Achievements and Results ■ Annual Report 2001

ISE

Fraunhofer Institut Solare Energiesysteme

Achievements and Results Annual Report 2001

Fraunhofer Institute for Solar Energy Systems ISE

After growing continuously to the current staff size of 300, Europe's largest solar research institute now has its own home for the first time. In summer 2001, Fraunhofer ISE moved into its new premises, which were financed equally by the State of Baden-Württemberg and the German Federal Ministry of Education and Research. With building costs of 35 million euros, which comply with the cost framework for publicly financed institute buildings of this size, a building was constructed which sets standards in combining architecture and solar technology, according to the motto "Exemplary building with the sun". High-quality working conditions and efficient use of energy, naturally with integrated solar systems, were the common goals of the building owners, the architects, Dissing+Weitling from Copenhagen, the engineering company, Rentschler&Riedesser from Stuttgart and the planning experts from Fraunhofer ISE.

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 in the areas of thermal use of solar energy, photovoltaics, solar building, electric power supplies, micro-energy technology, chemical energy conversion, energy storage and rational use of energy.

The institute's work ranges from investigation of scientific fundamentals for solar energy application, 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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Reports from the Departments

The major event of 2001 for our institute was the move into the long awaited new premises. For the first time in many years, most of Fraunhofer ISE is now united under a single roof. On the one hand, this encourages further important synergetic effects between research, development and high-technology services. On the other hand, the brand-new infrastructure of our institute offers an excellent basis for still better and more innovative work, to the benefit of our clients.

Extremely close co-operation between the architects and the external and internal planning experts of the ISE working group on "Solar Building" resulted not only in a very attractive, highly functional building for applied solar and energy research. It also succeeded in approximately halving the primary energy demand for the office area. In doing so, the limits of the pre-defined budget were of course observed. You can find more details on the building concept at www.solarbau.de, our Internet service, which we developed as part of the research accompanying the SolarBau (solar building) funding programme of the BMWi (German Federal Ministry of Economics and Technology).

The move into our new home coincided almost exactly with the 20th birthday of Fraunhofer ISE. We were able to honour both occasions fittingly, together with many high-ranking guests from politics, economics and science. During the festivities, I was able to sincerely thank the State Premier of Baden-Württemberg and Federal representatives on behalf of the entire institute for the joint financing of our new premises.

We were particularly pleased that more than 100 former employees of Fraunhofer ISE accepted our invitation to celebrate the two occasions with us.

As in 2000, Fraunhofer ISE grew again by about 10 % in 2001. This very satisfying development, which we can undoubtedly interpret as recognition of our work, nevertheless had the effect that working groups on optical-functional surfaces had to stay at their previous location, where they occupy about 2000 m^2. We will exert ourselves in 2002 to ensure that good working areas near the new premises can be provided for these groups.

Despite all my efforts, I did not succeed in convincing Prof. Angelika Heinzel to stay at our institute. A Chair at the University of Duisburg and a new "Centre for Fuel Cell Technology" were too attractive, in the true sense of the word. Dr Christopher Hebling succeeded her as the Head of the Energy Technology Department on 1st October, 2001. Prior to his new appointment, Dr Hebling had developed the "Micro-Energy Technology" market area very successfully at Fraunhofer ISE.

Klaus Preiser, Head of the Electrical Energy Systems Department, will become responsible for "Decentralised Generation of Electricity and Heat" at our regional utility, "badenova". His successor from 1st January, 2002, will be Dr Tim Meyer. Dr Meyer has already worked for several years in the Electrical Energy Systems Department. More recently, he co-ordinated strategic planning at Fraunhofer ISE.

At this point, I would like to express my sincere gratitude to Prof. Heinzel and Mr Preiser for all that they contributed to Fraunhofer ISE over many years. I am sure that I speak on behalf of the entire institute!

Dr Volker Wittwer was appointed as a lecturer in Microsystem Technology to the Faculty for Applied Science at the University of Freiburg in July 2001. I congratulate Dr Wittwer most sincerely. My gratitude also extends to the faculty for many years of fruitful co-operation, which were clearly reaffirmed with this appointment.

With considerable efforts on the part of all ISE employees, we succeeded in introducing a quality management system according to DIN EN ISO 9001:2000 for the whole institute before moving to the new premises. The certificate was issued on 30th March 2001. We expect that certification will guarantee optimised and transparent organisation of our project and research work. In particular, we hope that this status will make us still more interesting for industrial clients. At the international level, the certification has already borne fruit in our acquisition efforts.

My thanks also go to all members of the Institute for their creative, highly motivated and successful work. Their whole-hearted efforts for Fraunhofer ISE, particularly during the move, deserve undisguised admiration. I am especially grateful to those representatives of industry, ministries and the European Union, whose commissions demonstrated their interest and trust, and ultimately made our work possible.

Prof. Joachim Luther

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"Exemplary building with the sun" - this was the motto for the new institute premises, the result of co-operation between the architects, Dissing+Weitling, the engineering company, Rentschler&Riedesser and the planning experts from Fraunhofer ISE. Fraunhofer ISE now has its own home for the first time, thanks to support from the State of Baden-Württemberg and the German Federal Ministry of Education and Research, which each contributed half of the building costs, totalling 35 million euros.

Fraunhofer ISE also celebrated its 20th anniversary together with the official opening of the building. Around 400 guests from the solar industry, science and politics came to Freiburg on 23rd November 2001 to share in celebrating with the ISE staff.


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Illustrations
Guest speakers and VIP tour of the institute, photos on opposite page.

1 DGS President, Prof. Sigrid Jannsen; Premier of Baden-Württemberg, Erwin Teufel; Director of Fraunhofer ISE, Prof. Joachim Luther (from left to right).

2 Lord Mayor of Freiburg, Dr Rolf Böhme; State MP, Dr Walter Witzel; Premier of Baden-Württemberg, Erwin Teufel; Parliamentary State Secretary in the Federal Ministry of Economics and Technology, Siegmar Mosdorf; Director of Fraunhofer ISE, Prof. Joachim Luther (from left to right).

3 Erwin Teufel, Premier of Baden-Württemberg.

4 Siegmar Mosdorf, Parliamentary State Secretary in the Federal Ministry of Economics and Technology.

5 Dr Rolf Böhme, Lord Mayor of Freiburg.

6 Prof. Hans-Jürgen Warnecke, President of the Fraunhofer Society.

7 VIP tour inspecting micro-energy technology. Lord Mayor Dr Rolf Böhme; President of the Fraunhofer Society, Prof. Hans-Jürgen Warnecke; Parliamentary State Secretary in the Federal Ministry of Economics and Technology, Siegmar Mosdorf; State MP, Dr Walter Witzel; Premier of Baden-Württemberg, Erwin Teufel; Head of the Energy Technology Department, Dr Christopher Hebling (from left to right).

This page:

8 Prof. Joachim Luther, Director of Fraunhofer ISE (left); Søren Andersen, Dissing+Weitling, Copenhagen (right).

An international panel of representatives from industry and research (see photos) discussed R&D topics for the future in photovoltaics, thermal use of solar energy and hydrogen technology during the podium discussion on "What does the solar market need tomorrow and thereafter?"

9 Prof. Peter Woditsch, Deutsche Solar AG (left); Dr Rolf Blessing, Interpane Entwicklungs- und Beratungsgesellschaft mbH (right).

10 Prof. Claes-Goran Granqvist, Uppsala University, Sweden (left); Prof. Johan Nijs, IMEC, Belgium (right)

11 Dr Werner Lehnert, Research Alliance Baden-Württemberg (left); Ingolf Baur, moderator, SWR/3sat (right).

12 Günter Cramer, SMA Regelsysteme GmbH

The Institute in Brief

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 components, materials, systems and processes in the areas of thermal use of solar energy, solar building, photovoltaics, electrical power supplies, micro-energy technology, chemical energy conversion, energy storage and rational use of energy.

The institute's work ranges from investigation of scientific fundamentals for solar energy application, 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.

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-Ludwigs-Universität in Freiburg.

Research and Services Spectrum

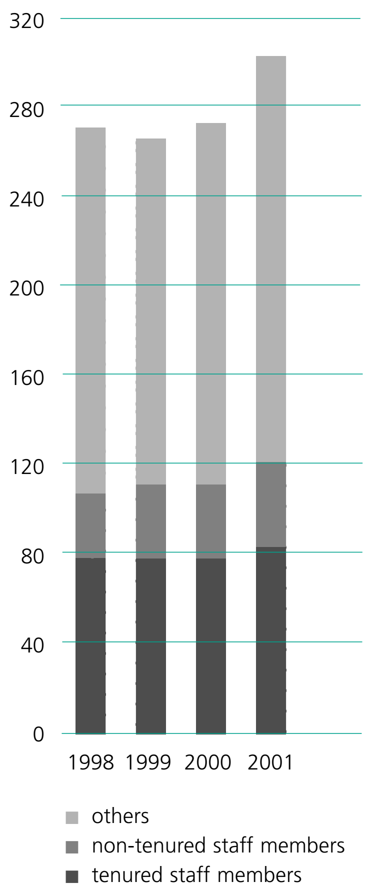
The Fraunhofer Institute for Solar Energy Systems ISE is a member of the Fraunhofer-Gesellschaft, a non-profit organisation, which occupies a mediating position between the basic research of universities and industrial practice. The Institute finances itself with applied research projects and services on the technical application of renewable energy sources. Whether it concerns a major project or brief consultancy work, the working method is characterised by its clear relevance to practice and orientation toward the wishes of the client.

Organigram

Institute Director	Prof. Joachim Luther	
Departments	Thermal and Optical Systems Dr Volker Wittwer	+49 (0) 7 61/45 88-51 43
	Energy Technology Dr Christopher Hebling*	+49 (0) 7 61/45 88-51 95
	Solar Cells - Materials and Technology Dr Gerhard Willeke	+49 (0) 7 61/45 88-52 66
	Electrical Energy Systems Klaus Preiser **	+49 (0) 7 61/45 88-52 16
Administration, Technical Infrastructure and Services	Wolfgang Wissler	+49 (0) 7 61/45 88-53 50
Press and Public Relations	Karin Schneider	+49 (0) 7 61/45 88-51 47
Strategic Planning	Dr Tim Meyer***	+49 (0) 7 61/45 88-53 46

* Prof. Angelika Heinzel until 30.9.2001
** Dr Tim Meyer from 1.1.2002
*** Dr Carsten Agert from 1.8.2002

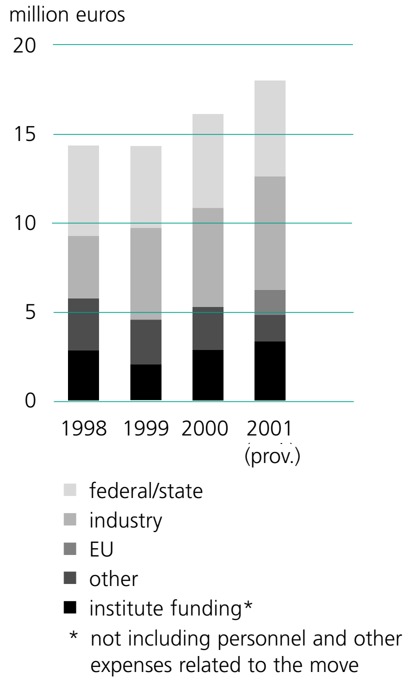
Personnel development



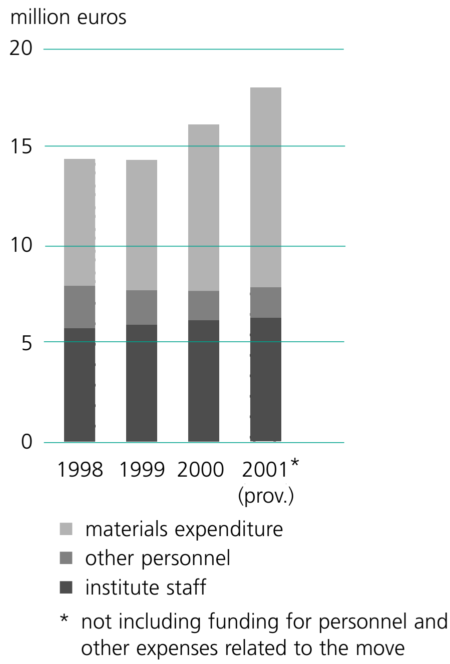
The "other" staff members are an important pillar of the institute, who support the work in the research projects and thus contribute significantly to the scientific results obtained. In December 2001, 35 doctoral candidates, 46 undergraduate students, 73 scientific and 28 other assistants were employed 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 2.6 million euros in 2001, not including investments associated with the new premises.

Income



Expenditure



Board of Trustees

The board of trustees assesses the research projects and advises the Institute directorate and the Fraunhofer Society Executive with regard to the working programme of Fraunhofer ISE.
January, 2002.

Research and Development

- zero-emission factory conceived for a collector manufacturer
- thermal collector with corrosion-resistant absorber for sea-water desalination successfully tested in a pilot system on Gran Canaria
- prismatic microstructures for daylighting applications produced with holographic exposure methods
- cross-sectional analyses of energy demand and supply completed for 100 solar passive houses
- Digiflow: thermo-hydraulically optimised controls for heating networks, based on an integrated "embedded system", tested for the first time in operation
- natural gas reforming implemented for domestic energy supply with a 1 kW fuel cell
- prototype developed to reform diesel for hydrogen generation
- miniaturised fuel cell system for commercially available camcorders presented to the public by the "Fraunhofer Initiative for Miniature Fuel Cells"
- highly efficient fuel cell control systems developed for extreme application conditions (camcorder, laptop)
- catalysts with reduced noble metal content achieve 80 % efficiency in petrol reforming
- 20.5 % efficient crystalline silicon solar conventionally processed from a 72 µm thin wafer
- new SSP (silicon sheet from powder) and Si CVD systems developed and installed in China
- in-line pilot line for multicrystalline silicon solar cells started operation in the Laboratory and Service Centre in Gelsenkirchen
- monolithic concentrator cell of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ with two junctions achieved an efficiency value of 31.1 % for 300x solar concentration
- mechanically stacked concentrator cell of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ - GaSb with three junctions achieved a record efficiency value of 33.5 % for 300x solar concentration
- first functional infrared solar with two junctions produced from AlGaAsSb/GaSb
- method to check photovoltaic system yields commercialised, based on satellite data
- compact system for decentralised supply and treatment of drinking water (WATERpps) developed as a product
- CLE Club zur Ländlichen Elektrifizierung (for rural electrification) founded with 20 industrial partners, and foundations laid for a successful German export strategy for renewable energy technology

University Appointments

Prof. Angelika Heinzel accepted a professorship at the University of Duisburg, Chair of Energy Technology.

Prof. Joachim Luther was appointed as a new member for four years to the "German Advisory Council on Global Change WBGU" by the Federal Minister for Education and Research, Edelgard Bulmahn, and the Federal Minister for the Environment, Conservation and Reactor Safety, Jürgen Trittin.

Dr Ralf Preu was awarded a prize for an excellent doctoral thesis by the Sparkasse Hagen. The prize was presented on 26th October during DIES ACADEMICUS 2001.

Dr Petra Schweizer-Ries was honoured with the "Young Professionals Award" during the 17th European Photovoltaic Solar Energy Conference in Munich.

Clients

The Fraunhofer Institute for Solar Energy Systems has co-operated successfully for years with clients from many different sectors and company sizes.

Clients, who have agreed to publication of their names:

- ACR GmbH, Niedereschbach
- Adam Opel AG
- Aixtron GmbH, Aachen
- Akkumulatorenfabrik Sonnenschein GmbH (Exide German Group), Büdingen
- Ambient Recording, Munich
- AMG Palermo, Palermo, Italy
- Applied Films, Alzenau
- Architekturbüro Köster, Frankfurt
- Autotype Ltd., Wantage, UK
- Badenova AG, Freiburg
- BASF AG, Ludwigshafen
- Bayer AG, Krefeld-Uerdingen
- Beratung für Batterien und Energietechnik - BBE, Osterode
- British Petroleum BP Solar International, Sunbury, Great Britain
- Bug-Alu Technik AG, Kennelbach, Austria
- Bundesministerium für Bildung und Forschung BMBF, Berlin (German Federal Ministry of Education and Research)
- Bundesministerium für Wirtschaft und Technologie BMWi, Berlin
- Bundesverband Leichtbetonzuschlag-Industrie e.V., Stuttgart
- Caparol Farben, Lacke, Bautenschutz, Ober-Ramstadt
- Centrotherm GmbH, Blaubeuren
- Compagnie Européenne d'Accumulateurs CEAC, Gennevielliers, France
- Creavis GmbH, Marl
- Daimler-Chrysler AG, Stuttgart
- Degussa-Hüls AG, Hanau
- DETA Batterien, Bad Lauterberg
- Deutsche Bundesstiftung Umwelt, Osnabrück (German National Foundation for the Environment)
- Deutsche Everlite GmbH, Wertheim (Main)
- Deutsche Gesellschaft für Technische Zusammenarbeit GmbH GTZ, Eschborn
- Deutsche Solar GmbH, Freiberg
- Deutscher Alpenverein DAV, (German Mountaineering Club), Munich
- ECN, Petten, the Netherlands
- EKRA Maschinenfabrik GmbH, Bönnigheim
- Energie Baden-Württemberg AG, EnBW, Karlsruhe
- E.ON Energie AG, Munich
- European Union EU, Brussels, Belgium
- Flabeg Holding GmbH, Gelsenkirchen
- Flughafen Köln/Bonn GmbH
- Ford AG, Cologne
- Freiburger Energie- und Wasserversorgungs-AG FEW, Freiburg
- Fresnel Optics GmbH, Apolda
- G+H Isover, Ladenburg
- Gaia Kapital-Beteiligungsgesellschaft mbH, Cologne
- Gebäudemanagement Schleswig-Holstein (GMSH), Kiel
- Gebr. Märklin & Cie. GmbH, Göppingen
- Grammer KG, Amberg
- GreenONEtec, Ebenthal, Austria
- Grundwert Verwaltungs- und Projektentwicklungs- GmbH (GVP), Frankfurt
- H.C. Starck GmbH & Co. KG, Goslar
- Haas-Laser-GmbH & Co. KG, Schramberg
- Hagen Batterie AG (Exide German Group), Soest
- Handwerkskammer zu Köln, Cologne
- Heidelberger Druckmaschinen AG, Heidelberg
- Heraeus Quarzglas GmbH & Co. KG, Kleinostheim
- Hochbauamt der Stadt Mannheim
- Hüppe Form, Oldenburg
- IBC Solartechnik, Staffelstein
- Institut für Mikrosystemtechnik IMTEK, Freiburg
- Institut für Angewandte Photovoltaik INAP GmbH, Gelsenkirchen
- Instituto Nacional De Tecnologia Agropecuaria, San Juan, Argentinia
- Interpane E&B mbH, Lauenförde
- Karl Süss GmbH & Co. KG, Garching

