting energy for an extra ageing test. With the aid of this information, we can apply special charging procedures that reduce the typical ageing effects as compared to conventional charging procedures, and thus significantly lengthen the battery lifetime. Furthermore, the electricity supplied by the generators is used more effectively, as precisely that battery which most needs recharging is charged.

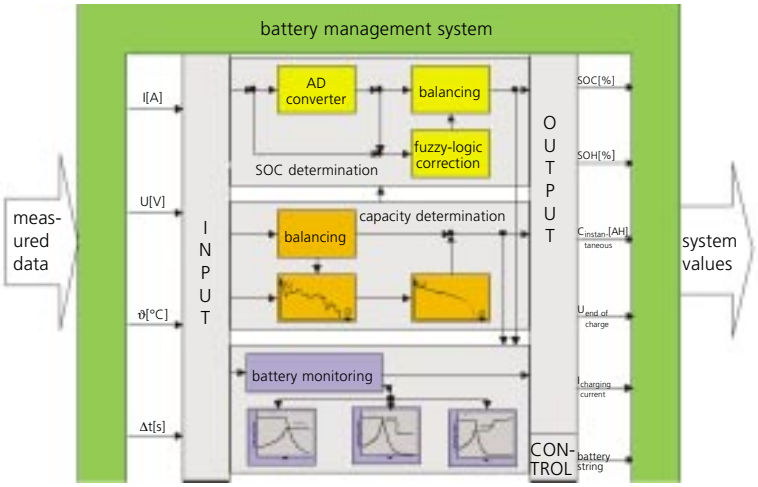


Fig. 1: The algorithms in the battery management system (BMS) determine the state of charge (SOC) and the state of health (SOH) from the externally measurable battery parameters (current, voltage and temperature). With the aid of an expert system based on fuzzy logic, very exact results are obtained and sent to the BMS as information on the instantaneous state of the battery. With the help of this information, the BMS is able to react automatically to the individual states of the battery strings, and decide how they should be used within the complete battery bank. The energy supplied to the system is always optimally used, and simultaneously the lifetime of the storage batteries is lengthened.

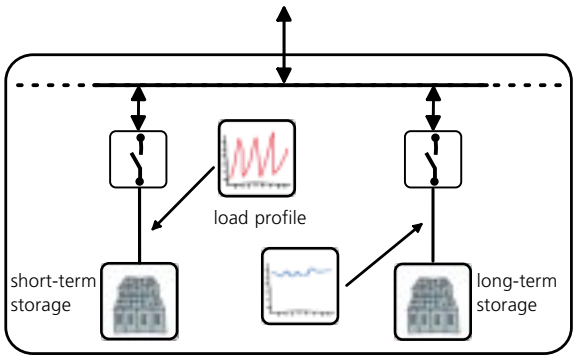
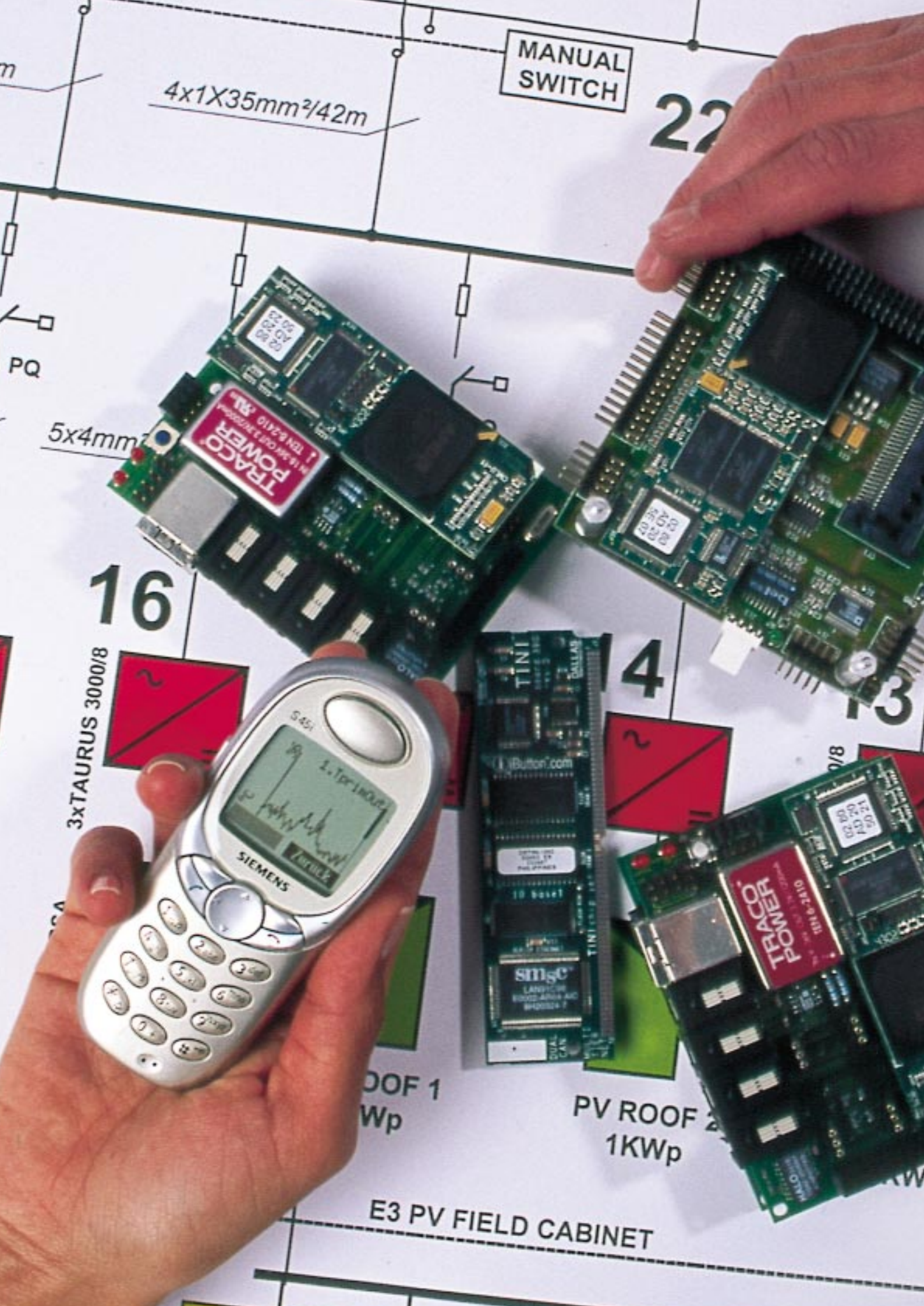


Fig. 2: From outside, the newly developed battery system looks the same as a conventional battery bank. Inside the system, several different types of battery are used, as indicated symbolically in the diagram by two batteries. The different types of batteries are designed to meet different specifications, and are thus correlated with different charging and discharging profiles. This is illustrated in the example by one battery that is designed for cycling operation (left) and another that is intended for long-term storage (right). The battery management system (BMS) determines the battery parameters (V, I, T, SOC, SOH, etc.) and uses this information to decide how each individual battery in the system should be treated.


MANUAL
SWITCH
4x1X35mm²/42m
PQ
5x4mm²
16
3xTAURUS 3000/8
PV ROOF 1
1KWp
PV ROOF 2
1KWp
E3 PV FIELD CABINET
TRACO POWER
SIEMENS
TINI

Distributed power generation

Grid-Connected Renewable Power Generation

Grid-connected systems represent the largest market for photovoltaics today. Well-implemented market penetration programmes, particularly in Japan, Germany and some States of the USA, are ensuring high growth rates. The cost reductions in photovoltaic systems, which have been achieved so far and which are needed further for stable growth, have mainly occurred in the systems technology: inverters, roof integration, assembly and cabling systems. In order to keep maintenance and repair costs low over the system lifetime of 20 years, the quality of the components must improve. For the same reasons, quality control and monitoring of system operation are playing increasingly significant roles.

The efficiency and quality of inverters for feeding photovoltaic electricity into the grid have reached a high standard. Nevertheless, there is still considerable potential for improvement with new circuit designs, digital controls technology, advances in power semiconductor components and passive components. We offer specialised know-how in the fields of circuit design and dimensioning, as well as configuring and implementing analog and digital controllers.

Large, commercial photovoltaic systems in particular raise questions of quality control for planners and operators. We advise on system planning, write expert reports analysing the yield, characterise solar modules, carry out measurements for authorisation procedures and develop concepts for system monitoring during operation or the visualisation of operating data, e.g. via Internet.

On the medium term, solar thermal power stations can make an important contribution to regenerative generation of electricity. We develop materials, optimise the controls and carry out system simulations.

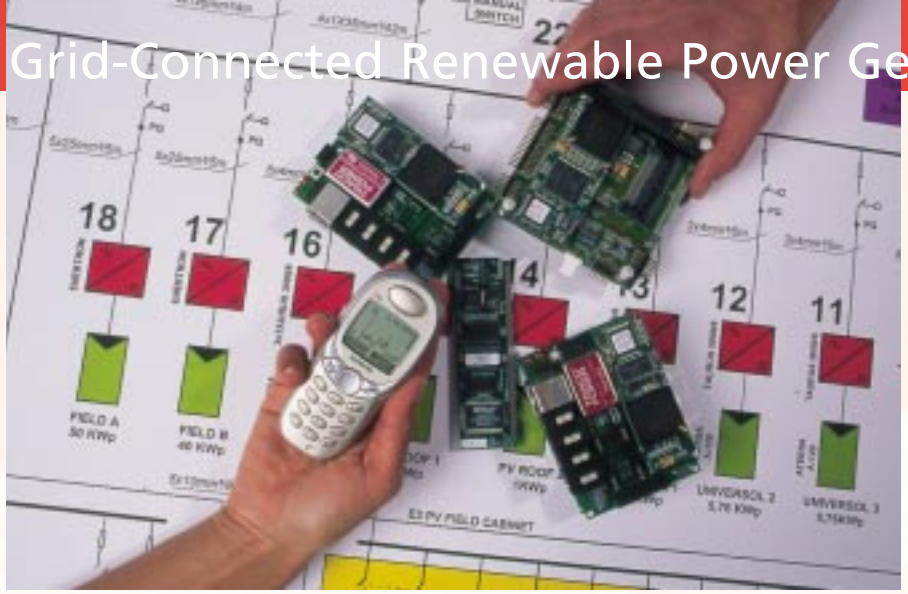
Optically concentrating photovoltaic systems can also reduce the price of solar electricity. Parallel to highest-efficiency solar cells, for instance, we are developing an inexpensive procedure to manufacture Fresnel lenses in concentrator modules and are testing complete modules in the field.

Photovoltaic systems and other decentralised electricity generators such as combined heat and power (CHP) plants interact with the electricity grids and the buildings into which they are integrated. The liberalisation of the electricity markets and the entry of climate-protecting energy technology to the market means that the number of distributed generators is rapidly increasing. Questions concerning operating safety, supply reliability and voltage quality, as well as the integration of heat generators in control strategies for the entire energy supply complex, will become increasingly important. Many small generators and controllable loads will interact and be actively controlled. This results in completely new demands on controls, operation management, communications and data management in electricity grids and buildings. We prepare concepts, electronics, planning instruments and management tools to address these issues.

For the regenerative, grid-connected electricity generation sector, we support component manufacturers, energy utilities, system planners and operators in the following areas:
- inverter development
- quality control and monitoring of components and systems
- investigation of concepts for distributed generation
- integration of heat and electricity generators, and storage units, into grids and buildings to optimise load flows and improve the supply reliability and voltage quality
- conception and technological development of photovoltaic and thermal power stations

The facilities we use for this 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 micro-controllers and digital signal processors (DSP)
- calibration laboratory for solar modules
- outdoor test field for solar components
- test equipment for batteries over a wide range of current, voltage and temperature values
- laboratory to develop battery charging and operation strategies
- development environments for controls based on "embedded systems".

Grid-Connected Renewable Power Generation



The provision of electricity and heat to modern energy supply systems by many distributed generators also places high demands on communications technology. Our response is to develop operation management concepts based on "embedded systems", which can be administered via mobile phones and Internet.

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Communications for Linked Control Systems

New communications concepts are needed for the energy management of power supply systems and technical building services, which can meet the demands of optimised operation. Linked control systems are needed for both technical systems and control technology, which can access decentralised information from the complete network. We implement systems based on established field bus concepts as well as novel solutions with Internet technology.

Christof Wittwer, Jochen Benz, Rainer Becker, Hans-Georg Puls

Energy-efficient buildings have a strongly reduced primary energy consumption. The remaining energy demand requires supply concepts such as the integration of solar thermal systems (fig. 1). The aim of such concepts is to integrate regenerative sources of energy optimally into the supply system, and to optimise the interactions with conventional energy supply equipment.

Linkage of the controls components plays a central role in this process. Whereas very many autonomous systems operating independently of each other have existed up to now, interconnection of subsystems is becoming increasingly important. For example, when a collector system can deliver solar gains, it may be sensible to turn off the conventional auxiliary heating, so communication between the two control systems for the solar loop and the boiler becomes necessary. We develop communicative software and hardware solutions and innovative management strategies that can meet these specifications.

Reacting to the specific requirements of our clients, we develop control systems which can be linked and integrated into existing infrastructure. We apply both classic microcontroller systems (fig. 2) and also "embedded systems", which are characterised by their intrinsic networking features and the availability of an operating system.

Typical system solutions are illustrated by gateways, which can be connected to the Internet via a network interface (e.g. XML-RPC), but also use a field bus interface, which allows access to commercially available appliances (e.g. measurement instruments with a Modbus interface).

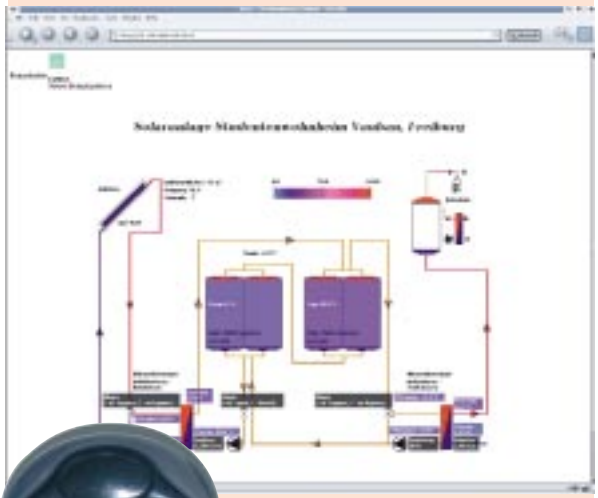


Fig. 1: Internet-based communications concept for a large thermal solar system: Embedded systems provide access to the system state parameters from any location. Meteorological data from the Internet are transferred here using the XML-RPC protocol (via TCP/IP).

Fig. 2: The GSM-Wap interface allows remote access to system operation via a mobile phone. If a fault occurs, the control system sends a signal with SMS (short message service).