- Klimahaus Hamburg, Hamburg
- Labor für Bildschirmtechnik, University of Stuttgart
- Landis & Staefa, Stuttgart
- M + W Zander GmbH, Stuttgart
- Maico Haustechnik, Villingen-Schwenningen
- Maxit Baustoff- und Kalkwerk Mathis GmbH, Merdingen
- Merck KGaA, Darmstadt
- Messer Mahler AG, Stuttgart
- MHZ-Hachtel, Leinfelden-Echterdingen
- Ministerium für Wissenschaft und Forschung, Baden-Württemberg, Stuttgart
- Moonlight, Wehr
- MVV Energie AG, Mannheim
- NLCC Architects Sdn. Kuala Lumpur, Malaysia
- Okalux Kapillarglas GmbH, Marktheidenfeld
- OMG AG, Hanau
- Prof. Michael Lange, Berlin
- Prokuwa Kunststoff GmbH, Dortmund
- PV Silicon AG, Erfurt
- RENA Sondermaschinen GmbH, Gütenbach
- Resol Elektronische Regelungen GmbH, Hattingen
- Robert Bosch GmbH, Stuttgart
- Roto Frank AG, Bad Mergentheim-Edelfingen
- RWE Power AG, Essen
- RWE Solar GmbH, Alzenau and Heilbronn
- RWTH Aachen, Aachen
- Saint Gobain Glass, Herzogenrath
- Schott Rohrglas GmbH, Mitterteich
- S.E. del Acumulador Tudor, S.A., Madrid, Spain
- Shell Solar, Gelsenkirchen
- Siemens & Shell Solar Deutschland GmbH, Munich
- Solar World, Bonn
- Solar-Application GmbH, Freiburg
- Solarenergieförderverein Bayern e.V., Munich
- Solar-Fabrik GmbH, Freiburg
- Solarwatt GmbH, Dresden
- Solvis GmbH, Braunschweig
- Sorpetaler Objekte GmbH, Sundern-Hagen
- Stadt Freiburg, Universitätsklinikum, Freiburg
- Stadtwerke Karlsruhe, Karlsruhe
- Stadtwerke Pforzheim, Pforzheim
- STAWAG, Aachen
- Steca GmbH, Memmingen
- Stiftung Energieforschung Land Baden-Württemberg
- Sto AG, Stühlingen
- Süd-Chemie AG, Munich
- Südwestrundfunk, Landesstudio Mainz
- Sunlight Power Maroc, Rabat, Morocco
- Sunways, Constance
- Suptina Grieshaber, Schapbach
- TeCe, Selb
- TNTA, National Institute of Aerospace Technology, Madrid, Spain
- Trama Tecno Ambiental, Barcelona, Spain
- Transénergie, Lyon, France
- Truma AG, Munich
- Uni Solar, Zulte, Belgium
- Vegla GmbH, Aachen
- Velux A/S, Vedbaek, Denmark
- Viessmann AG, Allendorf
- Wagner & Co., Cölbe
- Warema Renkhoff GmbH, Marktheidenfeld
- Webasto AG, Munich
- Wilo GmbH, Dortmund
- Wirtschaftsministerium NRW
- World Bank, Washington, USA
- Würth Solar GmbH & Co. KG., Marbach am Neckar
- Wuseltronik, Berlin
- Zentrum für Sonnenenergie- und Wasserstoff-Forschung ZSW, Stuttgart/Ulm

International Co-Operation

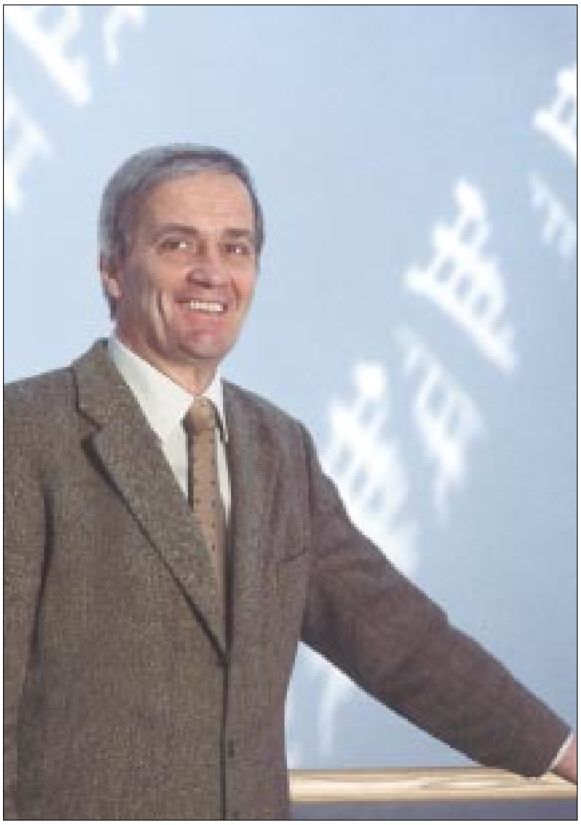
We co-operate with international partners in an increasing number of our projects.

- Agricultural University of Athens, Greece
- Air Liquide S.A., Sassenage, France
- Alcatel Standard Electricia S.A., Madrid, Spain
- Altai Centre for Non-Traditional Energy and Energy Saving, Barnaul, Russia
- APEX Ingénierie, Laverune, France
- Aplicaciones Technicas de la Energie S.A. - ATER SA, Valencia, Spain
- Arge Erneuerbare Energie, Gleisdorf, Austria
- A.S. Joffe Institute, St. Petersburg, Russia
- Australian Cooperative Research Centre for Renewable Energy - ACRE, Perth, Australia
- Australian National University - ANU, Canberra, Australia
- Berner Fachhochschule, Berne, Switzerland
- BPP Teknologi LSDE, Technical Implementation Unit, Energy Technology Laboratory, Serpong Tangerang, Indonesia
- British Petroleum BP Solar International, Sunbury, Great Britain
- Centre de Caderache - CEA-GENEC, Saint-Paul-Lez-Durance, France
- Centre for Renewable Energy Sources CRES, Pikermi, Greece
- Centre National de la Recherche Scientifique CNRS, Palaiseau / Meudon / Strasbourg / Marseille / Montpellier, France
- Centre Scientifique et Technique du Bâtiment CSTB, Grenoble, France
- Centro de Investigación en Energía y Agua, CIEA, Las Palmas de Gran Canaria, Spain
- Centro Elettrotecnico Sperimentale Italiano Giacinto Motta SpA - CESI, Milan, Italy
- CIEMAT Instituto de Energías Renovables IER, Madrid, Spain
- Compagnie Européenne d'Accumulateurs CEAC, Gennevielliers, France
- Consejo Superior de Investigaciones Cientificas CSIC, Madrid, Spain
- Council on Renewable Energy CORE in the Mekong Riparian Countries
- Curtin University of Technology, Perth, Australia
- Det Norske Meteorologisk Institutt, Bergen, Norway
- Ecole des Mines, Paris (Centre d'Energétique, Sophia Antipolis), France
- Ecole Nationale des Travaux Publics de l'Etat ENTPE, Lyon, France
- Elkem, Kjeller, Norway
- ENEA, Rome, Italy
- ENECOLO, Mönchaltorf, Switzerland
- Epichem Ltd, Merseyside, UK
- Esbensen Consulting Engineers, Virum, Denmark
- European Union EU, Brussels, Belgium
- Guangzhou Institute of Energy Conversion (GIEC), Guangzhou, China
- Hebrew University, Jerusalem, Israel
- Hochschule für Technik und Architektur, Burgdorf, Switzerland
- Hydrogen Systems, Sint-Truiden, Belgium
- Instituto Catalan de Energía ICAEN, Barcelona, Spain
- Instituto de Energía Solar IES, Madrid, Spain
- Instituto de Investigaciones Electricas, Cuernavaca, Morelos, Mexico
- Instituto Nacional de Tecnica Aerospacial "Esteban Terradas" INTA, Madrid, Spain
- Instituto Nacional de Engenharia e Tecnologia Industrial INETI, Lisbon, Portugal
- International Energy Agency IEA, Paris, France
  Photovoltaic Power Systems Programme PVPS
  - Task 5:"Grid Interconnection of Building Integrated and Other Dispersed PV Power Systems"
  - Task 7: "Photovoltaic Power Systems in the Built Environment"
  - Task 9: "PV Deployment in Developing Countries"

  Solar Heating & Cooling Programme SHCP
  - Task 21: "Daylight in Buildings"

  - Task 25: "Solar Assisted Air Conditioning of Buildings"
  - Task 27: "Performance of Solar Building Envelope Components"
  - Task 28: "Sustainable Solar Housing"
  - Task 31: "Daylighting in a New Century"
- Interuniversity Microelectronics Centre IMEC, Leuven, Belgium
- Joint Research Centre ISPRA, ESTI Group, Ispra, Italy
- Kema Nederland B. V., Arnhem, The Netherlands
- Laboratoire Charles Fabry de l´Institute d´Optique, CNRS, Orsay, France
- Lawrence Berkeley National Laboratory, LBNL, Berkeley, USA
- LG Caltex Oil Corp., Seoul, South Korea
- Microelectronic Centre - MIC; Copenhagen, Denmark
- National and Kapodistrian University of Athens, Greece
- National Institute for Chemistry, Ljubljana, Slovenia
- National Renewable Energy Laboratory NREL, Golden, USA
- Naval Research Laboratory, Washington, USA
- Netherlands Energy Research Foundation ECN, Petten, Netherlands
- Nuvera Fuel Cells, Milan, Italy
- Oxford Brookes University, Oxford, Great Britain
- Reflexite, Rochester, USA
- RISOE - National Laboratory, Roshilde, Denmark
- S.E. del Acumulador Tudor S.A., Madrid, Spain
- Solar Energy Research Training Centre SERT, Naresuan University, Phitsanulok, Thailand
- Solarenergie Prüf- und Forschungsstelle, Rapperswil, Switzerland
- Swedisch National Testing and Research Institute, Boras, Sweden
- TNO Building and Construction Research, Delft, The Netherlands
- Tokyo University of Agriculture and Technology, Japan
- Total Energie, La Tour de Salvagny, France
- Toyota Technological Institute, Nagoya, Japan
- Trama Tecno Ambiental, Barcelona, Spain
- University Center of Excellence for Photovoltaic Research, Atlanta, USA
- University of California, Berkeley, USA
- University of Indonesia, Jakarta, Indonesia
- University of New South Wales UNSW, Sydney, Australia
- University of Reading, UK
- University of San Juan UNSJ, Argentina
- University of Uppsala, Sweden
- University of Utrecht, Netherlands
- University of Zurich, Switzerland
- Vergnet S.A. Ingré, France
- Velux A/S, Vedbaek, Denmark
- World Bank, Washington, USA

Thermal and Optical Systems
Dr Volker Wittwer



Research Areas
- optically selective coatings
- nanostructured and microstructured surfaces
- optically switching windows and facades
- thermal collectors for domestic hot water and process heat
- thermo-chemical storage and solar cooling
- development and measurement of complex window and daylighting systems
- improved simulation programmes to model optical and thermal systems
- controls for energy supply systems
- visualisation of lighting distribution in buildings
- energy concepts and efficiency in buildings
- compact heat pumps, ventilation equipment, earth-to-air heat exchangers
- sea-water desalination with thermal processes

Services
- spectral measurements for quality assurance
- optical coatings as desired
- durability (accelerated ageing) tests
- fluid dynamics simulations
- thermal and optical test laboratory (TOPLAB): determination of optical and thermal system characteristics
- characterisation of sorption systems
- performance measurements of domestic hot water and high-temperature collectors (DIN testing centre)
- measurement of light and energy flows for facades in an outdoor measurement facility, FASTEST
- energy concepts and energy planning
- lighting design
- dynamic building and system simulation: TRNSYS, ESPr, SMILE, ColSim
- lighting simulation including video animation
- software development to model thermal and optical systems
- energy concepts for buildings
- monitoring and energy analysis of demonstration buildings
- measurement of compact heating and ventilation units

Equipment
- optical characterisation laboratories
- PVD coater (1 m^2 area)
- field emission scanning electron microscope
- thermo-chemical analytical laboratory
- laser exposure stand to produce large-area nanostructures and microstructures
- climatic chambers for accelerated ageing tests
- outdoor test area (collectors)
- two rotatable daylighting measurement rooms
- facade test stand
- solar collector systems and solar air conditioning
- test stand for compact heating and ventilation units
- laser goniometer and photogoniometer
- solar simulator (5 m^2) and indoor collector test stand

Energy Technology
Dr Christopher Hebling

Prof. Angelika Heinzel
until 30.9.2001

Research Areas
- polymer membrane fuel cell for hydrogen and methanol
- planar miniature fuel cells
- device-integrated solar modules
- thermophotovoltaics
- miniaturised power supply systems for electronic appliances
- hydrogen production by electrolysis
- hydrogen production by autothermal reforming, steam reforming and partial oxidation of liquid or gaseous hydrocarbons and regenerative (bio-)fuels
- catalytic burners for natural gas, heating oil and hydrogen
- hydrogen systems including safety and storage technology for hydrogen

Services
- advice and supervision during the construction of hydrogen systems
- conception of energy supply systems with fuel cells
- characterisation of fuel cells and fuel cell components
- simulation of fuel cell and reformer processes
- development of miniaturised fuel-cell systems
- development of fuel cells and components for fuel cell systems
- development of low-emission burners
- scientific studies, studies on market potential

Equipment
- prototype laboratory for hydrogen technology
- fuel cell laboratory for electrochemical characterisation procedures, spatially resolved measurements, impedance spectroscopy and production of membrane/electrode units
- burner laboratory with exhaust gas analysis and characterisation of catalysts
- measurement and analysis laboratory: gas chromatography, differential scanning calorimetry DSC
- scanning electron microscope with energy-dispersive X-ray micro-analysis
- Fourier Transform Infrared FTIR spectrometer
- micro-milling
- test stands for kinetic and integrated characterisation of catalysts for reforming and gas purification
- IR thermography camera to measure heat distribution in fuel cells
- test stand for thermophotovoltaic systems
- laboratory laminator

Solar Cells - Materials and Technology
Dr Gerhard Willeke

Research Areas
- high-efficiency silicon solar cells
- multicrystalline silicon solar cells with high efficiency values
- thin-film solar cells of crystalline silicon
- development of solar cell materials from Si and III-V semiconductors
- III-V concentrator solar cells and systems
- III-V epitaxy
- gas-phase deposition of silicon for crystalline thin-film cells
- recrystallisation of silicon films with optical heating
- characterisation methods for silicon
- plasma technologies for photovoltaics
- innovative metallisation techniques for solar cells
- industrially relevant solar cell technology
- texturing, structuring and passivation of silicon surfaces
- development of production equipment for Si ribbons (SSP), Si deposition (CVD) and Si recrystallisation (ZMR)

Services
- studies on photovoltaics
- evaluation of novel processing sequences
- optimisation of manufacturing processes for solar cell materials
- small series of high-efficiency solar cells
- development of semiconductor characterisation procedures
- characterisation of semiconductor materials and solar cells
- calibration and characterisation of solar cells

Equipment
- clean-room laboratory
- standard solar cell technology
- industrially relevant production line (screen-printing, pad-printing, in-line RTP oven, in-line RTP diffusion oven)
- characterisation of solar cells: I-V characteristic curve measurement, SR, LBIC, PCVD, MSC, diffusion length mapping
- characterisation of materials: MW-PCD, MFCA, DLTS, CV, SPV
- chemical vapour deposition of Si: RTCVD
- plasma etching system
- liquid phase epitaxy for GaAs: LPE
- MOVPE for III-V epitaxy
- optical heating systems for silicon production and processing
- thin-film technology: plasma deposition, evaporation, galvanisation, contacting
- characterisation: X-ray diffraction, charge carrier lifetime measurements, photoluminescence, ellipsometer, IR Fourier spectrometer, glow discharge mass spectrometer, scanning electron microscope with EBIC, ECV profiling
- screen-printing and pad-printing for solar cells
- calibration laboratory for solar cells
- solar simulator for continuous exposure
- filter monochromator
- grating monochromator
- RTP equipment

Electrical Energy Systems
Klaus Preiser

Dr Tim Meyer from 1.1.2002

Research Areas
- products with integrated photovoltaic power supplies
- electronic components for batteries and photovoltaic systems
- charging strategies for storage batteries
- stand-alone photovoltaic power supplies
- operation management for stand-alone systems
- rural electrification in areas remote from the grid
- rural water supply and treatment
- grid-connected photovoltaics
- photovoltaics in buildings
- computer simulation and energy flow analyses
- development of precision measurement technology for photovoltaics
- decentralised electricity generation and storage in electricity grids

Services
- planning, construction and evaluation of photovoltaic systems
- prototype development and accrediting of photovoltaically powered products
- development of customised electronic components
- modelling, simulation, data acquisition and data analysis for photovoltaic systems
- off-grid power supplies for telecommunications and information systems
- calibration and characterisation of solar modules and solar generators
- visualisation and optimisation of photovoltaics in buildings
- training and consultancy in the solar energy sector
- electromagnetic compatibility (EMC) measurements of components and systems

Equipment
- calibration laboratory for solar modules
- pulsed solar simulator (flashlight)
- DC laboratory for testing and developing PV system components and consumer appliances
- lighting measurement laboratory
- development laboratory for photovoltaically powered industrial products
- test stands for multiple-cell batteries, hybrid storage units and power-conditioning devices
- outdoor test area for solar components
- development laboratory for power electronics
- AC laboratory with an inverter test stand and instruments to characterise electromagnetic compatibility EMC
- EMC measurement chamber
- pump measurement stand
- testing and development laboratory for drinking water purification systems

Research Trends in 2002

In many economic sectors, renewable energy and energy efficiency already belong to the standard technological repertoire. Their market share is growing strongly, they are beginning to penetrate mass markets. A good example is the building sector: Low-energy solar houses are becoming increasingly competitive in the private market.