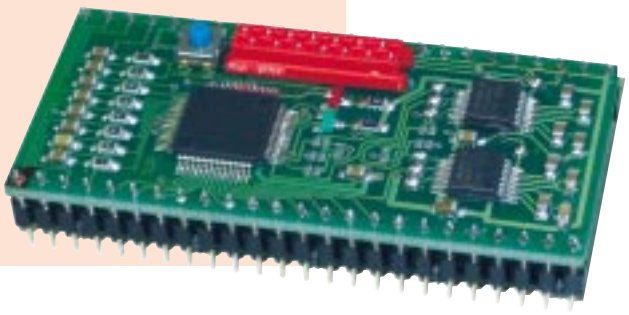


Fig. 3: Hardware prototype for the application of distributed control concepts: Microcontroller unit with energy-saving architecture to control sensors, actuators and field bus systems. System description: Embedded system unit, for integration into a building network based on Ethernet, TCP/IP protocol.

Management Concepts for Distributed Power Supply Systems

In contrast to a classic off-grid power supply system, the management of grid-connected regenerative energy sources raises completely new demands concerning operating safety, flexibility, upscaling potential and number of components. We are developing complete management systems that meet these new demands.

Hans-Georg Puls, Christof Wittwer, Jochen Benz, Thomas Erge, Malte Thoma, Anselm Kröger-Vodde*

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

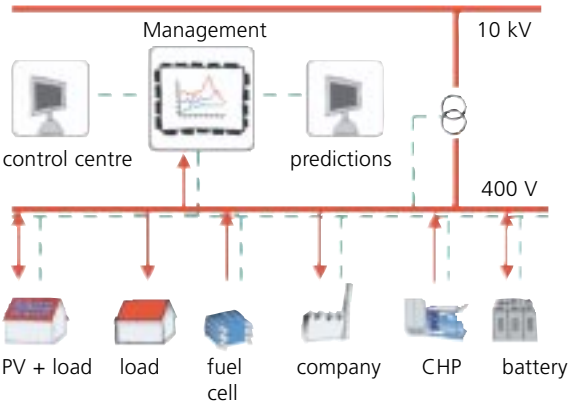


Fig. 1: When decentralised electricity generators are introduced, the unidirectional supply direction, from high-voltage through medium-voltage to low-voltage grids, can be reversed. The voltage quality in the grid and the operational economics of all components are affected. The illustrated management system meets the resulting new specifications and includes communication links to the individual components.

The number of grid-connected, decentralised electricity generators is increasing, partly due to favourable legal boundary conditions. Energy utilities and grid operators now have the task of integrating these generators into their grids and operation management, while continuing to maintain high supply reliability and quality. If they are intelligently controlled, decentralised generators can meet peak loads or reduce the loads on existing equipment, and thus save costs.

For the low-voltage level, we are developing an intelligent management system within the EU-funded "DISPOWER" project. As well optimising the control of generator, load and storage components according to technical and economic criteria, the system allows remote control of all components and monitoring. Fig. 1 shows the integration of such a system into a low-voltage grid.

In order to meet the requirements for flexibility and future extension, new approaches must be followed for the management. The central control unit must no longer be responsible for each component in detail. Thus, we use small, decentralised units (fig. 2), to connect one or more components to the central controls. The energy demand and generation potential are converted, taking boundary conditions into account, into cost functions, which are then evaluated in a stock-market model to optimise operation. For any specified time, the miniature stock exchange determines the most economic operating state, accounting for factors such as electricity price, component efficiency, etc. (fig. 3).

We are developing similar management concepts for off-grid power supply systems in the "UESP" project, which is funded by the BMWi (German Federal Ministry for Economics and Technology).

Fig. 2: The desired flexibility and upscaling potential of a power supply system can only be achieved if the components are equipped with decentralised, intelligent units. The photo shows the prototype of such a unit.

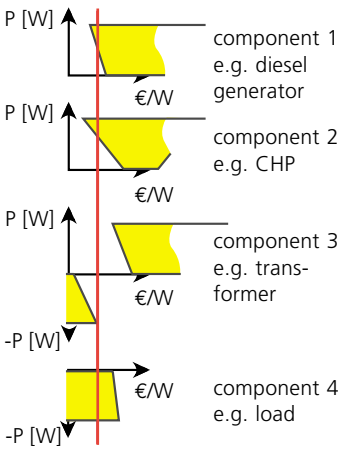


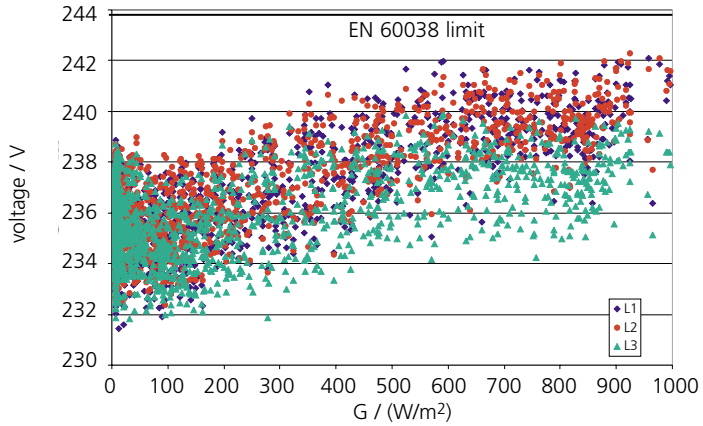
Fig. 3: All combinations of price (€/W) and power (P) falling within the yellow areas represent valid operating states offered by the individual components. Applying a stock-market model, the instantaneous price (shown here as the vertical red line) is increased, starting from zero, until a valid state has been found for all components. In further steps, the exact power values are set and the identified solution is tested technically. If the result of the technical test is negative, further solutions are sought at higher prices, and again tested technically.

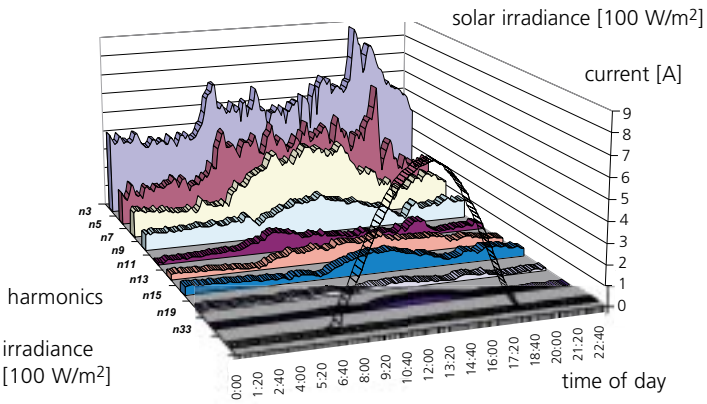
Voltage Quality and Measurement Concepts for Low-Voltage Grids

The European electricity grid includes an increasing number of distributed electricity generators. In this situation, new questions arise concerning the individual grid segments and the grid quality. We determine the power quality indicators with highly accurate measurement instruments.

Thomas Erge, **Hermann Laukamp,**
Tim Meyer, Malte Thoma

Fig. 1: In this solar settlement in Freiburg, about 40 household units with a total of 260 kWp of photovoltaics are in operation. Approximately 100 distributed inverters feed the solar electricity into the low-voltage grid.





The electricity economy will change considerably in the next few years. Distributed electricity generation from regenerative energy sources and combined heat and power plants is being promoted politically throughout Europe. In the next two decades, a large number of German power stations are due for replacement. We thus expect a strong increase in distributed electricity generation.

Already today, there are segments of the low-voltage grid where the high penetration of distributed generators means that more electricity is generated at times than is consumed. We measure this type of grid segment to determine the effects which decentralised export of electricity to the grid has on grid operation and voltage quality. The grid quality parameters are determined with extremely accurate measurement instruments. Additional measurement of the solar radiation or wind speed allows us to determine the influence of these quantities on grid operation. Our measurement instruments can determine the grid quality according to the standard EN 50160, but can also monitor dynamic processes with high temporal resolution to characterise special grid conditions. We use such measurements and corresponding simulations, also on commission to clients, to determine the true situation in low-voltage grids. This is our basis for optimisation measures, e.g. adapted operation management of private generation systems.

Fig. 2: The grid voltage of all three phases was measured in a flat at the end of the cable branch which connects the settlement. The effect of the solar electricity that is fed in along the course of the cable can be seen clearly. The voltage increases approximately proportionally to the solar irradiance. However, the limits set by EN 60038 are observed. The voltage level of phase L3 (green) is lower than that of the phases L1 and L2. This is due to the smaller number of inverters that feed into this phase.

Fig. 3: The harmonic currents are measured directly at the local grid transformer for the solar settlement. The harmonics, n3 to n33, are plotted in increasing order from the back to the front of the graph, for a sunny day. The curve at the very front shows the solar irradiance profile. The third and fifth harmonics are dominant. These harmonics are only weakly correlated with the solar irradiance and thus with the output power of the inverter. Some of the higher harmonics have a similar profile to the solar irradiance, indicating that they originate from the inverters. The level of all the harmonics is lower than the allowed limit.

The measurements were funded by the European Union within the "DISPOWER" project.

"MikroSolar" - Power Supply Platform for Autonomous Microsystems Technology

As components of management systems, battery-powered microsystems with radio communications are used to acquire measured data, communicate and control. In a joint project with industrial partners and other research institutes, we are developing a concept for autonomous power supplies for this type of system.

Bruno Burger, Jürgen Ketterer,
Heribert Schmidt, Christoph Siedle

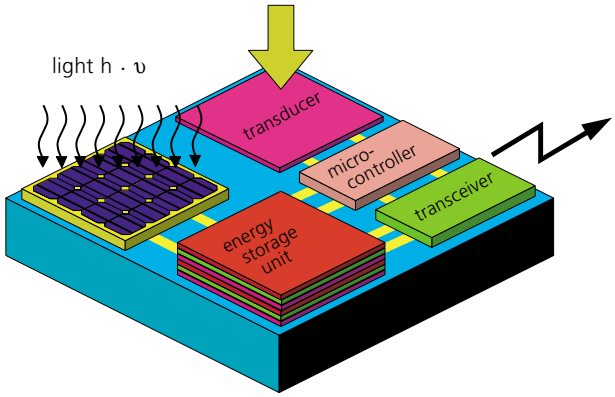


Fig. 1: Schematic diagram of an autonomous microsystem; the components are a functional unit (e.g. sensor, communications, control of electric motors), energy conversion device, energy storage component, energy management unit and transceiver for wireless connection to the surroundings.

In household installations, increasing numbers of radio-controlled sensors are being used, such as motion and occupancy detectors, temperature and illumination sensors, and switches. These systems are usually powered by primary batteries. Within the "MikroSolar" joint project, we are developing concepts and circuits to provide autonomous power supplies for these systems using photovoltaics.

The application of photovoltaically powered system components in household installations often encounters problems caused by the low and usually unpredictable lighting levels, often with artificial lights. In addition, the existing possibilities for installation in conventional, built-in sockets offer only small surface areas for mounting solar cells. Only specially optimised solar cells and consistent low-power design for the circuits can cope with these boundary conditions.

Taking these demands into account, we cooperated with our project partners to prepare the specifications for a solar-powered microsystem with a PIR (passive infrared) sensor.

Based on these specifications, prototypes of the battery (Li ion) and solar cell components were developed. By applying optimised timing and a consistent low-power design for the circuit, we were able to reduce the energy consumption by a factor of more than 50 compared to a conventional, battery-powered solution. A patent was granted for one circuit detail.

Our measurement equipment allows the energy consumption to be determined accurately, even for the highly dynamic power profiles that occur here in the µW range.

Parts of the project were supported by the BMBF (German Federal Ministry for Education and Research).

Solar-Thermal Power Stations with Auxiliary Biomass-Fuelled Boilers

Solar-thermal power stations generate electricity by allowing solar-heated steam to expand in conventional steam turbines. As the supply of solar energy fluctuates, combination with a biomass-fuelled boiler offers technical advantages and has the benefit of being CO_2-neutral. Together with the utility, E.ON Energie AG, we at Fraunhofer ISE have investigated the technical and economic feasibility of a solar/biomass hybrid power station for sunny countries.

Hansjörg Lerchenmüller, Max Mertins, Gabriel Morin, Andreas Häberle*

*PSE GmbH Forschung Entwicklung Marketing, Freiburg

Solar-thermal power stations can play an important role in extending regenerative electricity generation in sunny regions. An interesting variant on a purely solar-thermal power station is combining a solar steam generator with a biomass-fuelled boiler.

Together with the utility, E.ON Energie AG, we have carried out annual yield simulations for power stations with 20 and 50 MW power. The dimensions were chosen such that the biomass-fuelled boiler provides between 50 % and 100 % of the steam mass flow, depending on the solar energy supply. A directly evaporating Fresnel collector, a variation of the parabolic trough, was used as the solar "boiler" in the simulations. We applied ray-tracing calculations and heat-loss measurements of a test collector to determine and optimise the optical and thermal efficiency values of the Fresnel collector. The design of the solar field was economically optimised for the prevailing solar and economic boundary conditions in Spain.

One result was that an annual solar fraction of about 20 % is achieved with this type of concept. The predicted solar electricity generation costs (annual costs for the solar field divided by the solar electricity generated) are about 0.13 €/kWh. Thus, this concept represents a very economic type of solar electricity generation. Hybrid operation in combination with a biomass-fuelled boiler allows stable and predictable operation of a power station that operates completely with regenerative energy resources.

The BMU (German Federal Ministry for the Environment) supported this work as part of the "Investment for the Future" Programme.

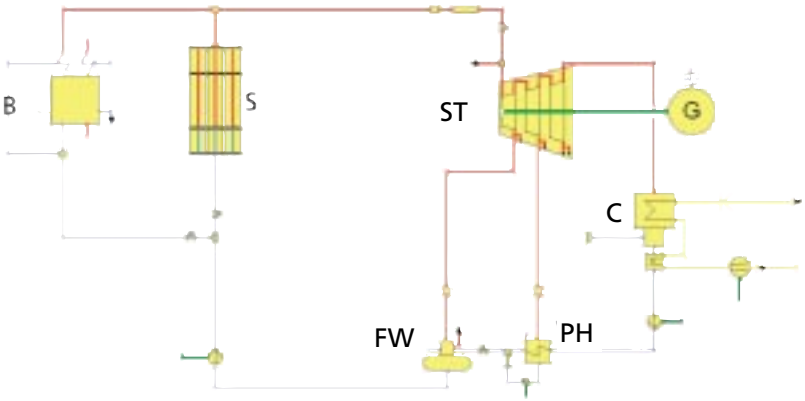


Fig. 1: Schematic diagram of a solar-thermal power station with a parallel-connected biomass-fuelled boiler. The generator (G) is driven by the steam turbine (ST), the biomass-fuelled boiler (B) and the solar field (S) are connected in parallel, so that guaranteed power can be provided even without solar radiation. The diagram also includes the condenser (C), a pre-heater (PH) and the feed water tank (FW).

Photovoltaic Monitoring Reveals the Potential for Optimisation

Since the beginning of 1999, Fraunhofer ISE has monitored the project, "Kirchengemeinden für die Sonnenenergie" (Church Parishes for Solar Energy), on commission to the DBU (German Federal Foundation for the Environment). The main technical data and the monthly yields of all photovoltaic systems are acquired and analysed.

Alfons Armbruster, **Klaus Kiefer,** Wolfgang Heydenreich, Carola Zerjeski, Stefan Haug

Fig. 1: Cover page of the annual report for 2002 on "Kirchengemeinden für die Sonnenenergie" (Church Parishes for Solar Energy).