Research which aims to support this diversification of applications must cover a wide spectrum: Bringing forth new materials, components, technology and application ideas is one constantly recurring aspect. The other aspect is orientation towards products and customers, which is determined by the market and responds to the needs of commercial enterprises. This type of research facilitates application, improves the economic viability, polishes up the final product, and guarantees quality and user satisfaction. The approaches encompass efficient calculation and simulation tools for professional planning and consultancy, rational production technology, quality control of components, dissemination of "lessons learned" from demonstration projects and preparation of standards, without losing sight of the overall effect - the object is to optimise the complete system, taking all technical, ecological, economic and social factors into account.
Fraunhofer ISE demonstrates this comprehensive philosophy clearly in its work on rural electrification. Not only scientists but also sociologists help to introduce Solar Home Systems in developing countries. The local users are involved in determining the introduction process and are able to service the technology themselves at the end of the project.

At the same time, applications-orientated research still depends on opportunities for creativity, where completely new approaches can be conceived and tested. Some examples of this type of applied fundamental research include the organic solar cell, the multiple-junction solar cell with potential efficiency values of 40 % and switchable nanostructures for optical applications.

Solar research today depends more than ever on interdisciplinary teamwork. From the high-flying visionary through the systematic calculator to the pragmatic engineer, all team members must be actively involved, so that good ideas are converted to successful products quickly and effectively. Applied research means supplying not only the basic idea but also the tools for production and marketing.

Thermal and optical systems

The buildings of the future will be largely self-sufficient with regard to energy. Fraunhofer ISE will combine with almost a dozen industrial partners in a major strategic project to establish the technical, planning and organisational basis needed for a fundamentally new approach to complete energy concepts for buildings.

Simulations make the complex interactions transparent and thus allow targets to be defined, also with regard to economic factors: Exact predictions mean that expensive tolerance factors can be avoided during planning, paving the way to "lean buildings". The accuracy is constantly being improved. At present, we work with one-minute averages for daylight, meteorological data and energy flows in buildings. Stochastic models will soon be able to represent individual user behaviour.

Integrated planning of the total energy supply gives the designer maximum freedom: The building owner can select from short-term economic viability as the highest priority, through additional solar options, to a building which supplies more energy than it consumes. Technical elements supporting this development in residential buildings include e.g. compact heating and ventilation units with miniature heat pumps to supply solar passive buildings with heat, and sorption storage units for seasonal thermal storage.

The more a building profits from solar gains, the more significant solar control also becomes. The research trend for windows is moving away from mechanical elements: Switchable glazing changes the transmittance of windows and skylights as desired, without moving parts. Microstructured surfaces deflect direct light in pre-determined directions.

Multifunctionality represents a general trend, not only for buildings. Whereas protective properties or aesthetics were the most important functions for a building envelope up to now, the surfaces of the future will also collect energy. Similarly, self-cleaning properties will be included among the multiple functions of future surfaces.

Commercial solar collectors for domestic hot water represent the technological state of the art. Research is now concentrating on two topics:

- Large systems
  Use of optimised control systems to make several applications feasible simultaneously: domestic hot water, heating suppport, air conditioning, industrial process heat.
- Access to new application areas
  Corrosion-resistant collectors can be used for seawater desalination to obtain drinking water, and desiccant cooling processes offer an environmentally acceptable method of air-conditioning, with water as the cooling agent and the sun as the driving power. Low-energy buildings shift solar space heating back into focus, with new materials and storage options.

Energy Technology

The focus on "micro-energy technology" reflects a general trend: smaller and more powerful. Fuel cells, which act as miniature power stations in battery format, could reflect a qualitative leap in electricity storage. Highly efficient, device-integrated solar modules guarantee power for recharging. Thermophotovoltaics converts heat into electricity without mechanical movement - with 100 % reliability even under the harshest environmental conditions, at remote locations.

The fuel cell has become a topic of major interest. Like a solar cell, it is modular, can be adapted as required to the demand and does not contain any moving parts. It supplies environmentally acceptable electricity from hydrogen with a high efficiency value. In the future, the generation of hydrogen by reforming gaseous or liquid fuels will play a central role, particularly for transport. Reforming is also the key needed to use natural gas in fuel-cell cogeneration plants, to provide energy for buildings. Furthermore, regenerative fuels can be used when biogas or bio-alcohols are reformed. Extremely pure hydrogen can be produced by electrolysis - an effective and environmentally friendly approach when combined with regenerative electricity generation.

Solar Cells - Materials and Technology

The common denominators for cells of crystalline silicon and III-V compound semiconductors are industrial relevance, improvement of efficiency and cost reduction. The Institute is following three approaches in these directions:

- Further developing well-proven materials: There is considerable potential to reduce the cost of the dominating market leader, crystalline silicon. The standard workhorses, block-cast and Czochralski silicon, can still win some races if spurred on by new production procedures. The next goals include rapid processing, the application of thin and extremely thin wafers and the industrial implementation of 10 x 10 cm^2 cells with an efficiency value of 20 %.
- Researching the technology of the next and the following generations: This includes the crystalline silicon thin-film cell, with its efficiency value of 20 %. The next aims are to use inexpensive substrates and large-area, continuous deposition processes.
  A different strategy is adopted with III-V high-performance cells, which are conquering the space market. For terrestrial applications, it makes sense to use them in concentrating systems, where significant cost advantages are achieved. The achieved cell efficiency value of 33.5 % can be further improved to above 40 %.
- Narrowing the gap between research and production: The production capacity is becoming larger, innovation cycles shorter, and the competition keener. Thus, research will include a growing component which accompanies production. Fraunhofer ISE is consistently following this approach with its production technology laboratory in Gelsenkirchen.

Electrical Energy Systems

Photovoltaics is overtaking a multimillion market in giant steps. The new Federal 100 000 Roofs Programme and the renewable energy law have opened wide the door to the market for grid-connected photovoltaics in Germany. Portable appliances and telecommunications are booming and Solar Home Systems have become a mass product. At the instant when the market finally begins to "pull", it is important that the market development be actively accompanied, so that the positive image of photovoltaics is preserved in its broad application. Examples include:

- Quality assurance: ensuring energy yields, certifying "green" electricity rates, exporting successful German models to other countries
- Energy distribution: preparing the reorganisation of grids to intelligent, customer-friendly, decentralised circuit structures in co-operation with electric utilities and industrial partners
- Rural electrification: involving local users, removing economic barriers with micro-finance, guaranteeing project sustainability with national testing laboratories, establishing new industries with local partners
- Bundling services: establishing off-grid power supplies for services such as telecommunications, drinking water supply and health care
- Electronics development: developing voltage converters, system controls and energy management systems to integrate decentralised electricity generators and storage units into portable appliances, off-grid power supplies and public electricity grids.

Hybrid systems are becoming increasingly popular for applications such as telecommunications equipment with stringent demands on reliability. In addition to PV systems for individual houses, power supplies for complete villages are growing in importance. In developing countries, the provision of clean drinking water is an increasingly significant application.

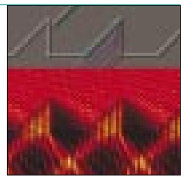
As has already been found in Solar Home Systems, it is becoming evident in all other stand-alone applications that batteries represent the weak link in the chain with regard to reliability and costs. Research is responding to this challenge with battery management concepts and the development of specifically tailored batteries.

The institute is looking for partners for development, production or marketing of these products and services, depending on the stage of development. None of the products is restricted by an exclusive licence.

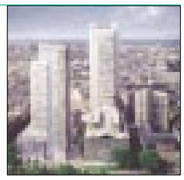
Product	Market/Sector	Fraunhofer ISE contact person, phone, email
micro-structured solar shading and light-redirecting films with partial viewing	windows and facades / solar shading	Dr Peter Nitz +49 (0) 7 61-45 88 -54 10 E-mail: Peter.Nitz@ise.fhg.de
reformer systems for hydrogen generation	car industry, oil industry, energy utilities, boiler manufacturers, municipalities	Dr Peter Hübner +49 (0) 7 61-45 88 -52 10 E-mail: Peter.Huebner@ise.fhg.de
catalytic burners	boiler manufacturers, energy utilities, municipalities	Dieter Schlegel +49 (0) 7 61-45 88 -52 09 E-mail: Dieter.Schlegel@ise.fhg.de
polymer membrane electrolysers in the low power range	gas suppliers, fuel cell operators, electrolyser manufacturers, operators of stand-alone power supplies	Ursula Wittstadt +49 (0) 7 61-45 88 –52 04 E-mail: Ursula.Wittstadt@ise.fhg.de
miniature fuel cels	manufacturers of electronic consumer appliances, sensor manufacturers	Dr Christopher Hebling +49 (0) 7 61-45 88 –51 95 E-mail: Christopher.Hebling@ise.fhg.de
laser processing methods	solar cells	Dr Ralf Preu +49 (0) 7 61-45 88 –52 60 E-mail: Ralf.Preu@ise.fhg.de
CVD silicon coating technology	semiconductor/PV industry	Dr Stefan Reber +49 (0) 7 61-45 88 –52 48 E-mail: Stefan.Reber@ise.fhg.de Dr. Albert Hurrle +49 (0) 7 61-45 88 –52 65 E-mail: Albert.Hurrle@ise.fhg.de
optical concentrator systems	photovoltaic industry	Dr Andreas Bett +49 (0) 7 61-45 88 –52 57 E-mail: Andreas.Bett@ise.fhg.de
SSP (silicon sheet from powder) technology	solar cells	Dr Achim Eyer +49 (0) 7 61-45 88 –52 61 E-mail: Achim.Eyer@ise.fhg.de
ZMR (zone-melting recrystallisation) technology	solar cells	Dr Achim Eyer +49 (0) 7 61-45 88 –52 61 E-mail: Achim.Eyer@ise.fhg.de
photovoltaically powered small appliances	telecommunications, telematics, industrial products	Werner Roth +49 (0) 7 61-45 88 -52 27 E-mail: Werner.Roth@ise.fhg.de
Charge Equalizer	battery industry, battery charging technology, motor vehicle industry	Dr Heribert Schmidt +49 (0) 7 61-45 88 -52 26 E-mail: Heribert.Schmidt@ise.fhg.de
state-of-charge meter for batteries	photovoltaics, electric vehicles, electric power supplies	Dirk Uwe Sauer +49 (0) 7 61-45 88 -52 19 E-mail: Dirk-Uwe.Sauer@ise.fhg.de

Reports from the Departments

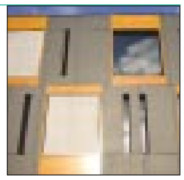
Research and Development in
Thermal Solar Energy and Optics



Measurement and Testing in
Thermal Solar Energy and Optics



Solar Engineering - Advising, Planning, Implementing



Energy Technology

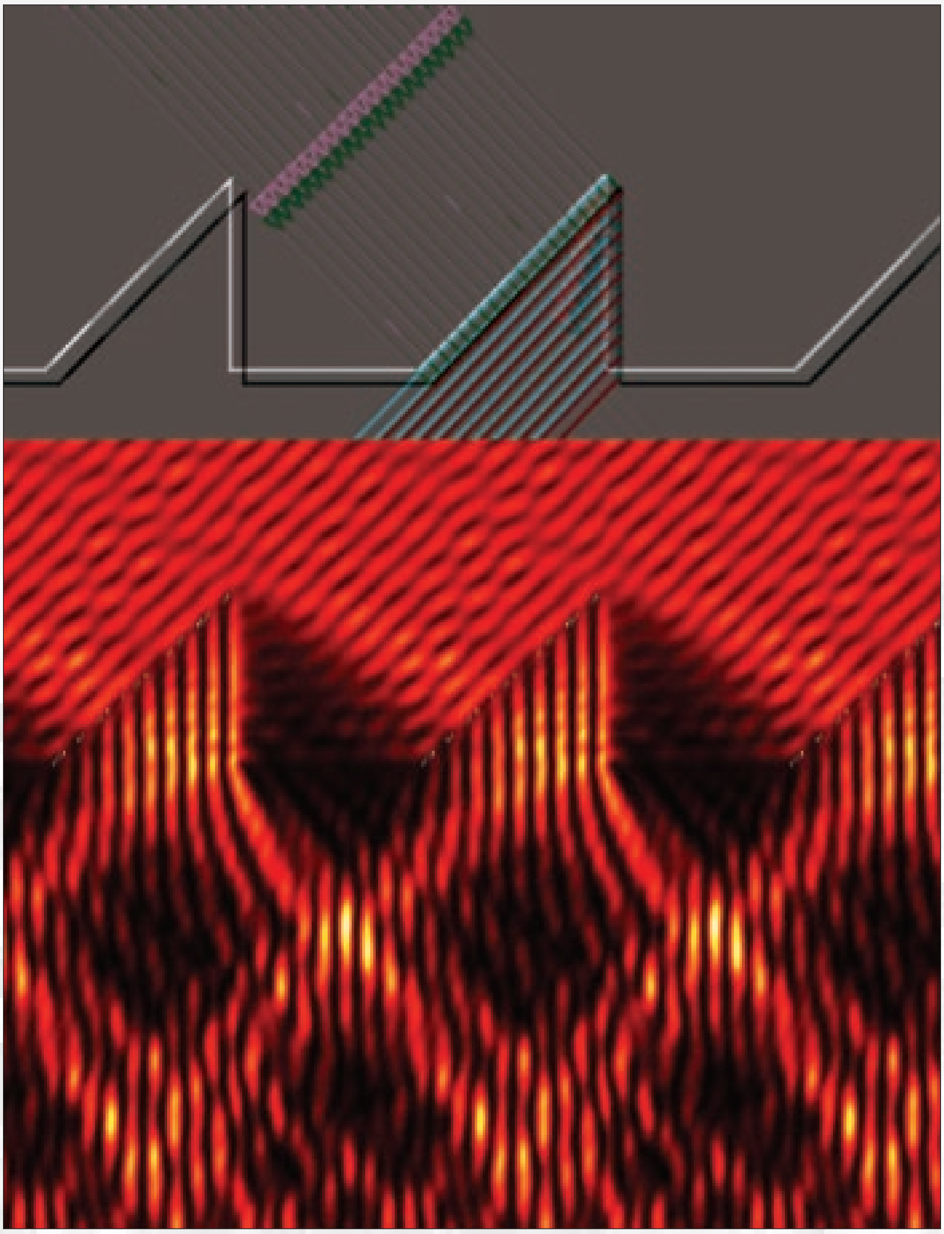
Solar Cells - Materials and Technology

ISE CalLab – Precision Measurement for Photovoltaics

Off-Grid Power Supply and Storage Systems

Electronics

Grid-Connected Electricity Systems



For architectural glazing, we are developing elements of microstructured transparent films to redirect light, and provide solar shading and glare protection. We simulate macroscopic light-redirecting structures as indicated above with optical ray-tracing methods. When microstructures are to be treated, beam optics is no longer valid. In optimising the optical functions of the elements, we take wave-optical effects into account with appropriate simulation tools. In the lower part of the illustration, the intensity distribution of light waves is represented with colour coding. Strong similarities to the beam-optical simulation (above) as well as purely wave-optical effects can be clearly recognised.

The building and residential market has a fundamental significance for the future from ecological and economic perspectives.

About a third of the end energy in Germany is consumed for heating and hot water. A gigantic potential to reduce CO_2 emission can be exploited by using energy efficiently and including solar energy. Many of these measures are already economically viable today. Rising energy prices make the market accessible to an increasing number of concepts, which were restricted to research and demonstration until only recently.

This is our starting point: We cooperate closely with manufacturers to develop materials and processes, so that new ideas and innovations can enter the market.

Two examples:
Surfaces gain special properties with the aid of extremely fine structures with dimensions from about 100 nanometres to several micrometres. As optically functional layers, they convert conventional products to innovations with add-on value, e.g. projection screens with improved image quality, cover glazing with higher transmittance for solar collectors or architectural glazing with selectively switchable solar control.

Interconnected controls optimise the complete energy supply to buildings, integrating electricity and heating. As buildings of the future will often be small, decentralised power plants, supplying energy to the grid, the control strategies will also react to requirements of the public grid and take account of weather predictions and electricity rates.

In this way, we apply our competence in renewable energy research to achieve attractive products on a rapidly expanding and sustainable market.

Contact partners

Coatings	Wolfgang Graf	Tel.: +49 (0) 7 61/4 01 66-85 E-mail: Wolfgang.Graf@ise.fhg.de
Analysis and energy optimisation of façades	Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-51 31 E-mail: Werner.Platzer@ise.fhg.de
Earth-to-air heat exchangers	Christian Reise	Tel.: +49 (0) 7 61/45 88-52 82 E-mail: Christian.Reise@ise.fhg.de
Light scattering and thermotropic layers	Dr Peter Nitz	Tel.: +49 (0) 7 61/45 88-54 10 E-mail: Peter.Nitz@ise.fhg.de
Nanostructured and microstructured materials	Dr Andreas Gombert	Tel.: +49 (0) 7 61/4 01 66-83 E-mail: Andreas.Gombert@ise.fhg.de
New collector concepts	Matthias Rommel	Tel.: +49 (0) 7 61/45 88-51 41 E-mail: Matthias.Rommel@ise.fhg.de
Control systems	Dr Christof Wittwer	Tel.: +49 (0) 7 61/45 88-51 15 E-mail: Christof.Wittwer@ise.fhg.de
Sorptive materials	Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-51 34 E-mail: Hans-Martin.Henning@ise.fhg.de

Surface Structures for Re-Direction of Light

Many applications in lighting technology aim to redistribute light in well-defined directions. We develop large-area, microstructured surfaces which meet this goal.

Benedikt Bläsi, Volkmar Boerner*, **Andreas Gombert**, Volker Kübler, Michael Niggemann

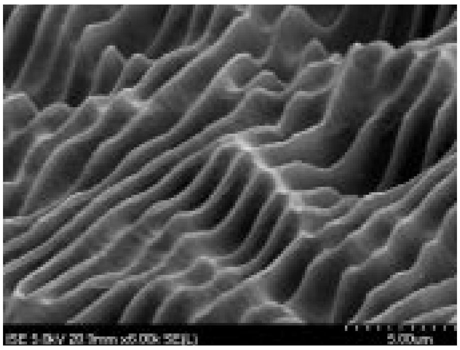


Fig. 1: Microstructure in photoresist.

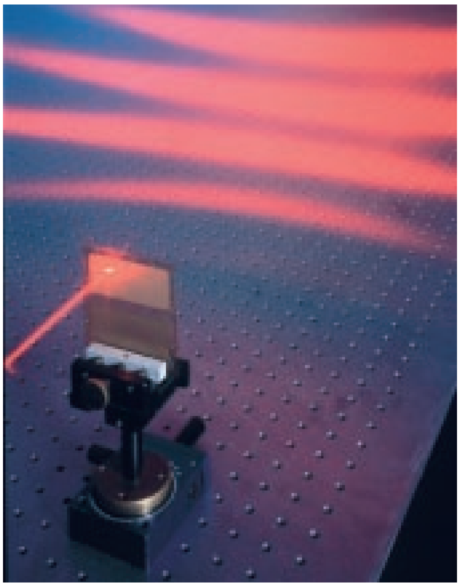


Fig. 2: Deflection of a HeNe laser beam by surface structures.

Re-directing light in specified directions is required in such varied applications as projection and lighting systems, beam shapers for light-emitting diodes and components for improved daylighting. Taking projection screens as an example: The light incident on the screen should be directed only into the space where viewers are located. This enables bright reproduction of the projected image. As the viewing space is generally wider than high, isotropically scattering screens are very unfavourable.

We develop microstructured surfaces which redistribute light into certain specific directions. Surface structures can be produced inexpensively, as the original, sophisticated structure can be reproduced in large quantities by embossing or casting processes.

We apply interference lithography to create the original structure. A laser beam is split, expanded and superposed. The superposition results in interference patterns, which are used to expose a photo-sensitive coating, called photoresist. During development, the photoresist is removed selectively and the surface structures result (figures 1 and 2). The advantage of interference lithography is that even very small structures can be produced homogeneously and inexpensively over large areas. At present, we generate original structures over areas of 60 x 80 cm^2.

When plane waves are superposed for interference lithography, periodic structures result. By contrast, when strongly deformed wavefronts are superposed, the resulting structures have a size distribution which can be determined. The two types of structures can also be combined, leading to great flexibility. Thus, we can technically produce practically any type of light distribution which is physically possible.

Our clients use the original structures we have developed to produce embossing stamps by galvanisation, for microreplication processes such as hot embossing, UV curing and injection moulding.

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* Holotools GmbH, Freiburg

Solar Control and Daylighting with Microstructures

Architects today design highly transparent building façades and include daylighting in their planning. High expectations of energy efficiency and visual contact, together with thermal and visual comfort, can only be achieved by selective treatment of the incident solar radiation. The combination of novel microstructured, light-redirecting elements with switchable coatings opens up new possibilities here.

Benedikt Bläsi, Christopher Bühler, Andreas Georg, Andreas Gombert, Jörg Mick*, **Peter Nitz**, Volker Wittwer

Microstructured surfaces can split light beams and deflect them in specified directions. Applied as a film to a glass pane, suitable structures can provide effective solar control. An insulating glazed unit can be transformed into a daylighting or sun-shading element.

Specially developed, novel structures allow partial viewing in addition to their light-deflecting or solar control functions. Thus, they are suitable for application over large areas in vertical façades (fig. 1). Visual contact to the surroundings, which is important for many façade applications, is retained with these structures, despite effective protection against direct sunlight. At the same time, the structures have high transmittance for the bright zenith skylight, and re-direct it toward the back of the room (fig. 2). This means that the room can be illuminated with natural daylight.

* University of Freiburg, Institute for Microsystem Technology

If the light from the low winter sun or deflected light is still too bright e.g. for work at computer screens, the function of the microstructures can be improved further by covering certain areas with switchable coatings. These could be used to selectively switch e.g. the "noses" in fig. 1 from transparent to opaque, and thus control the amount of daylight as desired, without reducing the existing partial view.

In the "Mikrofun" basic research project, which is funded by the German Federal Ministry of Economics and Technology BMWi, we are establishing the know-how and the technology which will allow us in future to develop glazing products in close co-operation with industry.

We can structure large areas in one step with interference-lithographic methods. At present, structure periods between 0.3 µm and app. 15 µm can be created. The diffraction effects which appear with these dimensions are taken into account when designing and optimising the structures.

The aim is to produce embossing tools which are homogeneously structured over large areas, and thus to replicate the structures in films at low cost.

By applying physical vapour deposition methods, we can deposit switchable tungsten oxide films over complete surfaces or selected facets with predefined orientation. The film transmittance is switched with low concentrations of hydrogen or oxygen ("gasochromic switching"), as has already been demonstrated on non-structured glass panes in test façades at the institute.

We calculate and optimise the optical behaviour of the novel microstructures both with ray-tracing methods and rigorous wave-theoretical analysis.

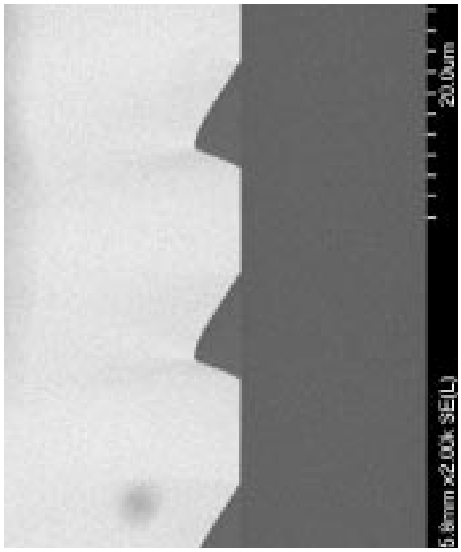

Fig. 1: Cross-section of a novel microstructure with a solar shading function and partial view. It will be mounted e.g. as a structured film on a window pane. Light obliquely incident from the upper left (summer) is initially refracted by the "noses" into the structure, and then leaves it again after total internal reflection. Light from the low winter sun enters the room without obstruction. The vertical sections of the structure always allow a clear view of the surroundings.

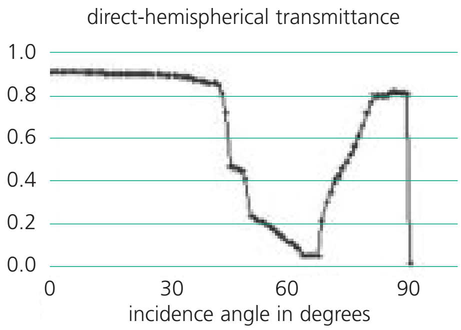

Fig. 2: Transmittance of a structure similar to that shown in fig. 1 (ray-tracing calculation). Summer light with incidence angles between 45 and 67 degrees is rejected by the structure.

Integration of Complex Daylighting Systems into the Planning Process - Further Development of Software Tools

Innovative daylighting systems promise efficient use of daylight, better working conditions and lower energy consumption. We extend simulation tools to calculate these daylighting systems and thus make them accessible to planners.

Jan Wienold, Roland Schregle*, Christian Reetz **

Many innovative daylighting systems are already on the market, others are being developed. The spectrum ranges from light-scattering surfaces, through stationary, light-deflecting systems, to movable reflectors based on metal or dielectric mirrors. In addition to multifunctional glazing, intensive efforts are being made to further develop solar shading systems, which are intended to provide daylight at workplaces without causing glare or overheating. Specifying these characteristics reliably and quantitatively is an ambitious task. To date, computer-supported simulation tools have been unable to predict the effects of many of these systems on the room behind them (fig. 1).

Fig. 1: Example of an effect of light-deflecting glazing, which cannot be calculated with existing simulation tools.

A research project which started early in 2001 aims to remove this obstacle. A user-friendly extension of the RADIANCE daylighting simulation program, based on an optical forward ray tracer, will assist developers of innovative systems in planning and optimisation. An independent, user-friendly program module to calculate and analyse diverse daylighting systems will be developed for building planners.

With these two extensions, systems can be appropriately specified and evaluated already during the development and planning phases. An integrated data bank will summarise all system data, specifications, images and application examples.

This project, which is funded by BMWi, is proceeding in co-operation with the Fraunhofer Institute for Building Physics IBP and system manufacturers. At the same time, it is a German contribution to the IEA group, "Daylighting in a New Century".

* University of Freiburg, Freiburger Materialforschungszentrum FMF
**PSE GmbH Forschung Entwicklung Marketing, Freiburg

"ConCheck": Developing and Testing Control Systems for Large Solar Thermal Systems

Up to now, most solar collectors have been mounted on free-standing and semi-detached houses. Increased application in high-density housing is needed if thermal solar energy is to be used more widely.

Konrad Lustig, **Matthias Rommel**, Arim Schäfer, Christof Wittwer

We investigate domestic hot water systems with collector arrays exceeding 100 m^2 (fig. 1). Many systems have inadequate control systems, which affect both the storage of solar heated water in the buffer tank and the heat transfer to pre-heat the domestic hot water. Thus, it can happen that the water is heated conventionally, although solar heat is available. In addition, a whole new series of questions arise in connection with future systems for supporting space heating.

The project entitled "Development and testing of control systems to charge and discharge large, solar thermal systems" thus has the following three goals:

The first goal is to answer the questions concerning controls technology by computer simulation. Four system variants each for charging and discharging will be combined and simulated with different control strategies, in order to fully exploit the potential offered by controls technology for systems designed purely for hot water heating.

The second goal is to answer the fundamental questions on controls technology which arise when systems with collector areas significantly exceeding

Fig. 1: System with a large collector area on a multi-storey building, from the "Solarthermie 2000" programme.

100 m^2 are to be constructed, not only for domestic hot water but also for space heating support. To do this, we will model the system by simulation and analyse the controls technology of three system variants.

The third goal is the development of a component set consisting of a heat exchanger, pump and controls for charging and discharging large thermal systems. It should be produced centrally, and largely pre-constructed and pre-assembled. These component sets, or heat transfer stations, will be installed and tested in two systems within the "Solarthermie 2000" funding programme.

For the investigations, we will use the open ColSim simulation environment, which was developed at Fraunhofer ISE. ColSim provides sufficiently accurate models and the time step resolution needed to investigate control strategies in detail. Furthermore, the control algorithm can be programmed in ANSI-C code and transferred directly to the control system.

The data for our investigations originate from systems within the "Solarthermie 2000" programme. Both it and the ConCheck project are funded by BMWi.

Micro-Encapsulated Phase Change Materials in Composite Wall Panels

Introducing phase change materials (PCM) into the wall construction of buildings increases their heat capacity. In a specific temperature range, sensible heat from the room is converted to latent heat of melting, and the room temperature cannot rise further.

Thomas Haussmann, Hans-Martin Henning, Alexandra Raicu*,
Peter Schossig

An increase in heat capacity is often desirable to cap peak loads and to release the stored energy at a more favourable time, e.g. during the night. In this way, overheating of office buildings in summer can be avoided. Particularly lightweight constructions benefit, both with energy savings and appreciably enhanced comfort.

Micro-encapsulation of paraffins is a technology which now allows PCM to be incorporated simply and inexpensively in conventional building materials.

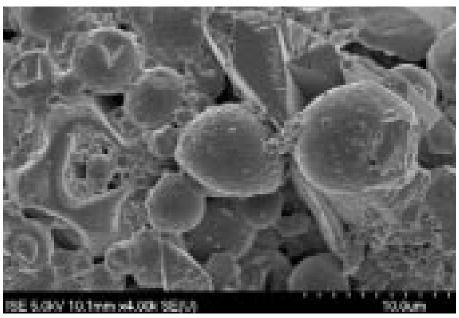

Fig. 1: Microscopic image of micro-capsules in the composite material.

We co-operate with our industrial partners, BASF, DAW, Maxit and Sto, to identify relevant application areas and develop marketable systems.

In the initial phase, we estimated the potential with building and component simulation, and set up a test stand for wall panel samples with dimensions of 50 x 50 cm^2.

This year, the first demonstration buildings were equipped with PCM products from our industrial partners. They are being monitored intensively and are providing the first practical experience.

To validate and refine our simulation models, we have equipped two identical cabins of Fraunhofer ISE's façade test stand with detailed measurement technology. PCM will be mounted in one cabin, the second serves as a reference. This experiment allows the PCM effect to be evaluated quantitatively and independently of user behaviour.

The joint project is funded by BMWi.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Materials Research for Adsorption Heat Storage: Application of Molecular Computer Simulation

Adsorption heat storage units allow heat to be stored over long periods with almost no losses. The current goal is to increase the thermal storage density by a factor of four compared to water tanks. Increasing the energy density primarily demands new adsorption materials, and thus presents new challenges to materials research.

Hans-Martin Henning,
Ferdinand Schmidt,
Stefan Henninger, Tomas Núñez

Adsorption is the accumulation of gas molecules on the surface of solids. During this process, heat is released, similarly to condensation of a gas to form a liquid. If heat is supplied, the adsorbed gas can be driven out again. We aim to use this cycle for storing heat. The more porous the internal surface of the solid is, the higher is its storage capacity. Silica gel and zeolites are microporous solids with large internal surfaces. The amount of gas adsorbed is a function of the gas pressure and temperature. We are now searching for materials with adsorption properties for water vapour that are optimally matched to the pressure and temperature conditions of the system cycle: For a given temperature of the heated water (heating system load) and regeneration temperature (solar collector), the exchanged sorptive heat should be as large as possible. The adsorbents which are commercially available today were optimised for quite different applications.

A wide range of modifications can be made by materials synthesis to alter the adsorption properties of both zeolites and silica gel type materials. However, it is not yet known which properties concerning molecular interactions in the micropores result in the adsorption characteristics needed for the storage application. In order to modify the materials synthesis appropriately, we need fundamental understanding of the microscopic materials parameters: How do the chemical structure of the pore surfaces, the pore geometry and variation in these parameters (structural heterogeneity) affect the adsorption performance?

We apply molecular computer simulation to answer these questions (fig. 1). Adsorption equilibrium in a modelled pore is calculated based on model assumptions for the intermolecular interactions. Monte Carlo simulation, employing the numerical generation of random numbers, is the method used. In this way, the influence of the materials parameters can be investigated for idealised model adsorbers. Particular care must be taken in validating the potential models for the molecular interactions.

We are working on these questions in co-operation with the School of Engineering and Applied Science, University of Pennsylvania (Philadelphia, USA).

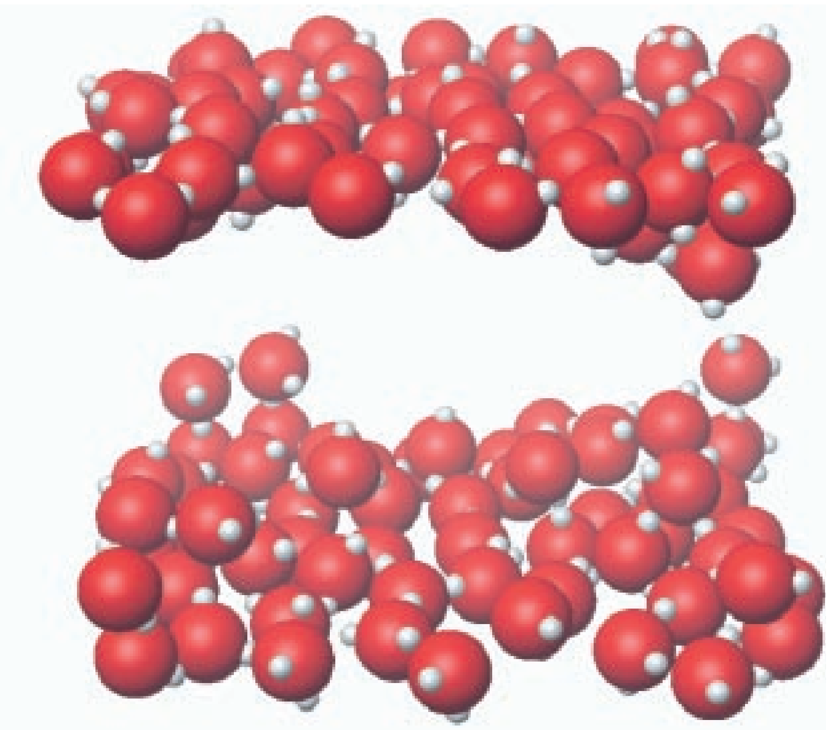

Fig. 1: Instantaneous image from simulation of water molecules in a slit-shaped pore with a smooth, non-polar surface. The large spheres represent oxygen atoms, the small ones hydrogen. The two pore surfaces are located directly above and below the water molecules; they are not shown here.

New Integrated Energy Supply Concepts for Buildings

Fraunhofer ISE is heading a consortium of twelve industrial partners to develop new systems and components for housing energy supplies and test them in field trials: fuel-cell based cogeneration plants, compact heating and ventilation units for solar passive houses, sorption-based storage units and new controls concepts.

Andreas Bühring, Sebastian Bundy,
Carsten Dittmar, Ulf Groos,
Peter Hübner, Walter Mittelbach,
Tim Schmid*, Matthias Vetter,
Christof Wittwer, **Volker Wittwer**

Fuel-cell based cogeneration plant

Decentralised generation of electricity and heat can reduce emission of pollutants and CO_2.
A new, fuel-cell based cogeneration plant is being developed within the project. We are designing the reformer for it. The pre-condition for environmentally beneficial use of these systems is modern energy management, which is also able to use solar gains optimally.

Compact ventilation units

We co-operate with industrial partners to develop compact heating and ventilation units as heat supplies for passive houses. They can be equipped with an integrated exhaust air heat pump or a small fuel-cell based cogeneration plant. Auxiliary components for free-standing, low-energy houses, and a new, decentralised unit to supply energy for apartment buildings, will be developed.

We have set up a test stand for compact heating and ventilation units, which allows measurements to be made under a wide range of operating conditions (fig. 1). We carry out test procedures running several days under reproducible boundary conditions (EN 255).

Storage concepts

Thermal storage units to buffer the heat supply and demand are decisive for optimised operation of fuel cells and compact heating and ventilation units. We are investigating stratified water tanks and novel sorptive systems (fig. 2).

Control concepts

Simulation of components and complete systems, including the controls systems, provides important information on system dimensioning, material strains, efficiency and operation management strategies. To design the controls, we model the complete energy supply system with computer simulation, e.g. fuel-cell based cogeneration plant, buffer tank and heating circuit. This allows us to predict the dynamic system behaviour and investigate any particular operating point.