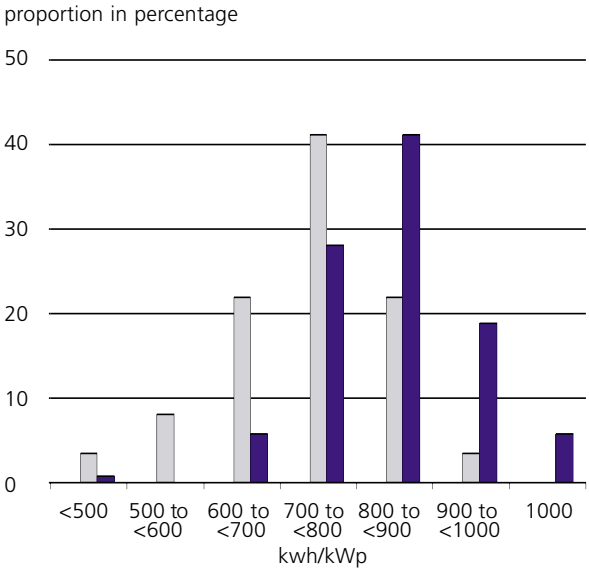


Fig. 2: Distribution of the specific annual yield for 2002 in Northern and Southern Germany. The share in percentages is relative to the total of all monitored systems for each region. The kilowatt-hours (kWh) that are fed into the grid by a photovoltaic system are measured with a calibrated meter and the accounts are settled with the local utility. If the annually generated electricity determined in this way is divided by the rated power of the system (peak power of the solar generator in kWp), the system yield in kWh per kWp is obtained. This value is strongly affected by the accuracy with which the module power (peak power in kWp) is classified by the manufacturer.

In addition to checking the power and the annual yield, one goal of monitoring photovoltaic systems is to determine the potential for optimisation. We have gathered the complete annual data from 2002 for 220 photovoltaic systems within the project on "Kirchengemeinden für die Sonnenenergie" (Church Parishes for Solar Energy), funded by the BMU (German Federal Foundation for the Environment). The average energy yield for the 107 systems in Southern Germany is 840 kWh/kWp. In Northern Germany, the 113 monitored systems yielded 730 kWh/kWp on average.

The Performance Ratio, a neutral quantity for comparison purposes, was determined for 200 sites. It allows the system efficiency to be evaluated, almost independent of the location, orientation and tilt angle of the solar generator.

The large number of systems monitored in 2002 provides reliable statistics for technical evaluation of the solar systems. The fact that about one third of the investigated systems had clearly reduced yields in 2002, or were characterised by a Performance Ratio that was too low, reveals the potential for optimisation.

At the same time, the dissemination of solar energy is promoted by the many positive examples of systems with high yields and peak values for the Performance Ratio, and also the architecturally successful integration of larger photovoltaic areas into or onto roofs. On the basis of this and other monitoring campaigns, Fraunhofer ISE offers advice and monitoring support for PV programmes. You can find further information at the web site: www.solar-monitoring.de

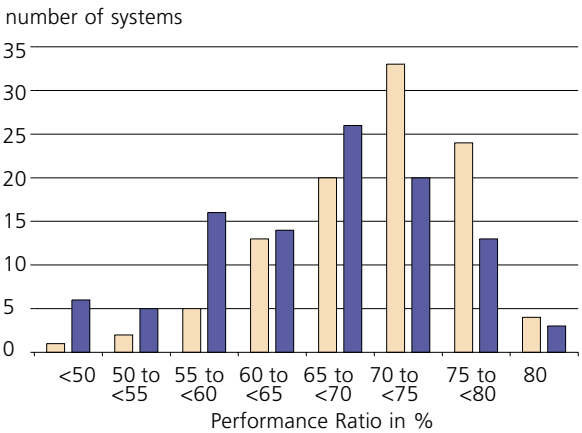
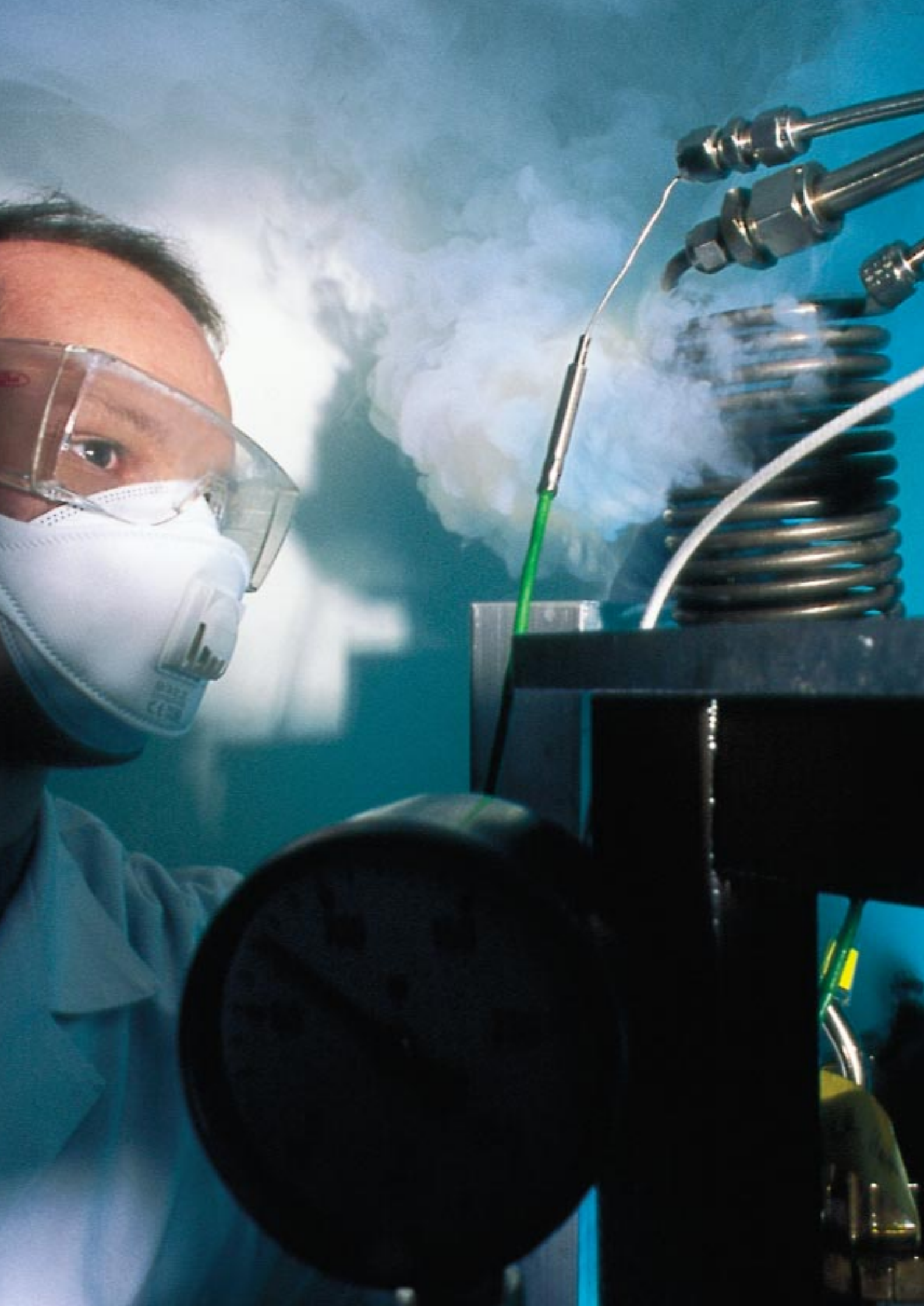


Fig. 3: Performance Ratio (see text) of 205 systems for 2002.



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 obtained from its diverse chemical compounds. This is achieved by applying energy – ideally renewable energy – e.g. in electrolysis with renewably generated electricity or by reforming biogenic and fossil fuels.

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. By using hydrogen, fluctuating forms of renewable energy will be processed such that all desired energy services can be provided with the accustomed reliability. Scientists and technologists are working intensively on realising this vision.

The application potential of hydrogen is enormous: In household energy centres, fuel cells can supply heat and electricity from natural gas with a total efficiency value of up to 80 %. "Distributed power stations" then consist of thousands of such fuel-cell combined heat and power (CHP) plants. Mobile applications of fuel cells, combined with electric motors, serve 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 complements to primary and secondary batteries in electronic appliances, due to the high energy density of the fuels, hydrogen or methane.

Innovative technology to obtain hydrogen and efficiently convert it 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 hydrogen systems for an inexpensive and environmentally friendly energy economy.

We develop reformer systems to convert liquid or gaseous fuels. To obtain hydrogen from water, we construct controlled electrolysers supplying power up to 2 kW. In addition, we conduct research on the catalytic combustion of gases such as hydrogen, propane and synthesis gas. The membrane fuel cell is our favoured energy converter in the low power range, being efficient, environmentally friendly, quiet and requiring little maintenance. Finally, we develop miniature fuel cells as power supplies for portable electric appliances. They complement our activities on device-integrated solar modules and thermophotovoltaic systems for the micro-energy technology sector.

In addition to developing components and hydrogen-conversion systems, we also work on their integration 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 a commercially viable hydrogen economy. It encompasses hydrogen filling stations, fuel-cell CHP plants producing both heat and electricity, stand-alone power supplies for off-grid applications, and miniature systems as portable power supplies.

Hydrogen Technology

Novel process for complete evaporation of liquid hydrocarbons: By using a catalyst and minimal air feed, diesel is transferred into the gas phase without production of residues. The resulting product gas is subsequently converted in a reforming reactor into synthesis gas for fuel-cell applications.

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Product Development of a Portable PEM Fuel Cell

Portable fuel cells serve as autonomous power supplies for electronic appliances. We develop not only prototypes but also complete systems ready for series production. Our activities encompass work on fuel-cell stacks, water and heat management, peripheral components, packaging, hardware controls and fuel-cell characterisation.

Jochen Benz, Bruno Burger, Jan Hesselmann, **David Pocza, Marco Zobel**

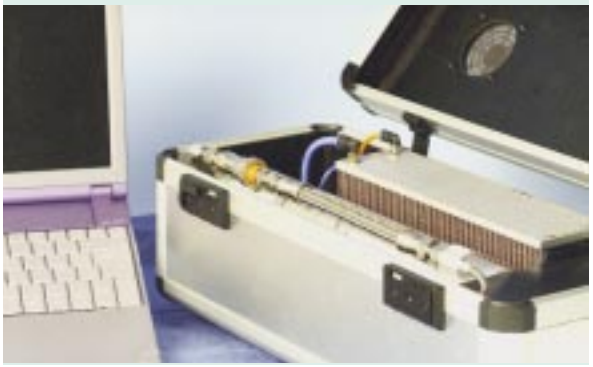

Fig. 1: Fuel-cell power supply for portable electronic appliances. The metal hydride storage unit with 250 Nl hydrogen is located in the front of the box at the right of the photo. Behind it is the fuel-cell stack with a peak power exceeding 100 W.

The operating time for grid-independent electronic appliances is often limited by insufficient capacity or the lack of possibilities to charge the batteries. Portable fuel cells do not suffer these disadvantages. Particularly for high capacities, fuel-cell systems are characterised by significantly higher equivalent energy densities than conventional rechargeable batteries. In accordance with the required duration of operation, reserves of the fuel, hydrogen, can be supplied in storage units of differing volume. The electric power is primarily defined by the dimensions of the fuel cell.

We construct and develop the appropriate fuel cell for each client's specific application. In addition to achieving functionality, another focus is on industrial series production. Attention is already paid during the conception phase to the necessary criteria concerning materials selection, manufacturing procedures and production steps.

In intensive co-operation with our colleagues who specialise in power electronics and controls technology, we develop highly efficient DC/DC converters and hardware control concepts, which ensure reliable continuous operation of our fuel-cell systems. The specially developed control structures are implemented with microcontrollers. These rapid, powerful control units

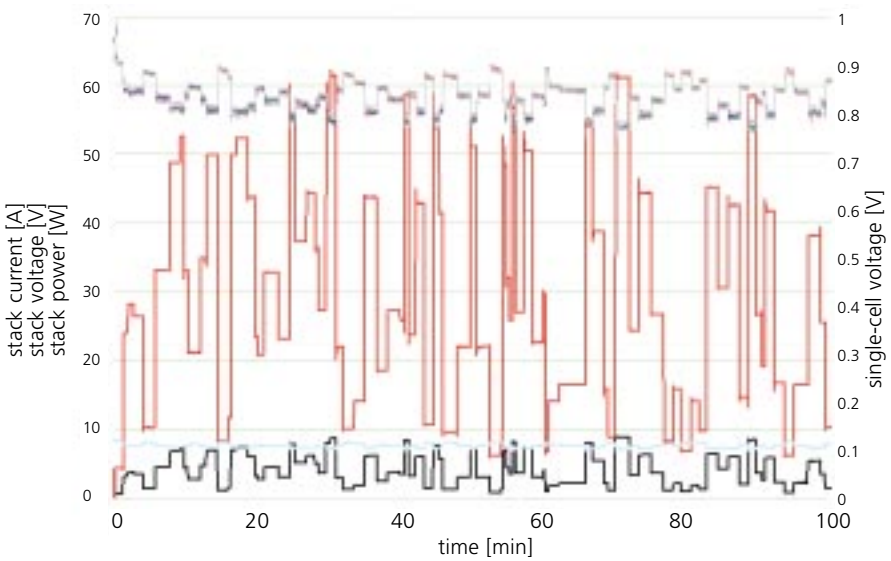

Fig. 2: I(t), U(t), P(t) plots for the nine-cell stack of the Mobile Power Box, when subjected to a dynamic load. The almost completely synchronous profile for all nine single-cell voltages for discontinuous changes in the load leads to stable operating behaviour for the stack.

guarantee stable operating behaviour for discontinuous, dynamic loads in the millisecond range. Further expertise in humidity and heat management allows us to adapt portable fuel cells to the most diverse sets of operating conditions.

All climatic conditions can be simulated in special test rigs, which allow the necessary characteristics to be determined. This is where the fuel-cell systems are characterised and the parameters for their control are specified. The controls software ensures short adaptation cycles and development times in this process. Among our activities, our core competence is the development of components and complete fuel-cell systems, which are characterised both by simplicity of operation and high reliability. For special applications, it can be necessary to modify components or develop new ones. The in-house fine-mechanical workshop allows us to implement our newly conceived designs. Three-dimensional software is used to optimally fit components into the housing. In this way, we can react to clients' wishes concerning the system geometry, or form factor, in the packaging. As a result, we can present compact systems with high power densities.

Together with the Masterflex AG company in Gelsenkirchen, Fraunhofer ISE is developing a portable fuel-cell system with a continuous power of 50 W. The stack consists of nine single cells. A pump supplies the fuel cell with atmospheric oxygen. The "Mobile Power Box" provides an autonomous power supply for electronic appliances. For example, a metal hydride cartridge with 300 Wh supplies electricity to a laptop for at least 10 hours.

The concept makes provision for attaching storage units of different dimensions. Great flexibility in application is achieved in this way. In addition, DC/DC converters can be used to set defined voltage levels at the output.

Stable continuous operation was convincingly demonstrated during the eight-hour exhibition periods at the Hanover Trade Fair HMI 2003. We have made significant progress with a new method of delivering hydrogen to the system. Combined with newly developed controls, stable operating behaviour and user-friendly handling is guaranteed. Thus, market introduction is on the agenda for 2004.