The controls system which has been tested in the virtual system can then be ported to "embedded systems" (electronic controller units, fig. 3) without needing to be implemented again. They include interfaces for integration into Intranet and Internet. Reaction to weather forecasts or communication with the energy utility is also possible. "Learning" dynamic electricity and gas rates and "awareness" of user behaviour is important for an optimal controls strategy. To achieve this, we are developing concepts and communication protocols in co-operation with energy utilities.

Fig. 1: Test stand for compact ventilation units in the Freiburg Solar House.

Fig. 2: Sorption storage unit in the Freiburg Solar House. The photo shows two containers filled with sorption agent and a water tank, which also contains the evaporator and condenser.

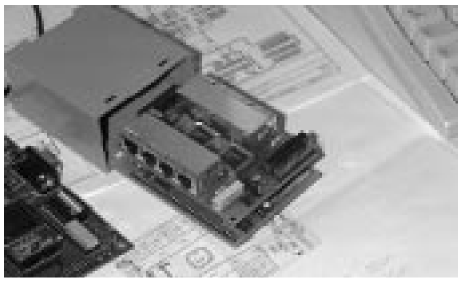

Fig. 3: Prototype of an embedded system.

BMWi is supporting all aspects of this work within the strategic NEGEV project.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Photovoltaic Battery

By combining a dye-sensitised solar cell with an ion intercalation layer, we have constructed a photovoltaic battery. It can convert light to electricity and store it. One application is as a power supply for small devices which still need to operate when the light is dim.

Daniel Abou-Ras*, **Andreas Georg**, Wolfgang Graf, Anneke Hauch*

Configuration:

A substrate (fig. 1) is coated with an electrically conductive electrode and a porous intercalation layer (e.g. WO_3). A nanoporous TiO_2 film is then deposited as the next layer. The surface of the TiO_2, which is greatly increased due to the porosity, is covered with a monolayer of a dye. The pores and the spaces between the TiO_2 and the counterelectrode (500 µm in fig. 1) are filled with an electrolyte, in which lithium iodide (LiI) is dissolved. The counterelectrode consists of a second substrate which is covered with a transparent electrode and coated with a thin, transparent Pt layer. The two electrodes supply an external load with electricity. In principle, the TiO_2 film and the intercalation layer could be exchanged or combined to form one layer. This is advantageous for special applications or production processes.

Charging process:

When illuminated, a dye molecule is excited to a higher energy level (upper half of the illustration). It donates an electron to the TiO_2, which conducts it to the WO_3. There, it reduces the tungsten. The dye gains its electron again from an I^- ion in the electrolyte, which is oxidised to I_3^-. The excess Li^+ ions diffuse through the porous TiO_2 into the WO_3 layer, maintaining charge equilibrium.

Discharging process:

If the two electrodes are connected via an external switch (lower half of the illustration), the electrons from the WO_3 can flow to the counterelectrode and provide energy for work. At the counterelectrode, platinum catalyses the reverse reaction of I_3^- to I^-. At the same time, Li^+ ions return to the electrolyte.

Initial measurement results

To produce the first laboratory samples, we applied sol gel procedures to make pastes suitable for screen-printing processes. The samples produce a potential of 0.6 V and a charge storage density of 1.8 C cm^{-2}. In the dark, the maximum discharge current is 5 mA cm^{-2}, and under illumination a current of 1.3 mA cm^{-2} flows continuously. The charge can be stored for more than a day. Storage for weeks to months is not yet possible.

During periods of maximum solar irradiation, the photovoltaic battery is charged within an hour. Lower irradiation intensity reduces the charge and voltage only slightly. For example, when the solar irradiation decreases from maximum to one seventh of this value, the stored charge decreases by 40 % and the voltage by only 17 %. This makes the system particularly suitable for applications under dim lighting. The storage capacity can be increased with thicker intercalation layers or use of other oxides.

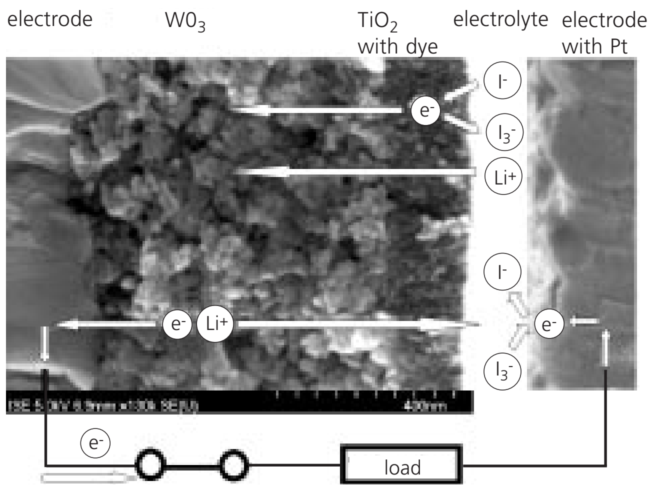

Fig. 1: Configuration and operating principle of the photovoltaic battery. The SEM image shows the pores to scale, but not the layer thicknesses. The true layer thickness of the WO_3 is typically 50 µm, of the TiO_2 is 10 µm and the electrolyte 500 µm (white stripe to the right). The material transport is shown schematically during charging (upper half) and discharging (lower half). The light comes from the right.

* University of Freiburg, Freiburger Materialforschungszentrum FMF

Dye-Sensitised and Organic Solar Cells

Dye-sensitised and organic solar cells have been the subject of research around the world for some time now. Completely different materials to those found in conventional solar cells are used in these cells, which have a high potential for cost reduction. Before industrial production of dye-sensitised and organic solar cells can be considered, the following questions must be resolved: long-term stability, efficiency, module and production concepts, manufacturing feasibility, testing of cells and modules.

Simone Baumgärtner*, Udo Belledin*, Anneke Hauch*, **Andreas Hinsch**, Rainer Kern, Michael Niggemann, Ronald Sastrawan*, Marion Schubert*, Jochen Wagner*, Uli Würfel

Since the beginning of the year, we have intensified our research on dye-sensitised and organic solar cells. The main goals were to set up baseline laboratory production of dye-sensitised solar cells and to increase the efficiency of organic solar cells with nanostructured electrodes. Further topics include tests of long-term stability and further development of characterisation methods such as impedance spectroscopy and time-resolved measurement methods.

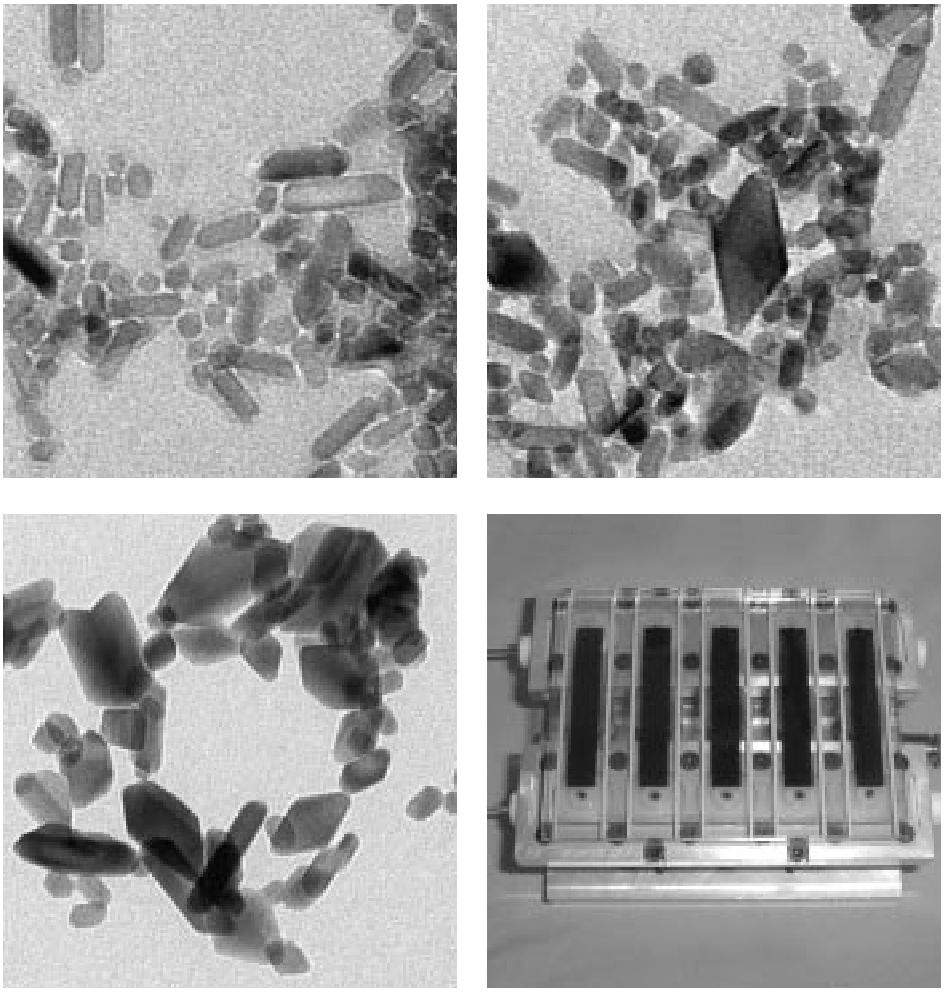

Fig. 1: Transmission electron microscope (TEM) images of titanium dioxide nanoparticles. Because of their large surface area, these nanoparticles are used in the photoelectrode of dye-sensitised solar cells. The lower right photo shows five identical test cells on a common plate during the staining production step.

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The baseline production is designed for demonstration modules with an area of 30 x 30 cm^2 and for the reproducible preparation of many test cells. We have focussed on:

- accurate screen-printing or stencil printing
- thermal sealing techniques with glass solder or ionomers
- equipment to structure the glass substrates
- dispersion units to prepare the screen-printing pastes
- filling stations to fill the cells and modules with dye or electrolyte solutions

The baseline production will be operational in the middle of 2002.
The work at Fraunhofer ISE is integrated into activities at the Freiburger Materialforschungszentrum FMF, Freiburg. This applies particularly to the synthesis of nanocrystalline metal oxides and investigation of electrically conductive polymers and strongly light-absorbing semiconductor nanoparticles. As participants in the European NANOMAX project, we co-operate with other leading research groups in the field of dye-sensitised solar cells. Recently, the calibration laboratory at Fraunhofer ISE measured the record efficiency value of 8.2 % for a 2.5 cm^2 dye-sensitised solar cell with which our group had been involved.

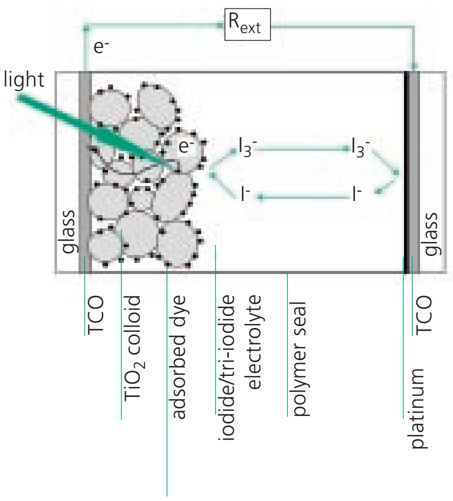


Fig. 2: Configuration of the dye-sensitised solar cell. See the text in the right-hand column for the operating principle.

Organic solar cells still have low efficiency values of about 2.5 % under AM1.5 conditions. The main reason is the low absorptance of light in the thin organic layers. New material concepts, but also improvement of the optical properties could change this. We are aiming to increase the light absorptance by embossing nanostructures onto the surface. In doing so, we can draw on the years of experience at the institute with large-area nanostructuring of polymer materials. The experiments are supported by modelling the electric field distribution in the structured absorber layers with rigorous coupled wave analysis (RCWA). In addition, we are working on cell concepts that are practical for production.

Fraunhofer ISE is co-ordinating two joint and network projects, which are funded by BMBF, with participants from universities and other research groups in Germany and Austria.

Configuration and operation of a dye-sensitised solar cell:
TiO_2 crystallites with typical dimensions of 20 nm form a nanoporous layer about 10 µm thick (fig. 2), which is deposited on a TCO-coated substrate (TCO = transparent conducting oxide, e.g. $F:SnO_2$). Dye molecules (usually a ruthenium dibipyridyl complex) are adsorbed on the surface. Facing the TiO_2 electrode and about 10 µm away is a platinum-coated TCO glass substrate. The pores of the highly porous nanocrystalline TiO_2 layer and the space between the two electrodes is filled with an electrolyte. This electrolyte usually consists of an organic solvent with a redox couple, e.g. iodide and tri-iodide anions.

An incident photon excites a dye molecule. The excited electron is rapidly injected into the conduction band of the TiO_2. The ionised dye is reduced by converting iodide to tri-iodide.
The electrons then flow in the TiO_2 conduction band to the TCO electrode, from there via an external load to the platinum-coated counter-electrode and then are transported by the electrolyte back to the dye:
Tri-iodide accepts electrons at the platinum catalyst and is thereby converted back to iodide.

Configuration and operation of an organic solar cell:
In an organic solar cell, the charge carriers are generated and separated in a thin (sub-micrometre) absorber layer, which consists of a mixture of n-conducting and p-conducting organic materials. Multi-layer systems or stacks of these materials are also possible. The external separation of the charge carriers happens specifically at the electrodes, i.e. a transparent con-

ductor such as ITO (indium-doped tin oxide) and a metal film. This is shown in fig. 2 for a variant developed at the University of Linz, in which a mixture of n-conductive fullerenes (1-(3-methoxycarbonyl)-propyl-1,1-phenyl-6,6-C61) and p-conductive PPV (poly-p-phenylene vinylene) is used.

Apart from the successful optimisation of the substituted fullerene in this concept, there has hardly been any specific materials development for organic solar cells. The currently used p-conductive and n-conductive materials originate from the international development of polymer LED's and are optimised for this application. Thus, in future the palette of available polymer or oligomer semiconductors should be extended, and their characteristics adapted to the specifications for use in solar cells. Adaptation of the layer morphology to achieve the longest possible charge carrier lifetimes will also play an important role for further developments.

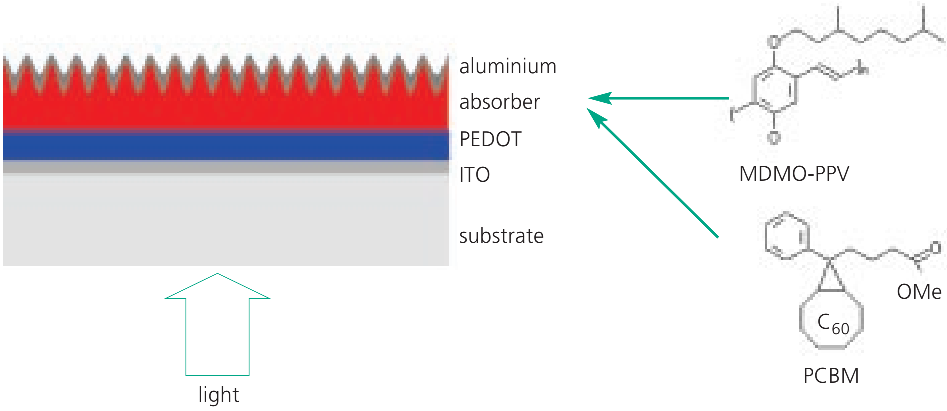
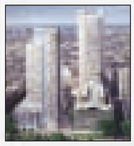


Fig. 3: Configuration of an organic solar cell as developed at the University of Linz. The periodic nanostructure can be seen, which was developed at Fraunhofer ISE to improve light coupling into the absorber layer. The electric contact to the transparent ITO layer is made with a commercially available conductive polymer, PEDOT.

Fraunhofer ISE has evaluated the solar shading effect of different façade types for the planned GALLILEO skyscraper of the Dresdner Bank (to the left of centre). A new feature of the evaluation was that the following parameters were taken into account: typical meteorological data, angle-dependent g values and different strategies to control the slat tilt angle of the venetian blinds (see article on p. 40).



A young market is like a young plant. It needs greater attention and care – in this case, quality assurance. Solar energy affects many aspects of everyday life and competes with technology which was new 100 years ago and has had time to mature since. If a new product does not bring the performance or lifetime which the user expects, the widespread positive attitude toward renewable energy can quickly turn into general scepticism.

We thus co-operate with the industry and standardisation bodies in drawing attention to high quality. We develop measurement procedures for new products, and conduct extensive long-term measurements to check whether the technology will still perform as well after 20 years of usage as it originally did in the laboratory. Our clients benefit in three ways:

Tests under defined conditions allow the user to compare products and enable manufacturers to assess new technology.

As globalisation expands, standardisation is becoming increasingly important. By participating in international projects (EU, IEA) and standardisation committees, Fraunhofer ISE is involved in defining new testing and standardisation procedures, and can represent the interests of the German economy.

The refinement of measurement technology and the development of accelerated ageing tests shortens the route from a prototype to the final product and provides the certainty needed for guarantees.

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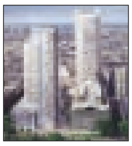


Transparent Building Façades: Evaluating Solar Thermal and Optical Properties

Transparent façades provide rooms with sunshine and daylight, and allow visual contact with the surroundings. At the same time, protection against overheating and glare must be ensured.

Ulrich Amann, Angelika Helde, **Tilmann Kuhn**, Werner Platzer, Jan Wienold

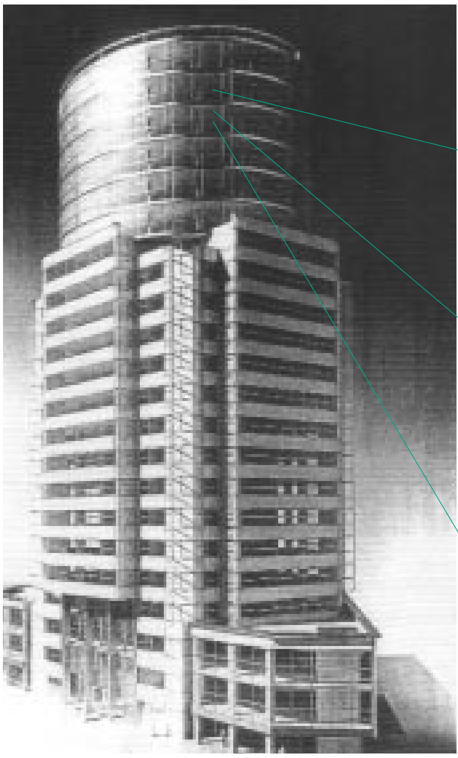


Fig. 1: Planned GALAXY high-rise building for the Commerzbank in Vienna. The planning predictions become more reliable when different strategies to control the solar shading and glare protection systems are taken into account. In particular, systems can be selected which are not too sensitive to "inappropriate operation".

Often the façade system control strategy and the angular dependence of solar irradiation are not taken sufficiently into account when buildings are planned. We develop new evaluation methods, act as consultants in planning teams and participate in the European Committee for Standardisation on questions concerning visual and thermal comfort.

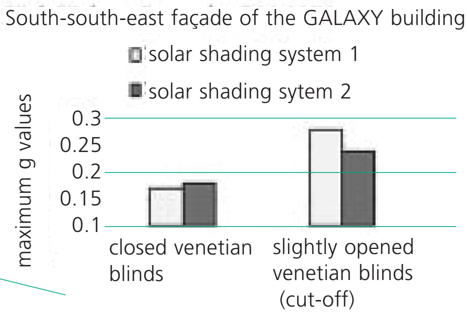


Fig. 2: The effectiveness of the solar shading devices depends strongly on the way in which they are used. The ranking of the different systems is reversed if the venetian blinds are not closed.

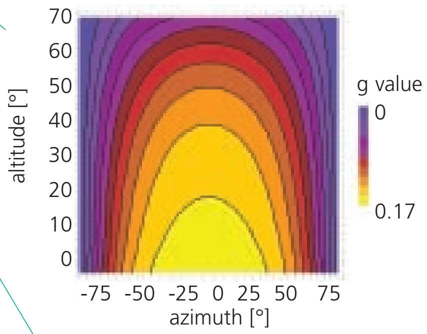


Fig. 3: Angle-dependent g values.

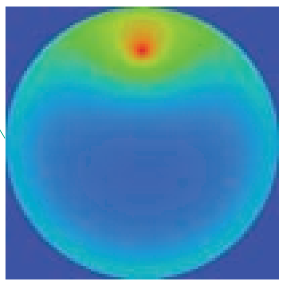
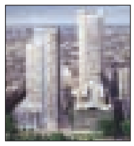


Fig. 4: Typical sky luminance values.

We applied our research results in practice during the planning phase for the high-rise buildings, GALAXY for the Commerzbank in Vienna and GALLILEO for the Dresdner Bank in Frankfurt am Main. Our contribution was to investigate several systems for each façade and different control strategies (slat tilt angle of venetian blinds as a function of the sun's position). We documented the advantages and disadvantages as the basis for decision by our client, Bug-Alutechnic, from Kennelbach in Austria. The following factors motivated the decision for internal venetian blinds:

- Not sensitive to inappropriate usage, neither as solar control nor as glare protection. We eliminated systems which function well only for very well-defined user behaviour, but are ineffective otherwise.
- The maximum g values, as determined for typical meteorological data for Vienna or Frankfurt, must be below certain limits, so that energy-saving dimensioning of the cooling system can be achieved.
- The frequency distribution for g values, based on hourly values for typical solar irradiation, was evaluated for the period from 21st June to 21st September. In doing so, we also took different control strategies for the slat tilt angle into account.

Together with Bug-Alutechnic, we will summarise the results of the investigation in a user manual, so that they are accessible to all future users of the building.



SWIFT - Switchable Façade Technology: Transparent Façades with Switchable Light and Energy Transmission

It is not sufficient to technically develop and test new products for buildings - they must also be equipped for integration into the complete building system. Future planners and customers need information and guidelines on how best to incorporate the new functionality and features, both architecturally and technically.

Ulrich Amann, Sebastian Bundy, Markus Heck*, Angelika Helde, Michael Köhl, **Werner Platzer**, Jan Wienold

Electrochromic glazing from Flabeg in Fürth, and gasochromic glazing (fig. 1) from Interpane in Lauenförde, forms the basis for transparent façades with switchable transmission of light and energy. Both types are being comprehensively characterised, evaluated and optimised in the EU-funded SWIFT project. Twelve partners from industry and research are participating in the project, which is co-ordinated by Fraunhofer ISE. Façade construction, controls, complementary artificial lighting and control algorithms for all components complement the glazing units. Two companies, Philips Lighting B.V. in Eindhoven and Metallbau Boetker in Stuhr, are working intensively on these aspects.

Many different aspects are being addressed in the project:

- The dynamic optical and thermal properties of the façades are tested in the laboratory and measured over longer periods of time in test façades.
- Durability and stability are investigated in accelerated ageing tests and outdoor exposure.
- This requires adaptation and further development of existing testing procedures to accommodate the new systems.
- The integration of switchable façade systems into the architecture and technical systems of a building is optimised. Controls for artificial lighting, the façade and cooling will be optimised simultaneously.
- Maximal thermal and visual comfort should be accompanied by minimal energy consumption. Evaluation in real offices provides information about the preferences and behaviour of users.

So far, in the project we have thoroughly characterised the façade systems optically and thermally, and described them in simulation models, so that we can optimise them in extremely diverse climatic zones for different usage profiles (figures 2 and 3). The long-term investigations have begun, so that we expect results next year.

Two handbooks on architectural and technical integration of switchable façades will be produced for building specialists, in addition to specific data and background information for the participating companies.

Fig. 1: View through coloured gasochromic glazing, equipped with temperature sensors at Fraunhofer ISE's façade test stand.

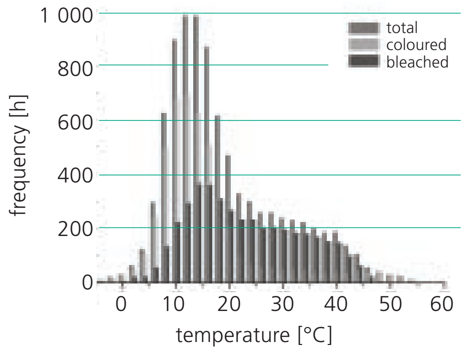


Fig. 2: Frequency distribution of surface temperatures for the coated glass pane in a gasochromic insulating glazing unit (hours per year).

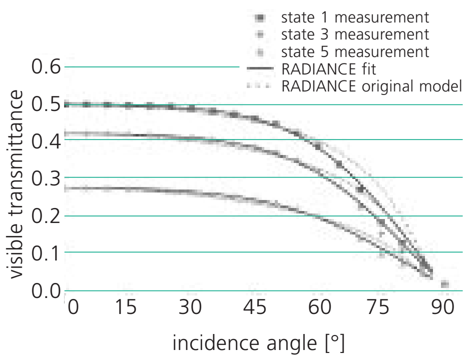
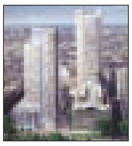


Fig. 3: Visible transmittance - modelling the different switching states of electrochromic glazing in the RADIANCE daylighting simulation program (state 1: completely bleached; state 3: intermediate; state 5: completely coloured).

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg



Performance, Durability and Sustainability of Innovative Windows and Solar Components

Innovative products with completely new functional properties and application areas, such as switchable windows, are being developed and introduced to the market at a rapidly increasing pace. Under the leadership of Fraunhofer ISE, 35 international partners from industry and research are co-operating within Task 27 of the Solar Heating and Cooling Programme of the International Energy Agency (IEA) to develop the basis for applications-orientated testing and evaluation of solar components.

Andreas Gombert, Bettina Greiner, Markus Heck*, Michael Köhl, Werner Platzer, Helen Rose Wilson**

To carry out the tests, we have set up an outdoor test stand on the roof of our new institute building, where meteorological and sample parameters are continuously monitored, and have designed and procured a dual climatic testing chamber (fig. 2).

The aims of the work are:
- to support industry in the further development and specialisation of their products
- to increase consumer confidence in application of these products, by evaluating the performance, durability and sustainability of solar components.

The broad international basis offered by Task 27, with experts from industry and research in Europe, Japan, USA and Canada, means that standards with international acceptance can be prepared.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg
**Interpane E&BmbH, Lauenförde

Fig. 1: Test façade with coloured and bleached switchable (gasochromic) windows at Fraunhofer ISE.

Fig. 2: Dual climatic testing chamber for windows and solar façade components at Fraunhofer ISE.

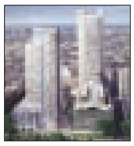
Performance:
The measurable thermal and solar properties of building envelope components, and their effect on the energy consumption and thermal and visual comfort in buildings, are to be combined and further developed as a structured knowledge base.
To this purpose, we are developing applications-orientated measurement procedures and calculation models for
- switchable windows
- daylighting systems
- transparent insulation elements
- double façades
- window-wall interfaces

Durability:
To be successfully commercialised, solar products for buildings must meet three important criteria:
- maximal performance
- minimal costs
- guaranteed lifetime

A further goal of the work is therefore a general methodology for durability tests and lifetime prediction. It should also be valid for many new materials and components developed for efficient use of thermal solar energy in buildings. Case studies on switchable windows, collector glazing, reflectors and façade collector coatings serve to validate the procedures.

Sustainability:
Within Task 27, primarily two aspects concerning sustainability of solar building envelope components are being studied:
- environmental effects of production, operation and recycling/disposal
- assessment of the restrictions in usage and lifetime resulting from ageing and associated component failure.

Relevant approaches (environmental impact assessment, failure mode effect analysis) will be initially tested on windows with insulating glazing units.



New Test Stand for Thermal Collectors - Faster and More Accurate

Fraunhofer ISE moved into its new premises in the summer of 2001. This opened the possibility of constructing a new, large solar simulator and an indoor collector test stand. With it, we can measure thermal collectors and façade components with dimensions of up to 2.4 x 2 m^2.

Uli Gardemann, Joachim Koschikowski*, **Matthias Rommel**, Arim Schäfer, Vitali Schmidt, Marco Schuler

With the new test stand, we are independent of the weather and can quickly

- test collectors according to European standards, and
- characterise new products, thus accelerating their development.

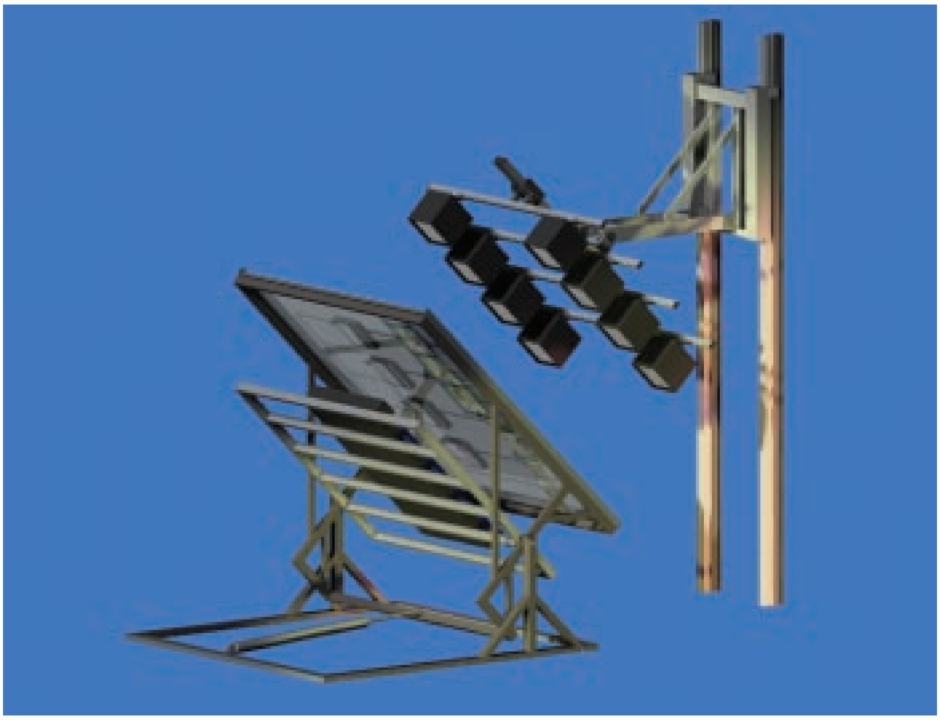


Fig. 1: The complete solar simulator facility.

We can imitate all practically relevant irradiation conditions, and can also investigate vertical façade elements or collectors with reflectors. The collector efficiency factor F' can be determined for complete absorbers.

Figure 1 gives an impression of the complete construction. The lamp array of the solar simulator consists of 8 single halogen-metal vapour lamps. Their spectrum is very well matched to the AM 1.5 solar spectrum. The lamps with their electric power supplies were bought from commercial suppliers. We designed and constructed all of the remaining components of the solar simulator and the indoor collector test stand ourselves. By altering the height and tilting the lamp array, we can flexibly modify the intensity, incidence angle and homogeneity of the radiation.

An "artificial sky" is located between the lamp array and the collector, consisting of two parallel panes of glass. The space between them is constantly flushed with cold air, so that the measurement conditions reproduce the radiative conditions in real applications.

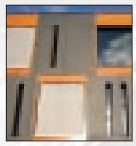
The most important technical specifications for the solar simulator are:

- test plane dimensions: 2.4 x 2 m^2. Other configurations of the test plane are possible.
- irradiation intensity: 1 200 Wm^{-2} without the artificial sky, 1 000 Wm^{-2} with the artificial sky.
- homogeneity: ±10 %.
- lamp array tilt angle: 0 - 90 °
- angular divergence: so small, that we can determine the incidence angle modifier IAM even for collectors with integrated reflectors.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

The amount of daylight, the air quality and thermal conditions in summer at workplaces benefit from interaction between architecture and technology early in the design process. The photo shows the façade of the new administration building for Pollmeier Massivholz GmbH in Creuzburg, near Eisenach. Despite specification of high-quality working conditions, the primary energy consumption for heating, ventilation, cooling and lighting is expected to be less than 100 kWh m^{-2} a^{-1}. Energy measurements and investigations of user acceptance are to begin in 2002.

Architecture: Seeling & Vogels, Darmstadt
Technical building services: solares bauen GmbH, Freiburg
Special planning services: Fraunhofer ISE, Freiburg



Sustainable buildings for the future demand that the energy consumption be clearly reduced. Starting in 2002, the new German energy-saving regulation will stimulate a continued decrease in the heating consumption of new buildings. Beyond this, already constructed buildings demonstrate that buildings up to the standard of a zero-emission house can be built today with the available strategies and technology for an acceptable price. Increased energy efficiency is the basis for a major contribution by solar energy to the building energy balance.

Whereas the energy demand for residential buildings is still dominated by the heat demand for space heating and hot water, electricity is already the major form of energy consumed in office buildings today. Appropriate solar concepts for office buildings are based on extending the use of daylighting and passive cooling, so that the electricity consumption for technical building services can be reduced, while maintaining high user comfort. Greater use of daylighting and passive cooling are goals which already have a large effect on building planning during the design phase. Success depends greatly on appropriate application of simulation tools for lighting and indoor thermal conditions. The savings in technical building services (lean building) require additional investment in the planning phase.

The following articles report on concepts, technology and projects for buildings designed for sustainable living and working in the future.

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Daylighting	Jan Wienold	Tel.: +49 (0) 7 61/45 88-51 33 E-mail: Jan.Wienold@ise.fhg.de

Solar Building - Residential Buildings

Solar passive buildings, with their very well insulated building envelope and ventilation heat recovery, have such low heat losses that these can be balanced by solar gains through the windows and inlet air heating. Solar systems for domestic hot water and electricity generation supply a large share of the energy demand.

Rico Blattert, **Andreas Bühring**, Volker Hoffmann, Klaus Kiefer, **Christel Russ**, Karsten Voss

In a monitoring programme, we are investigating the efficiency of new types of heating concepts in around 100 solar passive houses throughout Baden-Württemberg. The heating supply is based solely on electrically operated heat pumps and solar collectors.

A new category of building service equipment, the compact heating and ventilation unit, has been developed industrially for application in solar passive houses, with some support from Fraunhofer ISE. In addition to passive heat recovery with air-to-air heat exchangers, they include a heat pump, which draws heat from the exhaust air and uses it for space heating and domestic hot water. Usually the units are connected via a storage tank to a thermal solar energy system, so that it can provide most of the domestic hot water needed in summer.

In other investigated solar passive houses, heat is supplied by a ground-connected heat pump together with a solar system. In a small passive house settlement that we studied, this function is fulfilled by a central heat pump and solar system for a group of eight houses. A regional energy research foundation (Stiftung Energieforschung Baden-Württemberg) is funding intensive monitoring of this system, to allow detailed, comparative analysis of central and decentralised heating systems. Monitoring of the other houses is supported by the regional utility, Energie Baden-Württemberg EnBW.

Analysis of the results available to date shows differences depending on the supply structure (fig. 1). If the electricity consumption for heating, ventilation and domestic hot water is compared, the compact heating and ventilation units with their well-synchronised controls have the lowest values. The electricity consumption is significantly higher when ventilation, space heating support and domestic water heating is provided with modules from different manufacturers. This is caused partly by poor coordination of the control systems. With a central heating source, heat losses along the long connections and sub-optimal controls raise the electricity consumption for the building services technology.

In a passive house, the energy demand for heating and electricity is approximately equal. Fuel-cell based heating systems are particularly well suited to passive houses, as they have a high power to heat ratio, i.e. the ratio of supplied electricity to supplied heat. We are developing concepts for industrial partners to integrate fuel cells in the low power range into compact heating and ventilation units. We will be comparing fuel-cell based heating systems in passive houses with other heating systems in a project due to start in 2002.