We have developed another fuel-cell system with the industrial partner, Ambient Recording GmbH. The compact 40 W system supplies power to a professional camera throughout a complete recording day (8h). Up to now, the cameraman's work was frequently interrupted by the need to change batteries. This problem is now solved with a fuel-cell system that was tailored specifically to this application. There are no complications involved with handling, as the system is attached to the camera. The system is constructed of four stacks, each with 19 single cells. Ventilators supply atmospheric oxygen to the fuel cells, which are open on the cathode side.

Fig. 3: Professional TV camera with a fuel-cell system, including two metal hydride storage cartridges, each with 100 Nl hydrogen (cover removed).

Characterisation provides Criteria for Optimising Fuel Cells

We analyse PEM fuel cells with the help of numerical models. These are used to calculate the temperature distribution, the water content of proton-conducting membranes, the gas humidity content and the gas concentration in the cell. We can extract characteristic parameters from measured data by model-based analysis of impedance spectra. Multi-channel impedance spectroscopy is used to obtain spatially resolved information on the operating conditions of segmented test cells.

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Understanding of the loss mechanisms in the electro-chemical energy conversion process is essential for the optimisation of fuel cells. To this purpose, we analyse the different operating states of PEM fuel cells for use in portable electronic appliances. One example of our current investigations is a mathematical model for a self-breathing PEM fuel cell in a planar configuration. Our model takes account of all essential transport processes, i.e. mass, heat and charge transport. Beyond that, the electrochemical reactions in the electrodes are also included (fig. 1).

Our services include analysis of the coupled water and thermal budgets of PEM fuel cells. We have developed a dynamic fuel-cell model that calculates the transport of liquid and gaseous water in the porous gas-diffusion layers in two dimensions. This allows us to simulate the flooding of the gas diffusion layer and drying out of the membrane as a function of time.

Using our equipment for multi-channel impedance spectroscopy, we measure spatially resolved impedance spectra on segmented test cells. To analyse the impedance spectra, we use one-dimensional models which take account of gas enrichment in the diffusion layer and the electrode. By fitting calculated impedance spectra to measurements, we can identify the parameters of the gas diffusion layer and the electrode on the cathode side.

Anode: molar fraction of water (isometric lines), Membrane: water flow
Cathode: molar fraction of oxygen

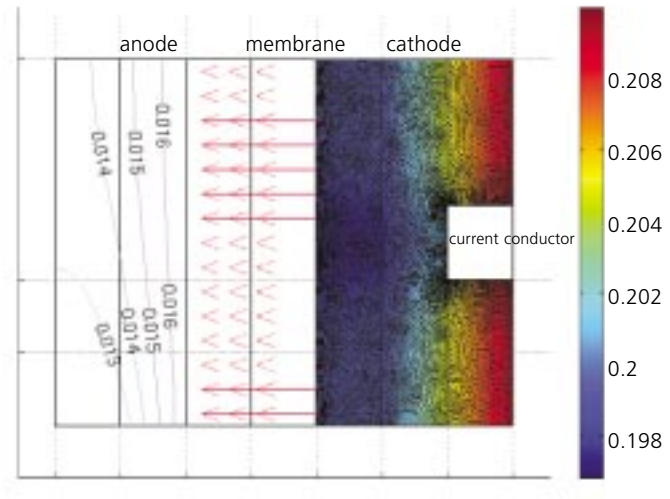


Fig. 1: The graph shows a simulation result that was calculated with our model for self-breathing fuel cells. The electrons are collected at the cathode of the fuel cell by the rectangular metal conductor. Air diffuses into the cell through the zone that is not covered by the conductor. The arrows show the direction of the electro-osmotic transport of water from the cathode to the anode. The isometric lines on the left side show the distribution of the molar fraction of water vapour in the gas channel and in the gas diffusion layer of the anode. A section of the discretisation grid is shown on the cathode side (right).

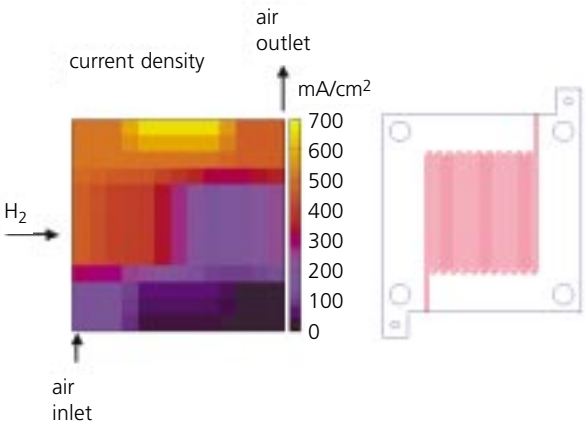


Fig. 2: We characterise PEM fuel cells by spatially resolved measurements. The graph shows the spatial distribution of the electric current density for a segmented test cell with a meander-formed gas distribution structure. It is evident that the current density is distributed inhomogeneously, i.e. the cell is not operated optimally. Analysis of the operating behaviour led to an improved design for the fuel cells.

Miniaturised Electrolyser System approaching Series Production

We develop electrolyser units in the lowest power range to produce pure hydrogen and oxygen according to clients' specifications. The most recent example is a zero-maintenance system in a design suitable for series production, which serves as a basis for switching gasochromic windows.

Thomas Jungmann, **Ursula Wittstadt,** Beatrice Hacker, Josef Steinhart, **Wolfgang Graf,** Andreas Georg

Gasochromic windows, as developed by colleagues working on windows and facades, are solar-control elements of modern architecture which allow users to switch the transmission of light and heat through windows. For the switching processes, they require hydrogen or oxygen with a high degree of purity. In our work on hydrogen technology, we have developed a miniaturised electrolyser unit for this application, which can be integrated into the facade.

The structured polymer plates for the electrolyser unit offer the advantage of inexpensive series production by injection moulding. A metal surface coating provides the electrical conductivity needed for electrolysis. In order to simplify assembly, we have chosen the geometry such that the individual parts can be snapped together and at the same time, the membrane-electrode assembly (MEA) is held in position.

As the gas supply units are connected directly to the gasochromic panes, the produced gas is dried within the electrolysis cell. In this way, we achieve a completely closed system. The gases that are no longer needed after switching are recycled and thus remain within the system. Due to this deliberate recovery of water, the system can be operated without need of maintenance.

The work is carried out in close co-operation with our partners, Interpane Entwicklungs- und Beratungsgesellschaft mbH & Co. KG, Werner Herr GmbH and FuMA-Tech GmbH, and is supported by the BMWA (German Federal Ministry of Economics and Labour).

Fig. 1: Complete system including an electrolyser unit to supply gas to gasochromic windows. In the foreground is the electrolyser unit (yellow) and the transparent tank housing (70 mm x 120 mm x 40 mm). Behind them is the pump (red/silver).

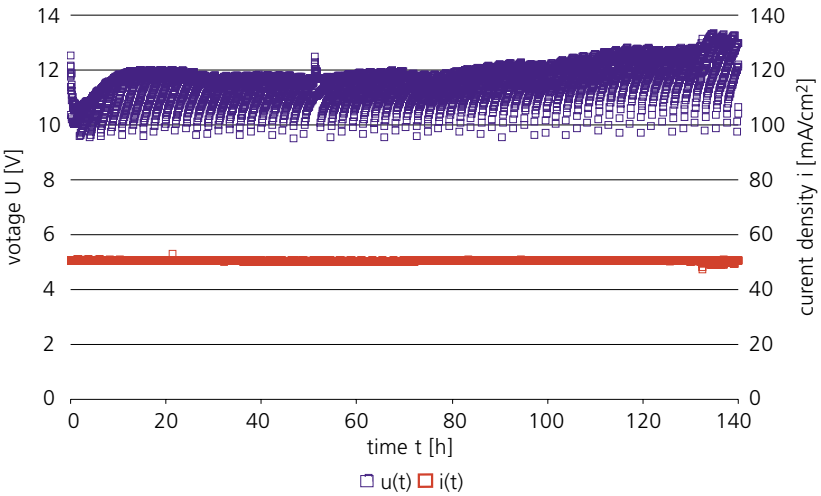


Fig. 2: Long-term test of an electrolyser system. Ageing is accelerated in contrast to real operation by applying short, frequent switching cycles. Laboratory measurements of current density (i) and voltage (U) with a cycling period of 3 minutes over 100 hours (t) correspond to real operation for more than two years. With these investigations, we can draw conclusions about the ageing performance of systems that are installed in field tests.

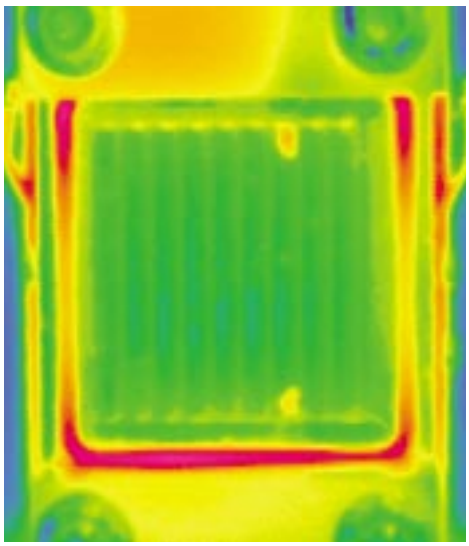


Fig. 3: Thermograph of an electrolyser unit (app. 40 mm x 60 mm) during operation. The homogeneous green colour in the reaction zone (centre) indicates homogeneous and lossless production of gas in the distribution structure. This method is used to identify less reactive zones, which generate less heat. It serves as a basis to optimise distribution structures and membrane-electrode assemblies.

Reliable Hydrogen Production for the Household Energy Centre of the Future

Product gas gained from reforming must contain the lowest possible concentration of CO. Based on a new methanisation reactor, we have developed a fully automated reformer system, which converts natural gas into hydrogen suitable for PEM fuel cells, with a CO content < 20 ppm in all operating states. The reformer will be integrated into a fuel-cell combined heat and power (CHP) plant next year.

Thomas Aicher, Robert Szolak

Fig. 1: View of part of the newly developed natural gas reformer. The components for dispensing the educts and the burner supply can be seen. Automatic burner control (upper right), controls for the feed (centre), feed lines (below).

Fig. 2: Complete view of the thermally insulated, natural gas reformer. The reformer reactor itself is in the lower part of the system, the CO shift and methanisation reactors are located above it.

Fuel-cell CHP plants are the household energy centres of the future. For a demonstration system, we developed a new natural gas reformer, which produces hydrogen for fuel cells. Under full load conditions, the fuel-cell CHP plant will supply 2 kW electricity and 5 kW thermal energy at 60 - 80 °C.

With this natural gas reformer, we succeeded in developing a fully automated system which produces hydrogen with less than 20 ppm CO, safely and reliably, in the range from 50 to 100 % load. The product gas of the reformer is suitable for the PEM fuel cell belonging to the complete system.

To reliably achieve CO concentration values below 20 ppm, we developed a new methanisation reactor (selective methanisation of CO), which can maintain the temperatures in the reactor within a narrow range. This guarantees that the methanisation reaction takes place under optimal conditions and the CO concentration remains well below 20 ppm. This became feasible with a new type of air cooling, which allows the temperature in the reactor to be controlled very accurately. The methanisation catalyst is a ceramic honeycomb which is coated with a mixture of noble metals. It was produced by one of our industrial partners.

The PEM fuel cell for the system will be supplied at the beginning of 2004 by our project partner, ZSW (Centre for Solar Energy and Hydrogen Research). In autumn, 2004, the components will be integrated into a fuel-cell CHP plant at WBZU (Fuel Cell Further Education Centre) in Ulm.

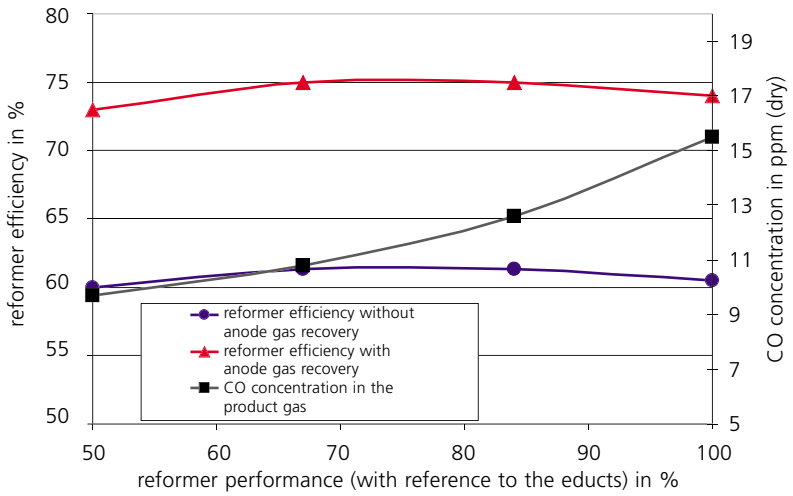


Fig. 3: Measured efficiency values for the system - without recovery of remnant anode gas from the fuel cell (blue curve). After the reformer system has been integrated into the fuel-cell CHP plant, the exhaust gas from the anode of the fuel cell, which contains unconverted hydrogen, will undergo combustion in the burner of the reformer system. This will increase the efficiency value further (red curve). The graph also shows the measured CO concentration in the product gas of the reformer (black curve).

Diesel to Synthesis Gas - Marine Auxiliary Power Unit

We developed an autothermal diesel reformer as an essential contribution to an auxiliary power unit with fuel cells for use on ships. This system converts diesel with air and water vapour into synthesis gas. The central component in the development was the reactor, which guarantees optimal mixing of the reaction educts to prevent the formation of soot, which is often a problem in reforming diesel.

Thomas Aicher, Christian Siegel

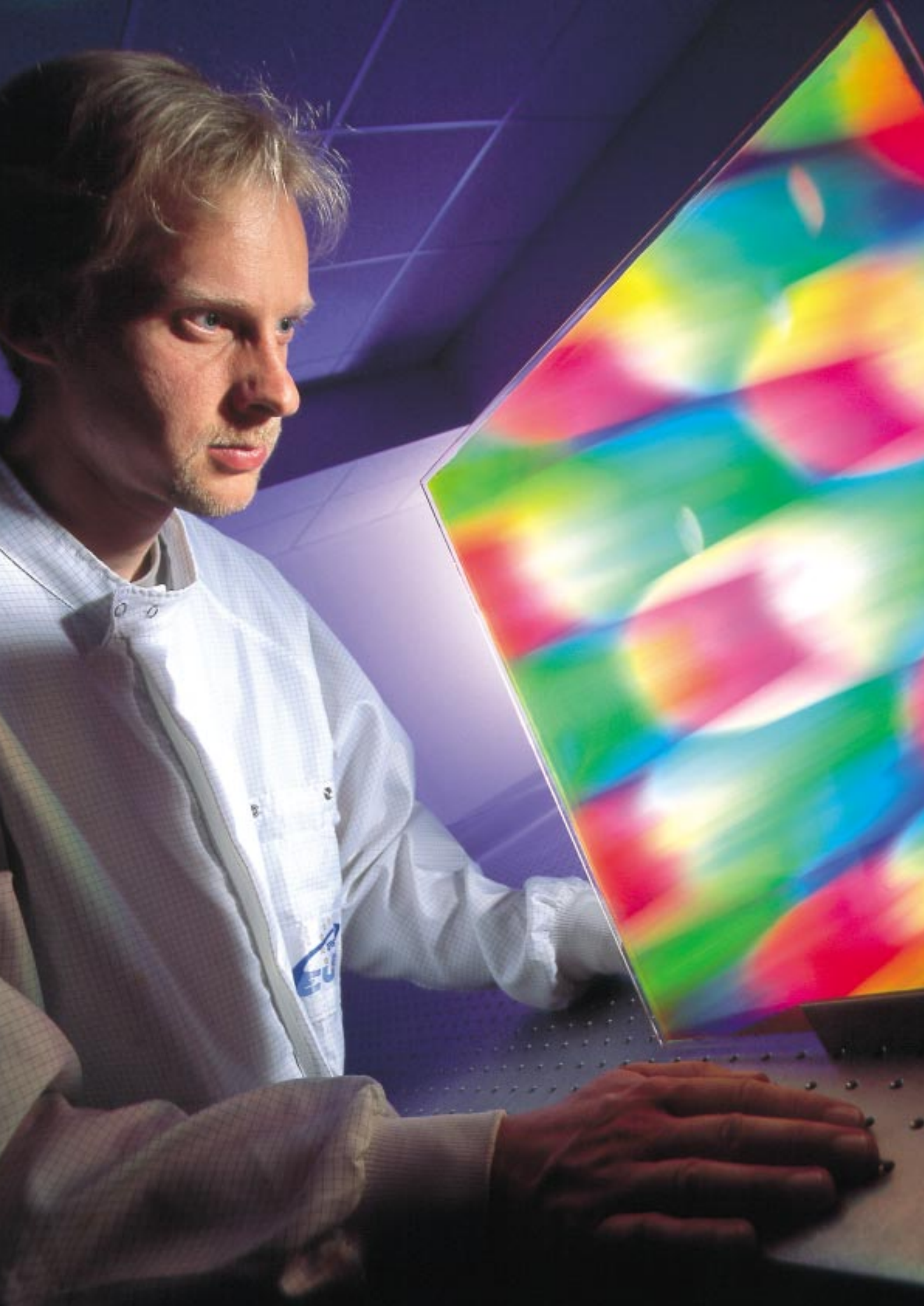
The conversion of liquid hydrocarbons to hydrogen is a central process in the development of auxiliary power units for large vehicles. We planned and constructed a reformer system that converts diesel into synthesis gas for the auxiliary power unit of a ship (500 kWel). The synthesis gas, a mixture of hydrogen and carbon monoxide, serves as fuel for a molten carbonate fuel cell (MCFC).

The system is based on the autothermal reforming process, in which diesel is converted on a catalyst surface with water vapour and air at 750 to 850 °C. We paid particular attention to the flow distribution in the reactor to ensure that the feed components are optimally mixed, preventing soot formation.

The newly developed reactor can also be used for autothermal reforming of other liquid hydrocarbons such as petrol and kerosene.

The diesel reformer system was developed as part of a project with the Italian industrial partner, Ansaldo Fuel Cells S.p.A, and produces enough synthesis gas for a 20 kW_{el} MCFC. Based on the development work at Fraunhofer ISE, this system will be upscaled by a factor of 15 and constructed during 2004. It will be combined with a 350 kWel MCFC to form a "technological demonstrator", which will not yet cross the oceans of this world, but should at least be tested aboard a ship.

Fig. 1: Exploded view of the reactor, with the inlet at the top and the outlet at the bottom. The reactor honeycomb is not shown. The reactor pipe has a diameter of 124 mm and a length of 400 mm.



Decorative aspects of spectral dispersion of light: Interference lithography can be used to apply thousands of millions of miniature structures, in micrometre or nanometre dimensions, to a surface in only a few minutes. The results include anti-reflective surfaces, displays with better contrast or sun-shading for windows and facades.

Special Areas of Expertise

In addition to the work described in the previous five chapters, Fraunhofer ISE also applies its special expertise to research and development in sectors beyond solar energy applications or in other solar technological sectors than those covered in the previous chapters. The Institute uses this work to gain access to new strategic areas. Seawater desalination and drinking water purification are described in the following articles. Similarly, specialised knowledge such as that existing on micro-structured functional surfaces is also applied to other technological areas. An example from laser technology is presented here.

Organic Lasers based on Micro-Structured Substrates

Within the project on "Tunable Photonic-Crystal Lasers based on Polymers", which is funded by the BMBF (German Federal Ministry for Education and Research), novel tunable organic lasers are being fabricated in co-operation with working groups at the Universities of Karlsruhe and Kassel. At Fraunhofer ISE, we produce polymer substrates that are micro-structured by interference lithography and serve as the basis for the organic lasers.

Andreas Gombert, Karen Forberich

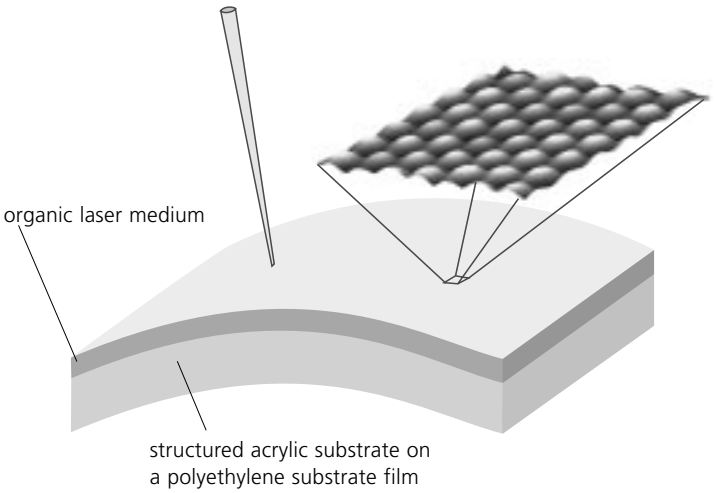


Fig. 1: Organic laser based on a flexible micro-structured polymer substrate. A scanning electron micrograph of the substrate is shown. The active laser material is optically pumped by another laser that is focussed on the sample. The operating principle of such a laser is described in the article.

Organic lasers are novel lasers which promise to be manufactured inexpensively due to the materials used. They are produced by applying an organic semiconductor onto a micro-structured polymer substrate (fig. 1). This substrate can be flexible and large in area.

If the semiconductor is then optically pumped, the micro-structures back-scatter some of the light emitted by the semiconductor such that the back-scattered partial waves interfere constructively. This sets up the feedback and amplification processes needed for laser operation (fig. 2).

The laser wavelength is determined by the period of the micro-structure, the refractive index of the semiconductor and the coating thickness of the deposited semiconductor layer. Thus, different laser wavelengths can be generated on a micro-structured substrate by local variation of the period.

Our project partners at the Universities of Karlsruhe and Kassel investigate the optical characterisation and synthesis of suitable semiconductors. At Fraunhofer ISE, we produce the required micro-structured substrates, drawing on our long experience in generating micro-structured surfaces by interference lithography, particularly over large areas of up to 0.5 m^2. These surfaces are used in many optical applications, e.g. for suppressing reflection or redirecting light.

Interference lithography involves initially splitting a laser beam into two or more component beams, which are superimposed again at the surface of a glass plate that is coated with a light-sensitive film, so-called photoresist. The interference pattern from the laser beams is transformed into a surface profile in the photoresist by exposure and subsequent development. A nickel copy of this profile can be produced by electro-forming, with which in turn larger amounts of polymer can be embossed.

In contrast to our previous work, the object in this project is not to create homogeneous structures over the entire photoresist plate, but to vary the microstructures over the substrate. To achieve this, we are developing and testing concepts which allow samples to be produced with different grating periods. The grating period is varied both discretely and continuously for different samples.

For structures created by interference lithography, the grating period is determined by the incidence angles of the two interfering beams on the photoresist plate. Methods to locally change this angle to the substrate were sought. By exposing the plates with a plane wave and a strongly diverging wave, we achieved a continuous variation in the period of 70 nm over a distance of 75 mm.

To vary the grating period discretely, we designed and constructed an automated, rotatable sample holder. In this design, one beam is directly incident on the sample, while the other is reflected by a mirror that is mounted at a right angle to the sample. In this way, a symmetric interference pattern is created, whereby the period depends only on the rotation angle of the sample holder. The photo plate can be transported behind a slit-formed mask, so that a separate field is exposed for each period. A sample that was prepared with this procedure is shown in fig. 3.

With the automated exposure equipment, structures can now be developed very efficiently also for other applications by using combinational methods.

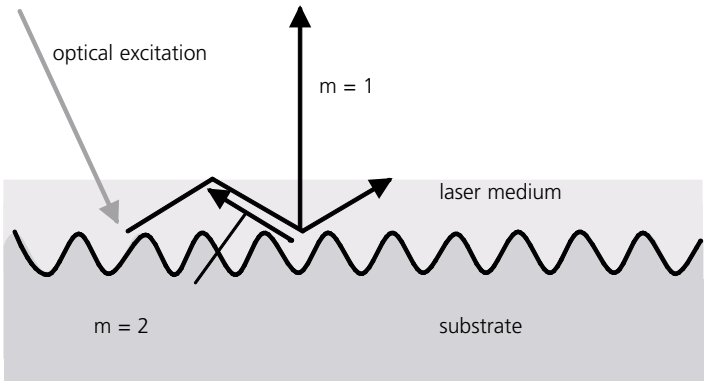


Fig. 2: Operating principle of an organic laser based on a micro-structured substrate. The second order of diffraction (m = 2) of the micro-structure is used for the laser feedback loop and the first order (m = 1) is used to couple out the laser light perpendicularly to the surface.

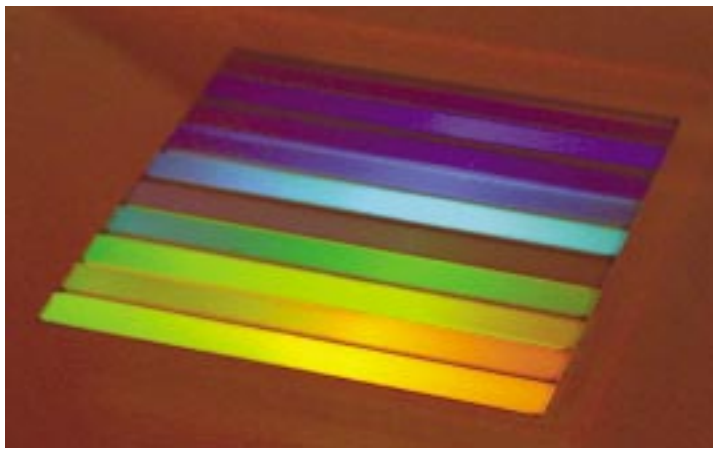


Fig. 3: Micro-structured sample, produced with the equipment that was newly constructed within this project. Individual strips are sequentially exposed with different grating periods by changing the angle between the sample and the incident light beams and transporting the sample behind a mask. Ten strips are shown, each with an area of 5 mm x 50 mm, which have grating periods ranging from 250 nm to 385 nm.

Seawater Desalination with Solar Energy

There is often a lack of clean drinking water in arid and semi-arid regions. At the same time, the solar radiation levels in these areas are often very high. These are excellent conditions for using solar energy to desalinate, purify and distribute water. This could help to prevent five million people from dying each year due to diseases caused by poor-quality supplies of drinking water.

Matthias Rommel, Joachim Koschikowski*, Marcel Wieghaus

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Fig. 1: View of the rolling machine to produce membrane distillation modules. The machine is equipped with eight rollers for rolls of material, and ten guiding rollers to form laminates of different materials. Prototypes and small series can be fabricated with the machine.

Numerous processes are known for seawater desalination, and large technical plants are in operation throughout the world. However, in remote areas with only limited infrastructure and no access to central supplies or electricity grids, small, decentralised, stand-alone systems driven by solar energy are of greatest interest to prepare drinking water from brackish water or seawater. These could supply smaller settlements or isolated farms with clean drinking water.

Within two new research projects, we are currently developing desalination systems that are driven by photovoltaics or thermal solar energy. The desalination process applied is based on membrane distillation. Our work is targeted toward systems that can be operated off-grid and which can provide desalinated water in quantities between 150 and 20,000 litres per day. The newly developed rolled modules are designed to require energy of only 100 kWh_{th} per m^3 of desalinated water. The thermal energy for the process must be supplied at a temperature level of about 80 °C. Process-heat collectors will be used to supply this in the test systems of the projects.

Both projects are supported by the EU. Our international research partners come from Morocco, Egypt, Jordan, Turkey, Spain and Germany.

Photovoltaically Powered Drinking Water Purification for Rural Areas remote from the Grid

Purification of drinking water in rural areas remote from the grid presents a multi-facetted challenge, not only concerning technical issues. The combination with photovoltaic power supplies requires particular care.

Ulrike Seibert, Andreas Steinhüser, Felix Holz

Regions without electricity grids often also lack good-quality drinking water. The obvious approach of powering a local drinking water supply with photovoltaic electricity demands careful planning.

For instance, the electric currents which occur when pumps are switched on play a much greater role than systems engineers for water supply systems usually assume. Using a testing stand that was specially designed to characterise pumps, we determine the data that make it feasible to dimension the systems reliably.

To support reliable operation with minimal maintenance and use of chemicals, we optimise the cleaning, flushing and energy-efficient disinfection strategies for filtration and membrane systems.

Further, we characterise the membranes used for drinking water purification and production. This sector encompasses micro-filtration, ultra-filtration, nano-filtration and reverse osmosis. The aim is to identify materials and material combinations that are particularly suited for use under harsh environmental conditions.

Fig. 1: Testing the disinfection and desalination performance of decentralised systems for drinking water purification.

As part of an international consortium which we co-ordinate, we are currently preparing a market overview of the small systems available for sea-water desalination. The results form the basis for optimising water supply systems using combinations of photovoltaics and other renewable energy sources. The project, which is planned to run for several years, also takes account of the nationally specific, non-technical boundary conditions, which should be considered during the introduction of stand-alone drinking water systems.

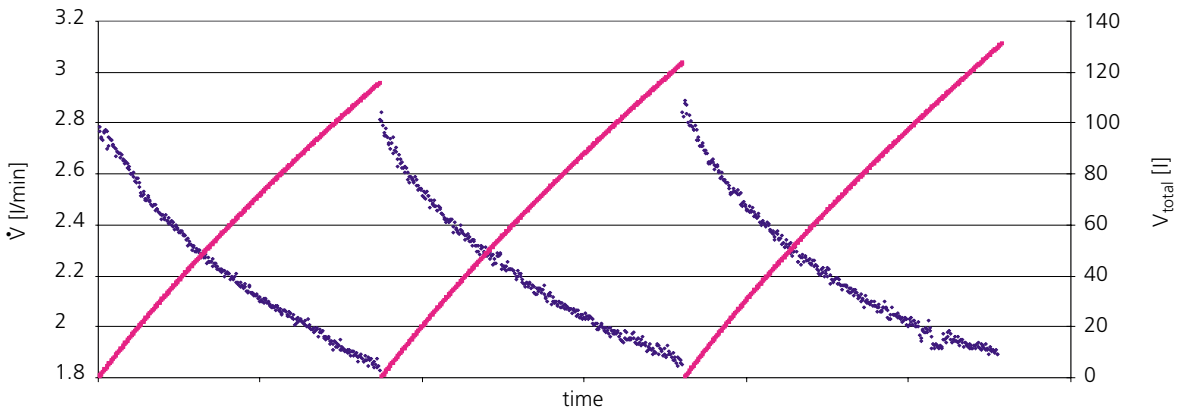


Fig. 2: Behaviour of a micro-filtration system during purification of untreated water with a high sediment content. The blue curve shows the decrease in the specific flow, the red curve shows the total amount of drinking water that is prepared during the same time. The filters that are used in drinking water purification block up at different rates, depending on the quality of the untreated water. The filter performance can usually be improved by regular flushing. This lengthens the operating periods and reduces the need for maintenance. Suitable flushing strategies thus increase the economic feasibility of the system, and are often essential if long-term usage is to be achieved.