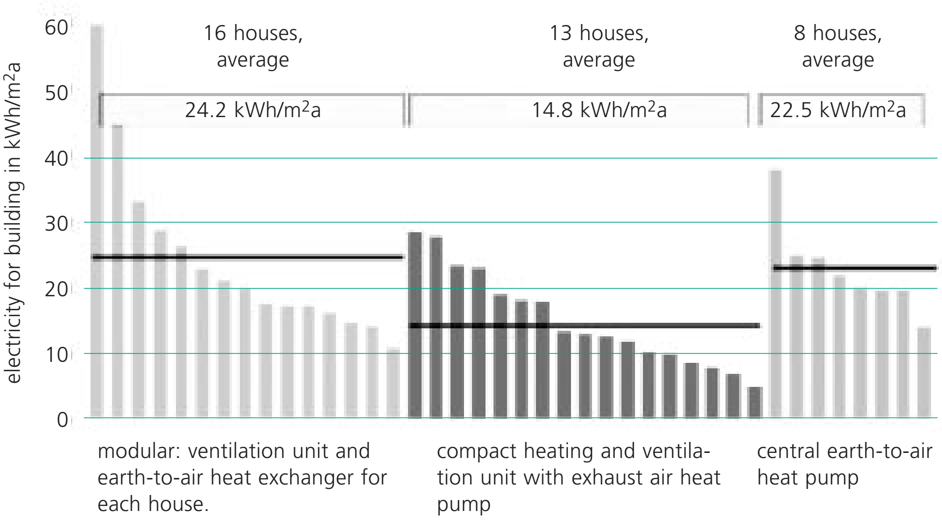


Fig. 1: Electricity consumption for building services in solar passive houses with three different types of heating technology. Each bar corresponds to one house. Within each group, the houses are arranged according to their energy consumption. Measurements on commission to the EnBW and the Stiftung Energieforschung Baden-Württemberg.

Solar Building - Commercial Buildings

Optimal working conditions represent a major criterion in planning commercial buildings. Thermal and visual comfort are decisive aspects and are closely associated with the planning concepts for ventilation, cooling and lighting in a building.

Armin Furkert, **Sebastian Herkel**, Tilmann Kuhn, Jens Pfafferott, Patrick Schröder, Karsten Voss, Jan Wienold

Row of terrace houses in Ötigheim.

Free-standing passive house in Hohenstein.

Passive semi-detached houses in Königsbach-Stein.

Free-standing passive house in Bretzfeld.

Photos above: Projects in Baden-Württemberg from the monitoring programme to evaluate the efficiency of different heating systems in solar passive houses.

Solvis administration and production building

The new administration and production building for Solvis in Braunschweig will be completed at the beginning of 2002 (fig.1). We are working on commission to the company in the planning team, which is aiming for a zero-emission factory with a high solar fraction in its energy supply (fig. 2). A 60 kWp photovoltaic system and a $200\ m^2$ solar collector system will be installed on the roof of the building.

The annual heating demand for the building is around $25\ kWhm^{-2}\ a^{-1}$.

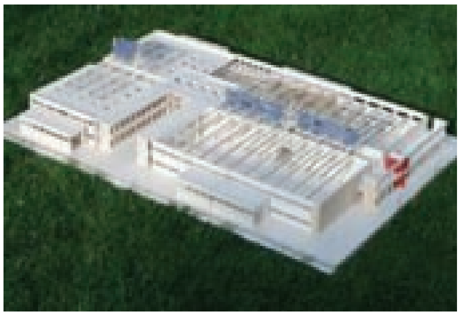


Fig. 1: Model of the Solvis building (source: Banz+Riecks).

The primary energy demand for heating, ventilation, cooling and lighting is about $85\ kWhm^{-2}$. It is met exclusively by renewable energy.

The offices are equipped with an exhaust air system combined with an exhaust air heat pump. The production halls have an inlet and exhaust air system with heat recovery. In summer, a higher air exchange rate supports nocturnal cooling.
The sprinkler tanks mounted in the building serve simultaneously as thermal storage units for the collector

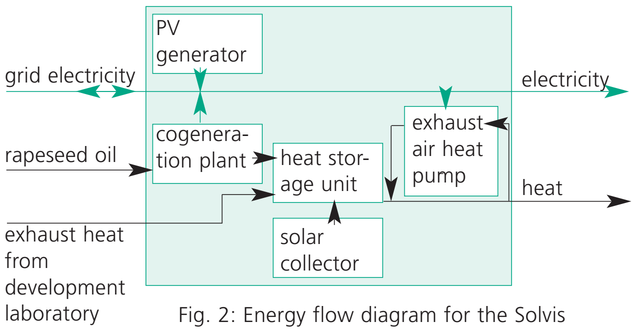
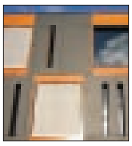


Fig. 2: Energy flow diagram for the Solvis building.



system. They are standing without insulation in the hall and contribute to the heating as low-temperature radiators.

Waste heat from the development laboratory for heating burners is fed into the buffer storage unit of the heat/electricity cogeneration plant, which is fuelled with rapeseed oil. Excess heat from the central computing system supports the heating of the warehouse in winter.

We optimised the proportion of glazing in the façade with coupled daylighting and thermal simulations. The offices, production halls and warehouse are equipped with daylight-dependent lighting controls. Daylight enters the production halls and warehouses through skylights.

	length [m]	rated volume current [m³/h]	heating energy [MWh/a]	cooling energy [kWh/a]
Lamparter	180	1 200	1.17	2.6
DB Hamm	2 150	11 000	25	22.9

Table 1: Specifications and yields of the earth-to-air heat exchangers for the Deutsche Bahn in Hamm and Lamparter in Weilheim.

Earth-to-air heat exchangers for office buildings

As a response to the strong demand for earth-to-air heat exchangers, we have expanded our activities in this field. In addition to design and integration into the systems technology, we now also offer operational optimisation and monitoring of installed earth-to-air heat exchangers.

Comparing two sets of results for a complete year reveals the potential of this technology (table 1). The earth-to-air heat exchanger for the Lamparter office building in Weilheim is very much smaller than that for the administration building of the Deutsche Bahn Netz AG in Hamm. The higher specific energy yield ($kWhm^{-1}$ a^{-1}) achieved in Hamm is due to a longer period of operation over the year and the configuration of the earth-to-air heat exchanger.

Both systems have potential for further optimisation: At times, the air is unintentionally cooled in winter or heated in summer (fig. 3). Thus, we have suggested controls based on the outdoor temperature for both systems. A further result of the monitoring is improvement in our dimensioning tools.

Galaxy skyscraper

We are supporting the planning team for the "Galaxy" skyscraper of the Commerzbank in Vienna with model calculations and calorimetric g value measurements. These were commissioned by Bug-Alutechnic, from Kennelbach in Austria.

	building concept	thermal simulation	lighting simulation	consultation	product testing	quality assurance	monitoring
DB Hamm							•
Fraunhofer ISE	•	•	•	•	•		•
Fraunhofer ZV		•	•	•		•	
Pollmeier			•			•	•
Gallileo				•	•	•	
Rocade	•	•	•	•			
Lamparter	•	•					•
Galaxy				•		•	
Solvis	•	•	•	•			

Table 2: Projects during 2001.

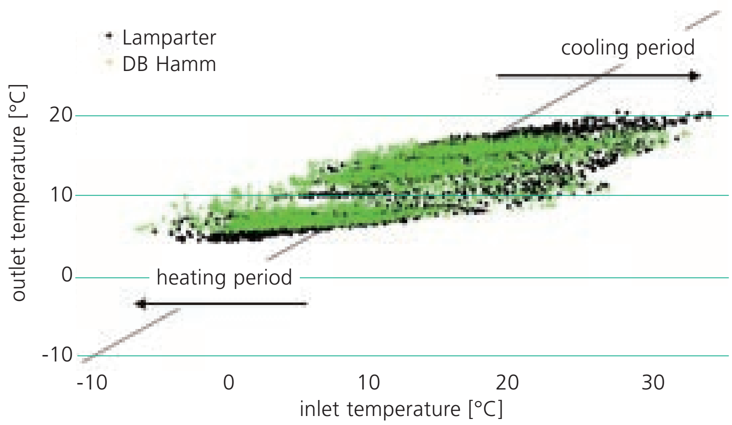
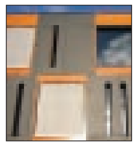


Fig. 3: The earth-to-air heat exchanger for Lamparter reduces the temperature in summer by up to 11 K, that for DB Hamm by up to 13 K. In winter, the temperature difference is up to 11 K for Lamparter and 13 K for DB Hamm. The system for DB Hamm provides a more constant outlet temperature than that for Lamparter. The entire temperature spectrum for the Lamparter system is 1.5 K higher due to the meteorological conditions at its location in Weilheim.



Solar Building - Cross-Sectional Analyses

We document and evaluate demonstration buildings in cross-sectional projects for national and international demonstration programmes, and carry out energy studies.

Karsten Voss, Jan Wienold

Sustainable Solar Housing

The working group with this name has existed since April 2000, and operates within the programmes on "Solar Heating and Cooling" and "Energy Conservation in Building and Community Systems" under the auspices of the International Energy Agency IEA (www.solarbau.de). As part of a BMWi project, we coordinate the international activities on well-defined building monitoring, and participate with our own demonstration projects, simulation calculations (earth-to-air heat exchangers) and test stand measurements (compact heating and ventilation units).

The lower the heating demand for a building becomes, the greater the significance of heat losses during storage and distribution and the proportion of auxiliary energy e.g. for pumps and valves. Thus, when analysing the monitoring results, we differentiate very carefully between the heat demand on the one hand, and the end and primary energy expended to meet it, on the other (fig. 1). To this purpose, we develop analytical procedures, which we will make widely accessible via the Internet.

SolarBau: MONITOR

Since 1998, we have co-operated with the University of Karlsruhe and the solidar architectural office in Berlin to summarise and evaluate the results of the SolarBau funding concept of BMWi. We analyse the results of demonstration projects in non-residential buildings in this work.

A highlight of 2001 was the symposium on "Solar-Optimised Building - planned - constructed - tested", held with 150 participants from planning offices, universities and institutes, on 24th/25th June at the Museum for Transport and Technology in Berlin. An 80-page document on this topic was already available at the beginning of the year (ordering possible by Internet: http://bine.fiz-karlsruhe.de).

With 20 000 visitors each month, the Internet site www.solarbau.de has achieved widespread acceptance in the building world. It is constantly being updated; at present, already 8 projects have been documented.

SolGain

As part of an EU project, we have calculated the contribution of passive solar gains in meeting the heating demand of European residential buildings. Up to now, this contribution has not been included in any energy statistics. For this reason, the share of renewable energy in the total energy supply is always significantly underestimated.

To determine the solar gains, we co-operated with the Technical University of Munich in developing and applying an internationally agreed procedure, based on statistical information about the building stock (building types, building age categories, energy supply technology) and heating demand calculations according to EN 832 for the "Thermal Performance of Buildings".

The results show that use of solar energy already plays a major role today in the energy budget of residential buildings. Depending on the location, building standard and other factors, the solar fraction of the heating demand is between 10 and 15 % (table 1).

The values in table 1 are relative to the appropriate heating periods. The "real" passive solar gains are still higher, as the heating period would be appreciably longer if no solar gains were present. Calculations for examples in Germany indicate that the useful solar contribution to the total heating energy balance doubles when periods outside the heating period are taken into account.

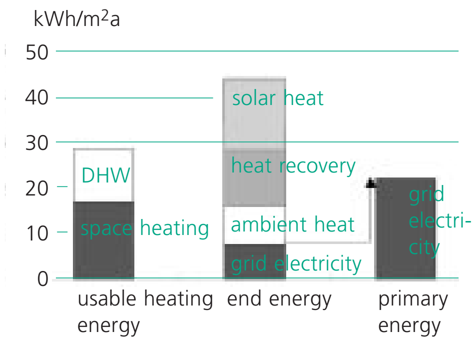
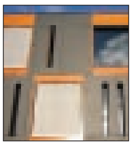


Fig. 1: Measured energy coefficients for the heating supplied to a solar passive house in Neuenburg. The house is equipped with a compact heating and ventilation unit, an earth-to-air heat exchanger and a thermal solar system (DHW = domestic hot water).

country	sf [%]	tsg [TWh]	te [Mio€]	tCO_2 [Mt]
N	10	4.4	295	0.4
SF	15	8.6	541	2.4
UK	15	57	2631	22.5
Irl	12	1.9	128	1.8
D	13	76	3230	30
B	12	13	646	4.4
Gr	12	5.5	352	2.1

Table 1: Solar contributions to the heating demand for residential buildings.
sf: fraction met by passive solar gains
tsg: total solar gains
te: total cost savings
tCO2: total savings in CO_2 emission



Solar Air Conditioning

For the last 6 years, we have intensively investigated ways of air-conditioning buildings with solar energy. Our R&D activities range from the development of new cooling processes based on adsorption technology, through scientific support of pilot and demonstration systems, to consultancy for planners and architects.

Andreas Baumeister,
Hans-Martin Henning,
Carsten Hindenburg, Mario Motta,
Tomas Núñez, Katja Scheuble,
Tim Selke*, Edo Wiemken

Use of solar energy to air-condition buildings in summer is an attractive option because the seasonal profiles for demand and solar supply are well synchronised. Practical experience shows, however, that the systems must be carefully designed and constructed, if the intended energy savings compared to conventional systems are to be achieved. We are working on processes which apply thermal solar energy for cooling and/or air dehumidification (fig. 1).

In addition to basic research (materials research, see article on p. 32; research on heat and mass transport in adsorption systems), scientific support of pilot and demonstration projects is an important aspect of our investigations. Table 1 gives a summary of the most important projects. With these projects and numerous studies on new systems, we have gained a broad knowledge base on the processes, possibilities and limits of solar air-conditioning.

We have investigated system concepts for different climatic regions (e.g. Bangkok in Thailand, Isfahan in Iran and Palermo in Italy) and can adapt them to other local requirements. Meanwhile, we have developed physical-mathematical models for all the essential components of solar air-conditioning systems and validated simulation tools.

Our experience will be documented in a handbook on solar air conditioning, which is currently being prepared within Task 25 on "Solar Assisted Air Conditioning of Buildings", in the Solar Heating & Cooling Programme of the International Energy Agency IEA, under the leadership of Fraunhofer ISE.

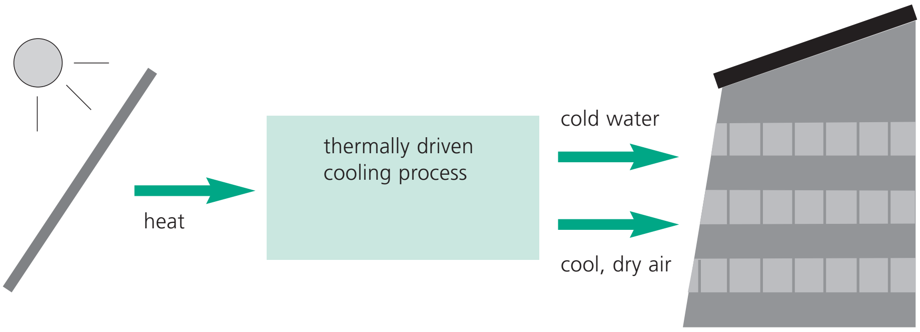
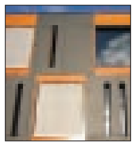


Fig. 1: General system diagram for solar air conditioning of buildings.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Project	Funded by	Tasks undertaken by Fraunhofer ISE	Start of operation
Desiccant Cooling System for the Technology Centre in Riesa	State of Saxony	project management; conception and planning of the complete system; support during installation and commissioning; supporting measurements	1997
Solar Desiccant Cooling System for an Office in Portugal	EU Thermie	project management; conception and planning of the complete system; supporting simulation; design of the monitoring system and the system controls	1999
Solar Cooling with an Adsorption Chiller	BMWi	consultancy during the planning phase; scientific support of operation; detailed measurement data acquisition and analysis, supporting simulation; development of optimised control concepts	1999
Design and Installation of a Solar Driven Desiccant Cooling Demonstration System	EU-INCO-COPERNICUS	conception and planning of a desiccant cooling system for solar air conditioning of a lecture theatre at the university in Eriwan, Armenia; development of the controls; support during commissioning; monitoring and supporting simulation	2001
Advanced Solar Desiccant Cooling Systems for Central European and Mediterranean Climates (see article on p. 51)	EU	project management; conception and planning of a solar desiccant cooling system for a meeting room at the Chamber of Commerce in Freiburg; support during commissioning; supporting measurements and analysis; development of the controls	2001

Table 1: Summary of the most important projects on solar air conditioning involving Fraunhofer ISE.



Solar Air Conditioning for the Meeting Room of the Chamber of Commerce in Freiburg

Solar desiccant cooling is an environmentally friendly technology for air conditioning, which operates without any cooling agents that attack the ozone layer or contribute to the greenhouse effect. Because of the low driving temperatures, it is very well suited to combination with thermal solar collectors and waste heat e.g. from heat/electricity co-generation plants.

Sascha Backes, Christian Bichler,
Carsten Hindenburg,
Volker Kallwellis*, Mario Motta

Last year, the first German air-conditioning system to be powered exclusively by solar energy in summer was installed and commissioned in Freiburg. It air-conditions the large meeting room and a cafeteria on the penthouse floor of the Chamber of Commerce for the Southern Upper Rhine region. The desiccant cooling system has a rated volume current of 10 200 m^3 per hour in connection with a 100 m^2 solar collector array for air heating.

We designed the system and dimensioned it using the simulation models we have developed. Together with a large controls technology company, we commissioned the system at the end of June, 2001. It has passed the first summer with flying colours. Even when the outdoor temperatures exceeded 35 °C, the indoor temperatures remained pleasant. The project (fig. 1) has two special features:

- The solar air collectors form the only heat source to regenerate the sorption agent.
- There is no thermal energy storage unit.

This meant that we could simplify the system technology and significantly reduce the investment costs for the solar systems technology. As a result, the proportion for the solar air collectors and their installation was less than 10 % of the total investment costs.

In addition to air conditioning in summer, the system also makes a noticeable contribution toward the space heating in the transitional and winter months. Figure 2 shows the 100 m^2 solar air collector field on the roof of the Chamber of Commerce.

Within the scientific support programme, apart from critically checking the concept in practice, efforts will be concentrated on optimising the system controls and operation management, and analysing the energy balance. The real measured system and room air parameters will be used to validate and improve the existing simulation models. This means that desiccant cooling systems can be planned and dimensioned still more reliably in future.

Leadership of and participation in the European project, "ASODECO: Advanced Solar Driven Desiccant Cooling Systems for Central European and Mediterranean Climates", with eight partners from four countries, ensures that comparison with other solar driven cooling systems can be made.

We are grateful to the European Union, the State of Baden-Württemberg, and the companies GWE Gesellschaft für wirtschaftliche Energieversorgung mbH & Co. KG in Freiburg, Dieter Bühler Ingenieurbüro GmbH in Bahlingen and Grammer KG Solar-Luft-Technik in Amberg for financially supporting this innovative system.