Service Units

Quality assurance plays a major role in all types of solar energy systems. This is the only way to gain and strengthen sustainable confidence in sustainable technology. At Fraunhofer ISE, we support our clients by evaluating products according to accepted quality criteria.

We do this by measurement, testing and evaluation, as well as calibration and certification of specifications according to national and international standards and procedures. The test objects range from individual components to complete systems. Our measurement and testing laboratories are independent and internationally recognised. We can test your products independently of the weather under standard conditions in the laboratory, or under realistic application conditions outdoors. Testing is quick, reliable and favourably priced, and the results are confidential. In some areas, we pass on our knowledge on testing and qualification procedures in training seminars.

Our spectrum of services includes a calibration laboratory for solar cells and modules, a thermal/optical testing laboratory, a lighting measurement laboratory, daylighting measurement rooms, a facade testing facility, a test stand for solar desiccant cooling, a testing centre for thermal solar systems, a battery testing laboratory and an inverter characterisation stand.

Contact Partners

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	Solar air collector test stand	Carsten Hindenburg	Tel.: +49 (0) 7 61/45 88-53 53 E-mail: Carsten.Hindenburg@ise.fraunhofer.de
Solar Air-Conditioning			
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	Facade testing facility FASTEST	Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fraunhofer.de
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	Test stand for compact heating and ventilation units	Dr Andreas Bühring	Tel.: +49 (0) 7 61/45 88-52 88 E-mail: Andreas.Buehring@ise.fraunhofer.de
Photovoltaic system components			
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	Lighting measurement laboratory	Norbert Pfanner	Tel.: +49 (0) 7 61/45 88-52 24 E-mail: Norbert.Pfanner@ise.fraunhofer.de
	Battery testing laboratory	Rudi Kaiser	Tel.: +49 (0) 7 61/45 88-52 28 E-mail: Rudi.Kaiser@ise.fraunhofer.de

Service Units

In our fully automated test rig, characteristic curves for pumps are recorded, start-up currents are measured and the performance of the pump under load conditions is determined. These data are the input for optimising system designs.

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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 the dimensioning and authorisation of photovoltaic systems.

Britta Hund, Klaus Kiefer,
Frank Neuberger, Wilhelm Warta

The PV Calibration Laboratory at Fraunhofer ISE (ISE CalLab) is one of the internationally leading laboratories in this field. Round-robin comparisons between these laboratories and the Physikalisch-Technische Bundesanstalt (German Standards Institute) in Braunschweig ensure constant quality control. Internationally renowned manufacturers and also TÜV Rheinland, the German technical authorisation body, have their reference cells measured by ISE CalLab. Scientists come with their new developments from all over the world to Freiburg, for a measurement from ISE CalLab is recognised by scientific journals and at conferences.

Thanks to our long years of experience in PV measurement technology and the extensive research background at the Institute, we offer excellent service and security to our clients:

- accurate and reliable results, which are guaranteed by regular participation in round-robin tests with other internationally recognised measurement laboratories
- observation of international standards in all calibration steps and in the use of reference elements and measurement facilities
- rapid, non-bureaucratic processing
- confidentiality guaranteed

Cell calibration - references for research and industry

We undertake complete characterisation of solar cells and detectors with areas up to 30 x 30 cm^2:

- calibration of standard solar cells
- calibration of concentrator cells and tandem cells
- calibration of reference cells
- spectral response measurement
- determination of the temperature dependence of the current
- determination of the annual efficiency value of solar cells

Module calibration - an efficient quality control method

Increasing numbers of wholesalers and installation firms commission measurements of random samples from large orders of solar modules. The primary aim is to check compliance with the manufacturers' specifications.

If the solar modules are already mounted on the roof and electrically connected, later characterisation is usually very complicated.

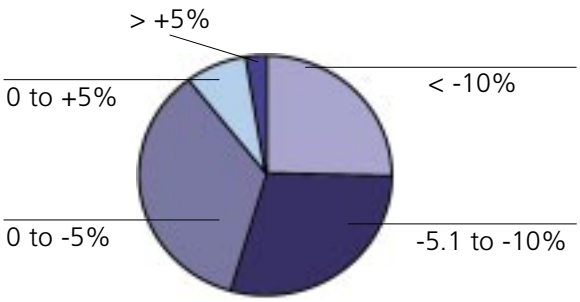

Fig. 1: 55 % of the modules measured deviated by more than the customary manufacturer's tolerance of ± 5 %.

We characterise PV modules up to an area of 2 x 2 m^2:

- module measurement with a pulsed solar simulator
- outdoor module measurements
- determination of the NOCT temperature and power
- measurement of the angular and temperature dependence of the module parameters

Internet

For detailed information, simply consult our Internet site at www.callab.de. From there, you can also place measurement orders very simply by email.

Testing Centre for Thermal Solar Systems

We operate an outdoor test stand. Our testing centre is authorised by DIN CERTCO and full accreditation by DAP (Deutsches Akkreditierungssystem Prüfwesen) is the goal for 2004 . 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.

Carsten Hindenburg, Joachim Koschikowski, Matthias Rommel, Arim Schäfer, Thorsten Siems

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

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 targetted 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

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

Beyond that, we offer the following services:

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

Test Stand for Desiccant-Cooling Air-Conditioning Systems

For two years, we have been running a test stand for desiccant cooling systems. The integration of two solar collector arrays and a buffer storage tank means that the interaction with solar radiation can be investigated under realistic conditions. We support equipment manufacturers in developing components and systems and optimise different connection options according to energy-relevant criteria. Flexible hydraulics and the option of adding outdoor air conditioning mean that we can investigate very diverse hydraulic configurations and optimise their energy consumption. The test stand makes rapid measurements feasible, which are independent of user behaviour.

Carsten Hindenburg,
Volker Kallwellis, Mario Motta

Fig. 1: The air-handling unit is the core of the test stand for desiccant cooling systems.

Component development

The modular construction of the test stand means that different components, such as sorption wheels, heat recovery rotors or humidifiers, can be exchanged independently of each other. Depending on the client's requirements, we can develop these components further or measure them in situ. We can also draw on results from our thermo-analytical laboratory, where sorption materials are characterised and optimised.

Optimisation of complete systems

Extensive measurement and controls technology also allows us to characterise and improve desiccant cooling systems as complete units. We can then optimise these with respect to their energy and water consumption. Simulation programs, some of which were developed at the Institute, shorten the measurement cycles and thus the total development time.

Development of standard controllers

The control performance of five different system concepts can be investigated simultaneously with the test stand due to the flexibility of the hydraulic circuit - ideal conditions for developing standard controllers for desiccant-cooling air-conditioning systems.

Field tests of solar collector arrays

Using the test stand, we can also measure complete arrays of solar hot-water collectors or solar air collectors with an area of up to 20 m^2. We offer the following services:

- measurement of the system efficiency value of solar collector arrays for defined loads. This enables realistic yield prediction for air-conditioning applications, domestic hot water or space-heating support.
- specific development of collectors for air conditioning.

Customised design software

We develop design and simulation software on commission to clients. In doing so, we continually draw on our experience with the test stand and in demonstration projects.
The programs can be used to calculate air-conditioning systems, both of the conventional type and those applying desiccant cooling. If desired, hydraulic circuits including solar energy components or connections specified by the client can be modelled. Program modules for cost calculations are used to compare different configurations not only with regard to energy but also economically.

Test stand specifications

- rated air flow rate: 4000 m^3h^{-1}
- 20 m^2 flat-plate collectors with liquid heat-transfer media
- 20 m^2 solar air collectors
- 2 m^3 buffer storage tank
- auxiliary heating with a gas boiler
- simulation of any outdoor air conditions
- simulation of room loads.

For further information, see also www.solar-cooling.de

Measurement of Building Facades 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, Christian Reise, Jan Wienold

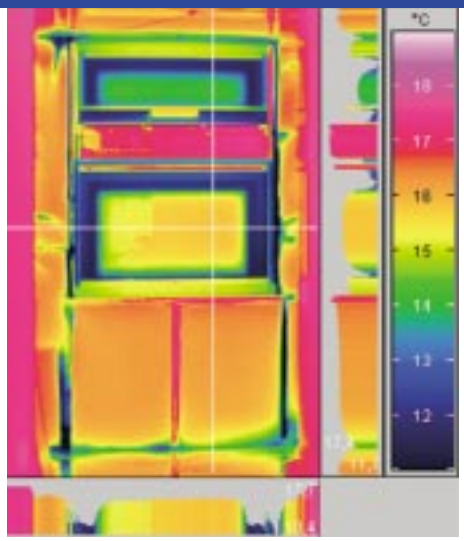

Fig. 1: Thermographic image of a facade module occupying the full height of a test cabin (viewed from indoors).

Thermal-optical measurement laboratory TOPLAB

Existing measurement procedures such as those specified in DIN EN 410 are not adequate to describe the properties of advanced glazing and facade 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 facade
- integrated photovoltaics.

Examples of equipment:

- solar calorimeter to determine the total solar energy transmittance of transparent components and sun-shading devices
- angle-dependent transmittance and reflectance measurements with a large integrating sphere
- thermal resistance measurements on glazing units according to DIN 52612
- measurement of the angular distribution of transmitted and reflected light with a photogoniometer

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 facade orientation can be chosen. Meteorological data and the global illuminance on the vertical plane of the facade 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 facade systems

Facade testing facility, FASTEST

In addition to characteristic values obtained under well-defined boundary conditions in the laboratory, we measure complete facades under real climatic conditions. Eight test rooms, all with the same facade orientation, are available to us. There, we investigate the dynamic performance of the test facades and record data on the temperatures in the internal cabins and within the facade 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 facade. The optimisation of controllers can be experimentally validated. In combination with building simulation, the measured data serve to validate facade models in programs such as ESP-r and TRNSYS.

Testing and Measurement in Buildings

We check your building with on-site monitoring and measurements.

Andreas Bühring, Sebastian Herkel,
Jens Pfafferott, Christian Reise, Jan Wienold

Air-exchange measurements with tracer gas

To ensure good room air quality, it is important that the specified air-exchange rates in buildings and air flow rates in ventilation systems be observed.

Using gas chromatography to measure the decrease in concentration of a tracer gas, we determine the air-exchange rates of rooms during operation. We measure the air flow rate with the constant injection method to analyse ventilation systems.

Our measurement method meets the specifications of VDI 4300, sheet 7. It allows SF_6 to be used as the tracer gas, even in occupied buildings, if an electron capture detector is used for the gas chromatography.

Test stand for compact heating and ventilation units

We support our clients in developing compact heating and ventilation units with integrated exhaust-air heat pumps.

Laboratory testing

Using our test stand for ventilation equipment, we measure the energy efficiency of the complete units and their components. Stationary test conditions can be selected within a wide range. As the test stand has been automated, we can also set dynamic, changing conditions, e.g. according to the standard, EN 255-3. Based on the measurements, we make recommendations to optimise the components and their interaction.

Monitoring

We are measuring the performance of compact heating and ventilation units from different manufacturers in a field test in various occupied solar passive houses. The data is analysed daily, so that we can immediately recommend how operation can be optimised. Possible faults are identified quickly, and corrected. We make suggestions to optimise equipment and the controls on the basis of these measurements.

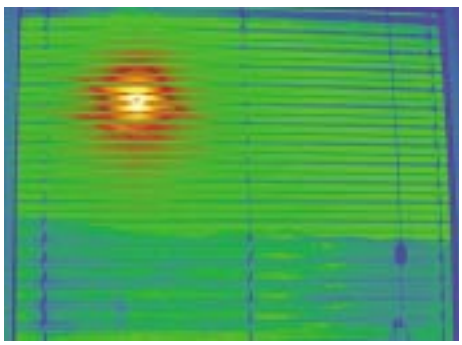

Fig. 1: Luminance measurements of a daylighting system in a rotatable measurement room.

Fig. 2: Visualisation of air currents in a room to check the air exchange in buildings.

Fig. 3: Automated test stand for simultaneous measurement of two ventilation units with integrated exhaust-air heat pumps.

Characterisation of Inverters

Inverters represent the link between DC voltage sources such as photovoltaic generators or fuel cells on the one hand, and the public AC grid or an island grid on the other. The control behaviour and efficiency of the inverter have considerable influence on the performance of the system. In addition, many standards have to be observed, which ensure the safety of service personnel, guarantee reliable grid operation and prevent electromagnetic disturbance of other electric equipment. We offer the characterisation of inverters as a service to our clients.

Bruno Burger, Jürgen Ketterer,
Rainer Schätzle, Heribert Schmidt

We characterise inverters in our laboratory with respect to:
- efficiency
- MPP tracking performance
- electromagnetic compatibility (EMC)
- burst and surge tests
- compliance with the relevant standards
- user friendliness

The following energy sources are available for testing the inverters:
- various freely configurable solar generators up to 10 kW
- six programmable solar simulators and
- four DC power supplies with different voltage ranges up to a power of 21 kW.

Using precise power analysers, we can accurately measure the efficiency of the inverters. A well-equipped EMC measurement chamber, with a floor area of 4.8 m x 3.1 m and a height of 3 m is available to characterise the EMC behaviour. If desired, experienced power-electronics engineers can modify the inverters during the measurements so that they comply with the EMC standards. Our staff, who work in standardisation committees, are happy to advise you on technical questions or clarification of the standards which must be observed.

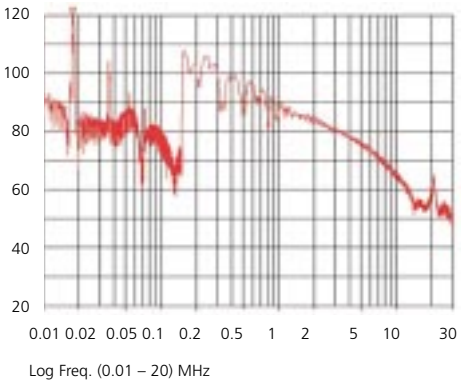

Fig. 1: EMC measurement of the AC side of an inverter without a transformer. The interference voltage generated by this inverter exceeds the allowable limits.
x axis: frequency in MHz
y axis: interference voltage in dBµV

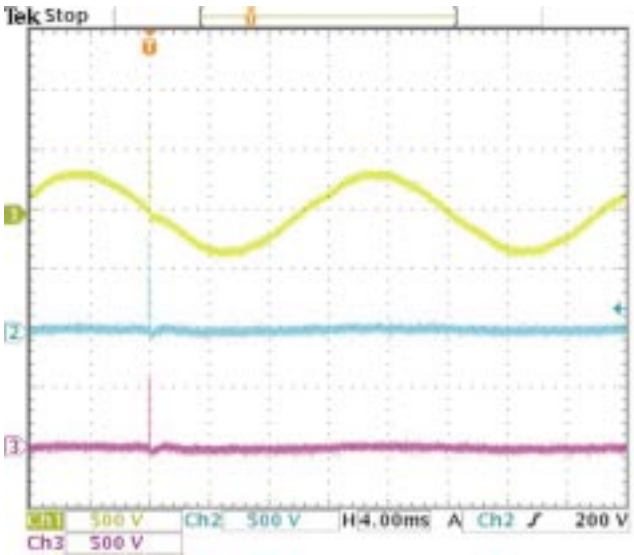

Fig. 2: Surge pulse with an amplitude of 1000 V (spike in all three curves) in the grid voltage (yellow sinusoidal curve, top), and its effect on the DC-link voltage of the inverter (blue, centre) and the voltage at the power semiconductor components (pink, bottom). Result: This equipment is not adequately protected against disturbance pulses. The external disturbance enters the unit unhindered and can destroy the power semiconductor components.
x axis: 4 ms/div
y axis: 500 V/div
The top curve is the grid voltage with 230 V_{eff}. The zero line is indicated at the left for each of the three curves.

Qualification Testing and Optimisation of DC Components for Photovoltaic Systems

Technical reliability and low costs are the key to long-term success for photovoltaically powered DC voltage systems.

Commercially available appliances, such as camping lamps, portable radios and television sets, but also certain system components, often prove not to be sufficiently well adapted for use in photovoltaic systems. Experience shows that maintenance and repair of these systems make up a large share of the operating costs.

We offer our clients measurements, qualification testing and optimisation of DC appliances, photovoltaic components and photovoltaic systems in three laboratories which are equipped with high-quality instruments and test stands.

Rudi Kaiser, Norbert Pfanner

Fig. 1: Integrating-sphere photometer to measure the luminous flux of DC lamps and light sources.

DC Testing and Development Laboratory

We measure, test and evaluate complete photovoltaic systems or individual components with respect to quality criteria such as:
- energy consumption and efficiency
- operation management performance
- fault performance
- protection against incorrect operation
- electromagnetic compatibility

Long-term tests and stress tests are the basis for making predictions of the lifetime and reliability with practical relevance. As a further service, we offer training courses on measurement and testing in our DC laboratory for technicians and engineers.

Lighting measurement laboratory

We investigate electrical characteristics of PV-powered light sources and lighting systems, such as:
- efficiency
- operation management performance (pre-heating, ignition voltage, operating current and waveforms, etc.)
- fault occurrence.

We also make precise measurements of lighting-technology parameters:
- luminous flux and luminous efficacy
- luminance
- lighting technology performance in operation.

A switching cycle test provides information on the anticipated lifetime of the lighting system in practical use.

Battery testing laboratory

By conducting comprehensive qualification tests for battery storage units, we support our clients in selecting a suitable battery type, and optimal operation management and charging strategies. In the tests, we determine the following characteristics for all common types of battery technology:
- capacity of new and used batteries
- charging and discharging curves
- charging performance
- temperature dependence
- efficiency
- self-discharge

Long-term tests in the laboratory or in real systems allow realistic appraisal of the storage unit lifetime.

Facts and Figures

Visiting Scientists

Participation in National and International Associations

Congresses, Conferences and Seminars organised by the Institute

Lecture Courses and Seminars

Trade Fairs and Exhibitions

Patents

Doctoral Theses

Press Releases

New Commercial Enterprise

Lectures

Publications

Abbreviations

Visiting Scientists

Prof. Andres Cuevas
Australian National University
Canberra, Australia
6.-20.8.2003
Research area: analysis of defects in monocrystalline silicon

Alessandro Dama
Dipartimento di Energetica, Polytecnico Milano, Milan, Italy
1.7.2003-29.2.2004
Research area: windows and facades, modelling of internal sun-shading units

José Roberto Flores Hernández
Instituto de Investigaciones Electricas (IEE)
Puebla, Mexico
1.10.2001-30.9.2004
Research area: fuel cells and electrolysis

Prof. Ashok Gopinath
Naval Postgraduate School
Monterey, CA - USA
1.7.2003-30.6.2004
Research area: TPV generator

Dr Daniel Macdonald
Australian National University
Canberra, Australia
17.-30.11.2003
Research area: analysis of defects in monocrystalline silicon

Anders Ødegård
Norwegian University for Science and Technology (NTNU)
Trondheim, Norway
21.8.2000 - 28.2.2004
Research area: Direct methanol fuel cells in the low power range

Prof. Werner Osterhaus
School of Architecture, Victoria University of Wellington, New Zealand
12.10-24.11.2003
Research area: Solar building

Gaute Stokkan
University of Trondheim
1.9.2002-28.2.2003
Research area: characterisation of mc silicon

Prof. Hongmei Yu
Dalian Institute of Chemical Physics
Chinese Academy of Science
Dalian, China
1.7.2003-31.12.2004
Research area: Investigation of membrane-electrode assemblies

Participation in National and International Associations

Bundesministerium für Wirtschaft und Technologie BMWi
Bundesministerium für Wohnungsbau BMWo
- Lenkungsausschuss »Solar optimiertes Bauen«

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

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

Deutsche Gesellschaft für Galvano- und Oberflächentechnik DGO
- Fachausschuss »Mikrosysteme und Oberflächentechnik«

Deutsche Gesellschaft für Sonnenenergie DGS
- Vorstand der Sektion Südbaden

Deutsche Physikalische Gesellschaft
- Arbeitskreis »Energie«

Deutscher Wasserstoff-Verein

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

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

European Fuel Cell Group

European Photovoltaic Industry Association EPIA
- Associate Member

European Solar Thermal Industry Federation ESTIF
- Member

Exportinitiative Erneuerbare Energien
- Kontaktgruppe Verbände

Fachinstitut Gebäude-Klima FGK
- Arbeitskreis »Sorptionsgestützte Klimatisierung«

Fachverband Transparente Wärmedämmung
- Fachausschuss »Produktkennwerte«

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

Forschungsverbund Sonnenenergie FVS
- Sprecher

German Advisory Council on Global Change
- Member

Global Network on Energy for Sustainable Development GNESD
- Member

Global Research Alliance GRA
- Member

Hahn-Meitner-Institut (HMI)
- Wissenschaftlicher Beirat

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«
- Task 28: »Sustainable Solar Housing«
- Task 31: »Daylighting Buildings in the 21st Century«
- Energy Conservation in Buildings and Community Systems ECBCS
- Task 42: »The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems«

International Solar Energy Society Europe (ISES-Europe)
- Governing Board

Kompetenznetzwerk Brennstoffzelle NRW, Nordrhein Westfalen

Passivhaustagung 2003
- Wissenschaftlicher Beirat

Progress in Photovoltaics
- Editorial Board

Fraunhofer-Gesellschaft
- Senat

Renewables 2004
- National Support Group

Symposium Photovoltaische Solarenergie
- Wissenschaftlicher Beirat

Verein Deutscher Elektrotechniker
- ETG-Fachausschuss »Brennstoffzellen«

Verein Deutscher Ingenieure, VDI-Gesellschaft Energietechnik
- Fachausschuss »Regenerative Energien«

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

Weiterbildungszentrum WBZU
»Brennstoffzelle«, Ulm

World Technology Network WTN
- Mitglied

Zeitschrift »Physik Journal«, Wiley-VCH
- Sprecher des Kuratoriums

Zentrum für Solarenergie und Wasserstoff (ZSW)
- Kuratorium

Congresses, Conferences and International Associations

OTTI Energie-Kolleg
Neuntes Symposium »Innovative Lichttechnik in Gebäuden«
Bad Staffelstein, Kloster Banz, 23./24.1.2003

OTTI Energie-Kolleg
Sechstes Fachforum »Innovative Wohnungslüftung«
Regensburg, 28./29.1.2003

OTTI Energie-Kolleg
Fachseminar »Netzferne Stromversorgung mit Photovoltaik«
Freiburg, 5./6.2.2003

Passiv-Haus 2003
3. Tagung und Ausstellung für energie-effizientes Bauen und Sanieren
Böblingen, 14.–16.2.2003

OTTI Energie-Kolleg
Drittes Fachforum »Oberflächennahe Geothermie«
Garching bei München, 18./19.2.2003

7. Internationale Passivhaustagung mit Fachausstellung
Hamburg, 21./22.2.2003

WorldSustainableEnergyDay 2003
Wels, Austria 6./7.3.2003

OTTI Energie-Kolleg
18. Symposium »Photovoltaische Solarenergie«
Bad Staffelstein, Kloster Banz, 12.–14.3.2003

Trinational Energy Conference
Freiburg, 26./27.3.2003

Fraunhofer-Solar Building Innovation Center SOBIC*
Fachseminar »Sommerlicher Wärmeschutz und Tageslichtnutzung in Verwaltungsbauten«
Freiburg, 27.3.03

Tagung von Eurosolar e. V. Energieagentur NRW
Dezentrale Energiespeicherung - Schlüssel zur wirtschaftlichen Entfaltung Erneuerbarer Energien
Wuppertal, 8./9.4.2003

Thermoidraulica Clima
Padua, Italy, 9.–12.4.2003

OTTI Energie-Kolleg
Fachseminar »Photovoltaik Anlagen«
Freiburg, 6.–7.5.2003

3rd World Conference on Photovoltaic Energy Conversion
Osaka, Japan, 11.–18.5.2003

OTTI Energie-Kolleg
13. Symposium »Thermische Solarenergie«
Bad Staffelstein, Kloster Banz, 14.–16.5.2003

EUREC Agency und AEE-INTEC
»Solarenergienutzung im Bürobau«
Graz, Österreich, 30./31.5.2003

ISES Solar World Congress 2003
Solar Energy for a Sustainable Future
Göteborg, Schweden, 14.–19.6.2003

Solar Promotion GmbH und Fraunhofer Solar Building Innovation Center SOBIC*
Solar assisted air-conditioning concepts and practical experience
Freiburg, 25./26.6.2003

OTTI Energie-Kolleg
Kompaktseminar »Solaranlagen erfolgreich verkaufen«
Freiburg, 26.6.2003

Sonderschau Ländliche Elektrifizierung + Industrieforum, zusammen mit C.L.E. auf Intersolar 2003, Freiburg, 27.–29.6.2003

2nd European Polymer Electrolyte Fuel Cell Forum with Exhibition
Lucerne, Switzerland, 30.6.– 4.7.2003

9th International Conference on Thermal Energy Storage Futurestock 2003
Warsaw, Poland, 1.– 4.9.2003

Jahrestagung des Forschungsverbundes Sonnenenergie FVS
Photovoltaik Neue Horizonte
Berlin, 25./26. 9.2003

Fraunhofer ISE
IEA SHC-Task 27 Workshop »Performance of Solar Facade Components«
Freiburg, 6.10.2003

OTTI Technologie-Kolleg
Brennstoffzellen
Berlin, 6./7.10.2003

First Leoben Symposium
Polymeric Solar Materials
Leoben, Austria 6.–7.11.2003

Fraunhofer Solar Building Innovation Center SOBIC*
Fachseminar »Wärmeschutz mit IR-reflektierenden Folien oder Beschichtungen«
Anforderungen an neue Baustoffe aus Zulassungen und EnEV«
Fellbach, 12.11.03

OTTI Energie-Kolleg und Fraunhofer Solar Building Innovation Center SOBIC*
Fachseminar »EMV und Blitzschutz in Photovoltaik-Anlagen«
Freiburg, 27./28.11.03

Fraunhofer-Solar Building Innovation Center SOBIC*
Fachseminar »Leichte Baustoffe – thermisch schwer«
Freiburg, 3.12.03

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

Lecture Courses and Seminars

Dr Dietmar Borchert
Photovoltaik
Vorlesung SS 03
Technische Fachhochschule Georg Agricola Bochum

Dr Bruno Burger
Leistungselektronische Systeme für regenerative Energiequellen
Vorlesung WS 03/04
Universität Karlsruhe

Dr Andreas Gombert
Mikrostrukturierte Oberflächen mit optischen Funktionen
Vorlesung SS 03 und WS 03/04
Albert-Ludwigs-Universität Freiburg

Sebastian Herkel
Bauökologie und Solare Energiesysteme
Vorlesung SS 03
Staatliche Akademie der Bildenden Künste Stuttgart

Prof. Joachim Luther
Photovoltaische Energiekonversion
Vorlesung SS 2003
Thermische Solarenergiewandlung
Vorlesung WS 03/04
Solare Energiekonversion
Seminar SS 03 und WS 03/04
Albert-Ludwigs-Universität Freiburg

Jens Pfafferott
Konventionelle und regenerative Energiewirtschaft
Vorlesung SS 03
Fachhochschule Biberach

Prof. Roland Schindler
Halbleitertechnologie I (Technologie)
Vorlesung WS 03/04
Halbleitertechnologie II (Bauelemente)
Photovoltaik II
Vorlesung SS 03
Fernuniversität Hagen

Dr Heribert Schmidt
Photovoltaik Systemtechnik
Vorlesung WS 03/04
Universität Karlsruhe

Dr Gerhard Willeke
Grundlagen von Halbleiterbauelementen und der optischen Datenübertragung
Vorlesung SS 03
Universität Konstanz

Dr Volker Wittwer
Energieversorgung für Mikrosysteme
Vorlesung SS 03
Innovative Energieversorgungssysteme
Vorlesung WS 03/04
Fakultät für Angewandte Wissenschaften
Albert-Ludwigs-Universität Freiburg

Trade Fairs and Exhibitions

R+T-2003
Internationale Fachmesse Rolladen, Tore und Sonnenschutz
Stuttgart, 18.–22.2.2003

Fachausstellung anlässlich des 18. Symposium »Photovoltaische Solarenergie«
Bad Staffelstein, Kloster Banz, 12.–14.3.2003

SEMICON Europe 2003
Messe München, 1.–3.4.2003

Hanover Trade Fair, HMI 2003
Hanover, 7.–12.4.2003

European Coatings Show
Nürnberg, 8.–10.4. 2003
Joint stand with Fraunhofer ISC, WKI, POLO

fgm fenster/glas/metallbau
Internationale Fachmesse für Fassadentechnologie
Stuttgart, 19.–21.6. 2003

Intersolar 2003
International Trade Fair and Congress for Solar Technology
Freiburg, 27.–29.6.2003

Bundesministerium für Bildung und Forschung BMBF
Ausstellung »Die Quelle – Energie und Chemie«
Halle/Saale, 28.8.–7.9.2003
Dresden, 19.–28.9.2003
München, 2.–11.10.2003

In 2004, Fraunhofer ISE will host the sixth international conference on thermophotovoltaics in Freiburg:

6th Conference on Thermophotovoltaic Generation of Electricity
Freiburg, 14.–16.6.2004
www.thermopv.org

Patent Applications

Dr Andreas Guntsch, Dr Andreas Hinsch, Stipan Katusic, Dr Rainer Kern, Dr Günther Michael, Roland Sastrawan
"Dye-sensitised photovoltaic cells, a procedure to produce these photovoltaic cells and their application"

Dr Gerhard Willeke
"Unit to concentrate solar radiation on a micro-solar cell"

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

Dominik Marin Huljic
"Procedure for temperature-controlled processing of substrates"

Christian Bichler, Dr Andreas Bühring
"Combined fluid-air evaporator and new connection concept for a heat pump in a ventilation unit"

Dr Christopher Hebling, Anders Ødegård
"Device and procedure to increase the fuel concentration in a fuel-containing liquid flow input at the anode of a fuel cell"

Michael Hermann, Werner Hube, Dr Werner Platzer
"Building component with variable optical properties, procedure to influence its optical properties and its application"

Patents Granted

Dr Andreas Gombert, Jörg Jungjohann, Dr Harry Wirth, Dr Volker Wittwer
"Solar-control device in the form of a venetian blind"

Prof. Konstantin Ledjeff-Hey, Dr Alexander Schuler, Bernhard Vogel
"Device for reforming educts containing hydrocarbons"

Dr Andreas Bühring
"Compact heat-pump unit with integrated primary-energy heat source for controlled ventilation and heat supply of low-energy buildings or passive houses and procedures therefore"

Volkmar Boerner, Dr Andreas Gombert, Andreas Heinzel, Dr Volker Wittwer, Christel Zanke
"Procedure to produce resonant filters"

Dr Angelika Heinzel, Dr Tim Meyer, Dr Roland Nolte, Dr Heribert Schmidt
"Fuel cell with integrated voltage converter"

Dr Ralf Lüdemann
"Thin-film solar cell configuration and procedure to produce it"

Franz Brucker, Michael Köhl, Volker Lieske
"Device for photo-activated production of singlet oxygen and procedure to produce the device"

Franz Brucker, Michael Köhl, Volker Lieske
"Device and procedure to produce singlet oxygen"

Dr Dirk Uwe Sauer, Dr Heribert Schmidt
"Device to determine the density of an electrolyte"

Dr Andreas Bühring, Dr Pedro Da Silva
"Ventilation configuration for buildings"

Franz Brucker, Michael Köhl
"Procedure to influence the optical properties of polymers"

Dr Andreas Georg, Dr Anneke Georg
"Photovoltaic self-charging storage system"

Rudi Kaiser, Dr Dirk Uwe Sauer
"Electricity supply device"

Dr Andreas Hinsch, Dr Andreas Georg, Michael Niggemann
"Solar cell and procedure for its production"

Dr Benedikt Bläsi, Dr Christopher Bühler, Dr Andreas Gombert, Tilmann Kuhn, Dr Peter Nitz, Dr Werner Platzer, Dr Volker Wittwer
"Solar-control device with many parallel-oriented slats"

Doctoral Theses

Sandra Bau
"High-temperature CVD silicon films for crystalline silicon thin-film solar cells"
Doctoral thesis, University of Constance
Constance, 2003

Daniel Biro
"Durchlaufdiffusion für die Photovoltaik"
(In-line diffusion for photovoltaics)
Doctoral thesis, University of Freiburg
Freiburg, 2003

Christopher Bühler
"Mikrostrukturen zur Steuerung von Tageslichtströmen"
(Microstructures to control daylighting flows)
Doctoral thesis, University of Freiburg
Freiburg, 2003

Jochen Dicker
"Analyse und Simulation von hocheffizienten Silizium-Solarzellenstrukturen für industrielle Fertigungstechniken"
(Analysis and simulation of highly efficient silicon solar cell structures for industrial production technology)
Doctoral thesis, University of Constance
Constance, 2003

Anneke Georg
"Photoelektrochrome Fenster"
(Photoelectrochromic windows)
Doctoral thesis, University of Freiburg
Freiburg, 2003

Ji Youn Lee
"Rapid Thermal Processing of Silicon Solar Cells - Passivation and Diffusion"
Doctoral thesis, University of Freiburg
Freiburg, 2003

Gergö Létay
"Modellierung von III-V Solarzellen"
(Modelling of III-V solar cells)
Doctoral thesis, University of Constance
Constance, 2003

Christian Reise
"Entwicklung von Verfahren zur Prognose des Ertrags großflächiger Energieversorgungssysteme auf der Basis von Satelliteninformationssystemen"
(Development of procedures to predict the yield of large-area energy supply systems on the basis of satellite information systems"
Doctoral thesis, University of Oldenburg
Oldenburg, 2003

Dirk Uwe Sauer
"Optimierung des Einsatzes von Blei-Säure-Akkumulatoren in Photovoltaik-Hybrid-Systemen unter spezieller Berücksichtigung der Batteriealterung"
(Optimisation of applications of lead-acid batteries in photovoltaic hybrid systems, taking special account of battery ageing)
Doctoral thesis, University of Ulm
Ulm, 2003

Press Releases

www.ise.fraunhofer.de/english/press

21.3.2003
Natural Gas Reformer for Fuel Cell Application in Combined Heat and Power Plants
Fraunhofer ISE presents new work on hydrogen generation in Hanover

27.3.2003
Off-Grid Power Supply
Mobile Power Box from Fraunhofer ISE about to enter the Market

8.4.2003
Innovation Prize for Newly Developed Energy-Efficient Sunshade System
Integral Daylight Planning Saves Energy and Costs

16.7.2003
Wax-based heat storage for buildings

15.9.2003
Compact control system increases the efficiency of large solar thermal systems
Fraunhofer ISE develops internet-connected energy management systems

10.12.2003
Paper-thin 20% solar cells with new technology

Newly Founded Commercial Enterprise

IoLiTec G.b.R.
Engesserstraße 4b
79108 Freiburg
Germany
www.iolitec.de

Lectures

Bett, A.W.; Dimroth, F.; Glunz, S.W.
»Development of Concentrator Solar Cells and Systems at Fraunhofer ISE«, 2nd Int. Solar Concentrator Conference for the Generation of Electricity or Hydrogen, Alice Springs, Australia, 10.–14.11.2003

Bett, A.W.; Baur, C.; Dimroth, F.; Lange, G.; Meusel, M.; van Riesen, S.; Siefer, G.; Andreev, V.M.[1]; Rumyantsev, V.D.[1]; Sadchikov, N.A.1
»FLATCON™- Modules: Technology and Characterisation«, 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, 11.–18.5.2003
([1]: Ioffe Institute, St Petersburg, Russia)

Bett, A.W.
»Multi-Junction Solar Cells and Their Applications«, University of New South Wales, Sydney, Australia, 17.11.2003 und Australian National University, ANU, Canberra, Australia, 20.11.2003

Bett, A.W.; Baur, C.; Dimroth, F.; Meusel, M.; van Riesen, S.; Siefer, G.
»III-V Solar Cells and Their Application«, EU-Russian Workshop »Efficient Use of Solar Spectrum in Photovoltaics«, St Petersburg, Russia, 2.–5.11.2003

Bläsi, B.
»Solare Energiesysteme – Technologie, Anwendung und Zukunftsperspektiven«, TU München, Ringvorlesung Umweltschutz, München, 22.1.2003

Bläsi, B.; Bühler, C.; Georg, A.; Gombert, A.; Hoßfeld, W.; Mick, J.[1]; Nitz, P.; Walze, G.; Wittwer, V.
»Microstructured Surfaces in Architectural Glazings«, ISES Solar World Congress 2003, Gothenburg, Sweden, 18.6.2003
([1]: FMF, Albert-Ludwigs-Universität Freiburg)

Bühring, A.;
„Wärmepumpen in Niedrigstenergie- und Passivhäusern", 1. Forum Wärmepumpe, Berlin, 23.–24.10.2003

Bühring, A.;
„Heizen mit dem Lüftungssystem - vom Einfamilienhaus zum Geschosswohnbau", Fachforum Innovative Wohnungslüftung, Otti-Energiekolleg, Regensburg, 28./29.1.2003

Dimroth, F.; Baur, C.; Meusel, M.; van Riesen, S.[1]; Bett, A.W.
»5-Junction III-V Solar Cells for Space Applications«, 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, 11.–18.5.2003
([1]: FMF, Albert-Ludwigs-Universität Freiburg)

Dimroth, F.
»Growth of Arsenides, Phosphides and Antimonides on AIX 2600-G3 Reactor at Fraunhofer ISE«, Aixtron User Meeting, Lecce, Italy, 8.6.2003

Dimroth, F.; Bett, A.W.
»III-V Halbleiter Konzentratorzellen«, FVS Jahrestagung, Berlin, 25.–26.9.2003

Disch, A.
»Interferenzlithographie«, Vorlesung: Lithographie, Albert-Ludwigs-Universität Freiburg IMTEK, 21.7.2003

Glunz, S. W.
»Solar Cell Research at Fraunhofer ISE«, University of New South Wales, Sydney, Australia, 20.12.2002

Glunz, S.W.; Schäffer, E.; Rein, S.; Bothe, K. [1]; Schmidt, J. [1]
»Analysis of the Defect Activation in Cz-Silicon by Temperature-Dependent Bias-Induced Degradation of Solar Cells«, 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, 11.–18.5.2003
([1]: Institut für Solarenergieforschung Hameln/ Emmerthal ISFH, Emmerthal)

Glunz, S.W.
»Lebensdauerspektroskopie zur Analyse von Defekten in Silicium«, Vortrag im Kolloquium »Physikalische Elektronik«, IPE, Stuttgart, 2.6.2003

Glunz, S.W.
»New Concepts for High-Efficiency Silicon Solar Cells«, SWH (Solar, Wind, Hydrogen and Fuel Cells) Conference, Segovia, Spain, 7.–11.7.2003

Glunz, S.W.
»Lebensdauerspektroskopie zur Analyse von Defekten in Silicium«, Seminarvortrag, HMI, Berlin, 3.7.2003

Gölz, S.; Ruf, J.; Schüpach H.[1]
»Increasing Renewable Energies in Future Energy Supplies – A Socio-Technical Approach to Include the Consumer into Overall Energy and Grid Management«, 5. Fachtagung Umweltpsychologie; Eindhoven, Netherlands, 3.9.2003
([1]: Albert-Ludwigs-Universität, Freiburg)

Gölz, S.; Vosseler, I.
»High Standard Energy Service By Multi-User PV Hybrid Grids (MSG): An Integrated Approach In »Veinat De Cal Peraire«, Catalonia, Spain«, 2nd European PV-Hybrid and Mini-Grid Conference, Kassel, 25.9.2003

Gombert, A.
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Abbreviations

AC	alternating current
Ag	silver
Al	aluminium
AlGaAs	aluminium gallium arsenide
AM	air mass
APCVD	atmospheric pressure chemical vapour deposition
ASTM	American Society for Testing and Materials
Bi	bismuth
BFC	bifacial cell
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BMWi	Bundesministerium für Wirtschaft und Technologie (German Federal Ministry of Economics and Technology)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry of Economic Co-operation and Development)
BSF	back surface field
CDI	carrier density imaging
CFD	computational fluid dynamics
CIS	copper indium diselenide
CNRS	Centre Nationale de la Recherche Scientifique
CO	carbon monoxide
CO_2	carbon dioxide
CPC	compound parabolic concentrator
c-Si	crystalline silicon
CV	capacitance/voltage
CVD	chemical vapour deposition
Cz	Czochralski
DC	direct current
DIN	Deutsches Institut für Normung (German Standards Institute)
DLTS	deep level transient spectroscopy
DMFC	direct methanol fuel cell
EBIC	electron beam induced current
EBR	etchback regrowth
ECR	electron cyclotron resonance
EFG	edge-defined film-fed growth
EMC	electromagnetic compatibility
EN	European Norm (European Standard)
EU	European Union
FF	fill factor
FhG	Fraunhofer-Gesellschaft (Fraunhofer Society)
FCHC	fluorinated/chlorinated hydrocarbons
FZ	float zone
GaAs	gallium arsenide
GaInP	gallium indium phosphide
GaSb	gallium antimonide
Ge	germanium
GSM	Global System for Mobile Communication
IEA	International Energy Agency
IR	infrared
K	Kelvin
kWp	kilowatt peak
LBIC	light beam induced current
LBSF	local back surface field
LED	light-emitting diode
LFC	laser fired contact
LPE	liquid phase epitaxy
mc	multicrystalline
MCFC	molten carbonate fuel cell
mc-Si	multicrystalline silicon
MFCA	modulated free carrier absorption
MgF_2	magnesium fluoride
MOCVD	metal organic chemical vapour deposition
MOVPE	metal organic vapour phase epitaxy
MPP	maximum power point
MSCM	miniature solar cell mapping
MW-PCD	microwave-detected photo-conductance decay
N_2	nitrogen
NOCT	nominal operating cell temperature
PCM	phase-change material
PCVD	photocurrent and voltage decay
Pd	palladium
PDA	personal digital assistant
PECVD	plasma enhanced chemical vapour deposition
PEM	proton exchange membrane
PEMFC	proton exchange membrane fuel cell
PERC	passivated emitter and rear cell
POA	power optimised aircraft
PV	photovoltaic
RCC	rear contacted cell
RCWA	rigorous coupled wave analysis
RIE	reactive ion etching
RPHP	remote plasma hydrogen passivation
RP-PERC	random pyramid, passivated emitter and rear cell
RRC	realistic reporting conditions
RTCVD	rapid thermal chemical vapour deposition
RTP	rapid thermal processing
S/C	steam/carbon ratio
SDCS	solar desiccant cooling system
SEM	scanning electron microscope
Si	silicon
SIMOX	separation by implanted oxygen
SiN_x	silicon nitride
SiO_2	silicon dioxide
SIR	simultaneous infiltration and recrystallisation
SME	small and medium-sized enterprises
Sn	tin
SOFC	solid oxide fuel cell
SPV	surface photovoltage
SSP	silicon sheets from powder
SR	spectral response
SR-LBIC	spatially resolved light beam induced current
TCO	transparent conducting oxide
TDLS	temperature-dependent lifetime spectroscopy
TI	transparent insulation
Ti	titanium
TiO_2	titanium dioxide
TPV	thermophotovoltaics
VOC	open circuit voltage
WO_3	tungsten trioxide
WPVS	world photovoltaic scale
ZMR	zone melting recrystallisation
Zn	zinc
η	efficiency value

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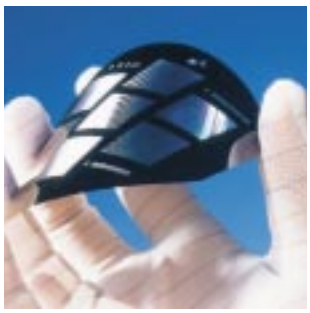

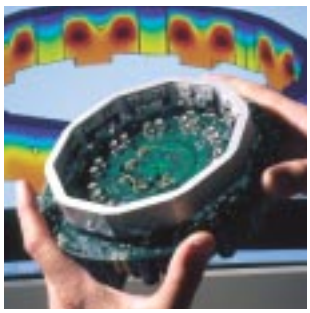

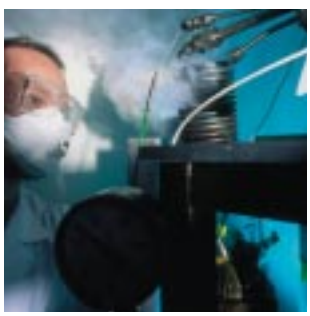

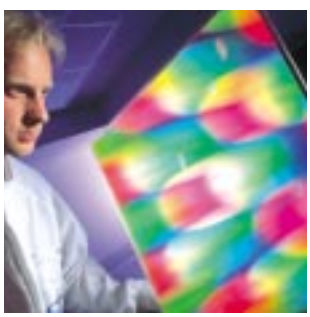

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