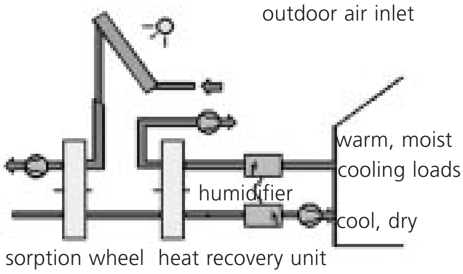


Fig. 1: Schematic diagram of the system.

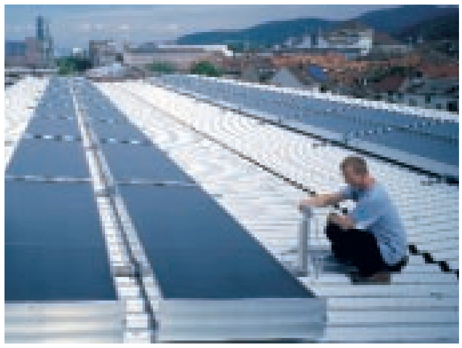
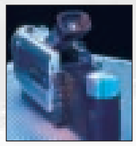


Fig. 2: Solar air collector system on the roof of the Chamber of Commerce for the southern Upper Rhine region.

Fig. 3: View of the air-conditioned cafeteria.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

Fuel cell power supply for a digital video camera. The Fraunhofer Initiative on "Miniature Fuel Cells" developed novel bipolar plates, the fuel cell stack, the system controls and processes for series production (see article on p. 54).



A fuel cell instead of gas heating? New building concepts need a new type of energy supply. In energy-saving houses, only a minimal heating demand still needs to be met. A conventional heating system is not warranted and is also not desirable ecologically: Polymer membrane fuel cells now generate electricity from hydrogen with a conversion efficiency of up to 50 %. Low-temperature heat is produced during electricity generation as a "waste product". Thus, with a power rating of several kilowatts, fuel cells could provide all the electricity and heat that a building needs. Surplus electricity is fed into the grid. In this way, a house will become part of the decentralised energy economy of tomorrow. If a reformer is used, conventional natural gas can be used as the fuel.

Reforming is a chemical process which extracts hydrogen from biological and fossil fuels. It offers two advantages: On the one hand, it enables fuels such as natural gas, which are already widely available, to be used, so that consumers do not have to wait for hydrogen from regenerative sources. On the other hand, fuels with a high storage density such as methanol or petrol can be used, e.g. in the transport sector.

The application in buildings is typical for the trend to use fuel cells in increasingly lower power ranges. Our micro-energy technology group is working on systems with 0.1 - 50 W. Replacing rechargeable batteries with fuel cells opens up a new dimension in operating times for appliances, be they notebooks or camcorders, and allows customised design: The electric power and the operating time are independent parameters. The fuel cell dimensions determine the former, the storage unit capacity the latter.

Our new project on a reversible electrolyser/fuel cell system for long-term storage of high-quality energy follows the trend towards miniaturisation and cost reduction. The same cell which converts electricity into hydrogen for storage is also able to generate electricity from the hydrogen when needed.

The common aim of all our work is to provide efficient and low-maintenance energy converters which make the sustainable use of energy still more convenient and economically attractive.

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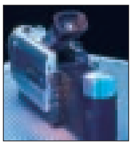
Marketing	Ulf Groos	Tel.: +49 (0) 7 61/45 88-52 02 E-mail: Ulf.Groos@ise.fhg.de



Miniature Fuel Cell System for a Digital Camcorder

The "Fraunhofer Initiative on Miniature Fuel Cells", which is led by Fraunhofer ISE, has developed the first miniaturised and completely operational power supply system for a camcorder based on a PEM fuel cell. Furthermore, solutions for production and assembly in series have been proposed.

Ulf Groos, Alexander Hakenjos,
Christopher Hebling,
Andreas Schmitz,
Jürgen Schumacher, Mario Zedda

The Fraunhofer Initiative has two aims:
- to develop fuel cell systems in the power range up to 50 W
- to prepare technology for inexpensive series production.

The Initiative is responsible for both the individual functional units and for portable fuel cells as complete systems.

It combines the competence of several different Fraunhofer Institutes:
- fuel cell development for hydrogen or methanol operation (Fraunhofer ISE)
- simulation and characterisation of fuel cells (Fraunhofer ISE)
- development of system controls (Fraunhofer ISE / Fraunhofer IZM)
- development of production processes (Fraunhofer IPT)
- development of assembly technology (Fraunhofer CMI)
- development of conductive and hot-pressable polymer materials for bipolar plates (Fraunhofer ICT)
- development of functional and easily assembled casings (Fraunhofer ICT)
- development of microvalves and micropumps for fuel transport (Fraunhofer IMS)
- development of connection technology (Fraunhofer CMI and Fraunhofer IFAM)

A commercially available camcorder (figures 1 and 2) demonstrates the performance of the miniaturised fuel cells. They provide 10 W power. A highly efficient voltage converter, with an efficiency value exceeding 95 %, regulates the output voltage to 8 V. The self-breathing fuel cell operates with the assistance of a ventilator. A metal hydride storage capsule provides energy for four hours of operation.

The modular construction of the fuel cell means that it can be flexibly adapted to the power, voltage and geometric configuration required.

In addition to stacked fuel cells, the Initiative is developing a novel planar fuel cell based on polymer plate or film technology (Fraunhofer ISE and Fraunhofer IZM; fig. 3). Systems for hydrogen (PEMFC) and for methanol (DMFC) are planned. Methanol offers the advantages of a higher energy

Fig. 1: Commercially available camcorder with a fuel cell system as its power supply. The cylinder to the right is a metal hydride storage capsule for hydrogen.

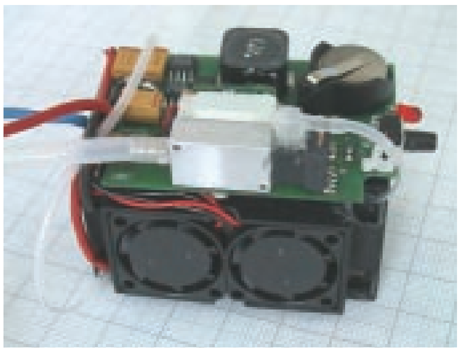
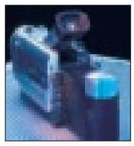


Fig. 2: Completely integrated fuel cell system with ventilators, the fuel cell stack (below) and microvalves for the hydrogen transport (centre). The electronic controls the ventilator, regulates the voltage and cycles the valve. Note the dimensions indicated by the (millimetre) graph paper.



density and variable tank geometry. By contrast, the hydrogen-fuelled fuel cell provides a higher power density.

Processes suitable for series manufacture can be used to produce the planar fuel cell on polymer plates, so that very low production costs are to be expected. As the polymer plates are elastic, they do not break as easily as brittle graphite plates. With its flat configuration, the power supply can serve as a casing wall.

The first operational samples (fig. 3) achieved the very high power density of 150 $mWcm^{-2}$ (current density up to 300 $mAcm^{-2}$, cell voltage 0.5 V) when operated with hydrogen under ambient conditions. The values for operation with methanol are 15 $mWcm^{-2}$ at 0.3 V so far.

A promising approach is the development of a fuel cell in film technology. Air and fuel (hydrogen or methanol) enter the membrane-electrode unit through structured films. Metal films conduct the current away at the sides. Production processes adapted from microsystems technology will allow economic manufacture later. The fuel cell films can be integrated flexibly into appliances. It is even conceivable that the films be wound. It would be equally simple to mount the power supply on the casing surface.

We are supporting the construction work in the Fraunhofer Initiative by simulation of the PEM fuel cell, where we apply single or multi-dimensional numerical methods. The calculations include a description of the reaction kinetics and mass transport within the fuel cell.

In parallel, we have set up testing equipment, which allows spatially resolved measurement of characteristics such as temperature, impedance, current density and voltage on the electrodes (fig. 4). We apply iterative comparisons between simulation and spatially resolved measurements to optimise the reliability and power density of the fuel cells.

One result of this work is a system control strategy, which guarantees a quick start and stable operation of the fuel cell system.

Further information can be found at www.mikrobrennstoffzelle.com and www.mikroenergietechnik.de

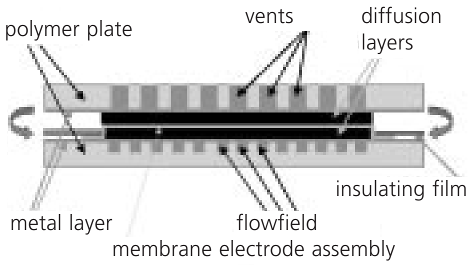


Fig. 3: Schematic diagram of the planar fuel cell.

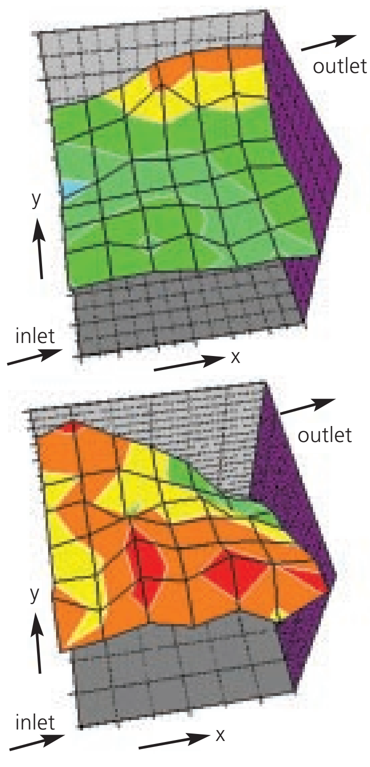
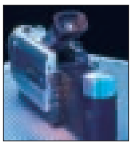


Fig. 4: The spatial distribution of the electric current density is shown for the meander-formed gas channel of a square test fuel cell, which is lying in the xy-plane. Upper graph: after 58 minutes of operation. Lower graph: after 134 minutes of operation.



Energy Storage with a Reversible Electrolyser/Fuel Cell System

We have developed an electrochemical polymer membrane cell for use in an energy storage system, which can be operated not only as an electrolyser but also as a fuel cell.

Angelika Heinzel, Ansgar Rau, Marc Valerius, Ursula Wittstadt

The system, which was developed in co-operation with various European partners, consists of the following components (fig. 1): a reversible electrochemical cell, storage units for hydrogen, oxygen and water, and gas drying units.

A stack of 15 cells is the heart of the system. It can act as an electrolyser to produce hydrogen and oxygen or generate electricity as a fuel cell. This reduces the material costs, volume and mass compared to a system with separate cells for each process.

Components such as membrane-electrode assemblies and diffusion layers are usually optimised either for electrolysis or fuel cell operation. In order to achieve the highest possible efficiency and long-term stability for both operation modes, new solutions must be found.

For instance, platinum is the best catalyst for fuel cell operation, whereas other noble metals are better suited for oxygen generation in electrolysis. Thus, we have developed a membrane-electrode assembly which is coated with a mixture of platinum and iridium on the oxygen side.

The gases generated during electrolysis are stored. For hydrogen, we use a metal hydride storage capsule which is adapted to this application. It features a compact design and a small pressure window (2 - 10 bar) for charging and discharging.

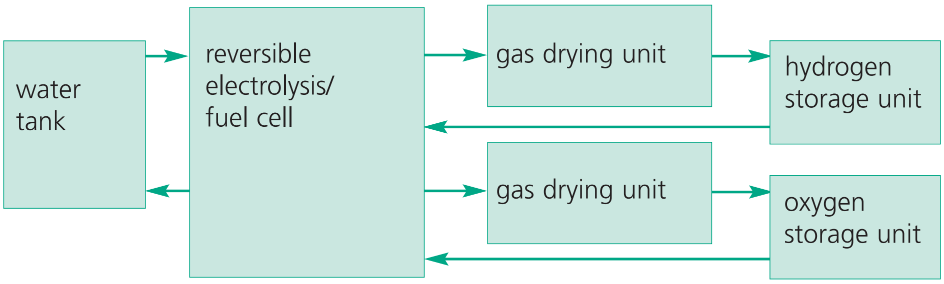


Fig. 1: Schematic diagram of the energy storage system based on a reversible electrolysis/fuel cell unit.

Oxygen is stored by adsorption on active charcoal. At 10 bar, this allows the storage capacity of the tank to be tripled as compared to a conventional pressure storage tank.

The generated gases are saturated with water. To prevent water from collecting in the gas storage units, which would reduce their capacity, drying units based on silica gel are introduced into the gas connections. As an alternative, different membrane processes were investigated, which allow maintenance-free operation.

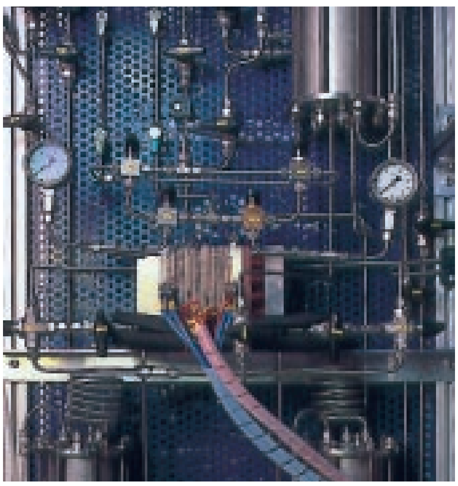
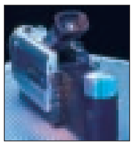


Fig. 2: Demonstration energy storage system with a reversible electrolyser/fuel cell stack.

Figure 2 shows our first prototype. Peripheral system components are chosen so that the auxiliary energy consumption is as low as possible. The water for electrolysis enters without any additional energy for its transport. It is only during the fuel cell process that low-power pumps (app. 1 - 3 W) recirculate the gas, to drive the produced water out of the cell stack.

The EU is funding the project.



Hydrogen Production by Electrolysis as a Component for Zero-Emission Power Generation

Long-term storage of energy helps the potential of renewable energy to be better exploited. For instance, hydrogen could make the excess energy from summer available for use in winter. We develop electrolysers for hydrogen production which are adapted to the energy sources and storage technology available in each case.

Beatrice Hacker, Thomas Jungmann*, Sven Kerzenmacher, Carsten Krämer, **Ursula Wittstadt**

When developing the electrolysers, we have three goals:

- optimisation of the electrolysis cell
- well harmonised complete system with gas and water management
- automation and safety technology

Component development and materials selection are of primary importance. Figure 1 shows a diagram of an electrolysis cell. The central component is the membrane-electrode assembly (MEA). It consists of a proton-conducting membrane which is coated with catalysts. When voltage is applied, the water is split at the catalyst layer. Oxygen is produced and the protons diffuse through the membrane to the cathode, where they recombine to form hydrogen.

The atomic oxygen produced is highly corrosive. Thus, the cell consists of extremely durable materials such as titanium or polymers which can be injection-moulded. An operating pressure of up to 30 bar places additional high stresses on the materials' stability.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

We are continually improving the existing concepts for membrane pressure electrolysers. By changing the form of the electricity conductors, we increased the power and significantly reduced the costs.

The modular construction of the cells in the stack configuration means that it can be simply adapted to the characteristics of the relevant energy source. For instance, we can vary the voltage level by changing the number of individual cells connected to form the stack.

Within the FIRST project, which is funded by the EU, we have developed an electrolyser with 20 A rated current (fig. 2) as part of a stand-alone power supply for telecommunications systems. In combination with a fuel cell and hydrogen storage unit based on a metal hydride, it provides an energy storage system. In contrast to batteries, it is intended to store energy over long periods of time. During sunny periods, excess electricity from a photovoltaic system is used to produce hydrogen by electrolysis, which is converted back into electricity by the fuel cell when there is little sunlight.

With an electric power of 1 kW, our electrolyser produces 250 standard litres of hydrogen per hour. An additional gas diffusion barrier on the membrane keeps the amount of oxygen in the produced hydrogen below 0.2 %.

During operation, the waste heat from the fuel cell prevents freezing even when outdoor temperatures are low. The system includes integrated water purification and needs maintenance only once a year.

The system is controlled automatically. Pneumatic valves reduce the energy consumption for controls to a minimum. An independent safety chain monitors the electrolyser and automatically switches it off if a fault arises.

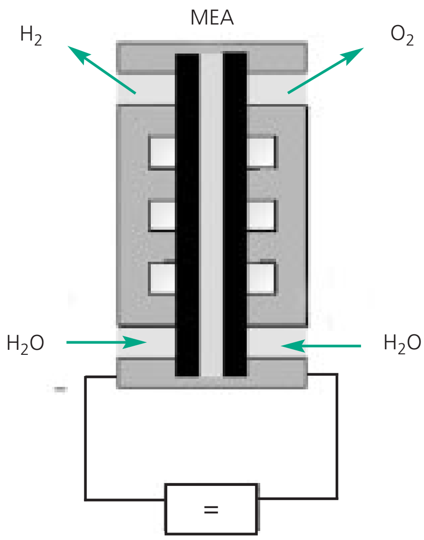


Fig. 1: Schematic diagram of a polymer membrane (PEM) electrolysis cell. MEA denotes the membrane-electrode assembly.

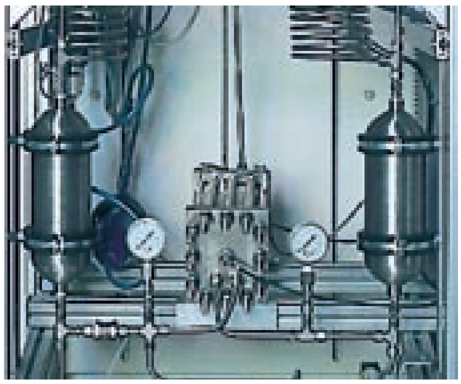
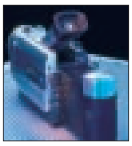


Fig. 2: PEM pressure electrolyser (250 l_N/h, 1 kW_{el} for a stand-alone power supply system for a telecommunications facility (EU-funded FIRST project).



Reforming of Liquid Fuels

Reforming of liquid fuels has been strongly promoted recently to supply hydrogen for polymer membrane (PEM) fuel cells. Thus, we are expanding our research activities to include the reforming of various liquid fuels for mobile and stationary applications.

Peter Hübner, Thomas Rampe, Christian Siegel, Bettina Lenz

The motivation for increased activity on reforming is the use of fuel cells in electrically powered "zero-emission vehicles". Almost all of the major car manufacturers have presented demonstration vehicles of this type to the public during the last few years.

As regeneratively produced hydrogen will not be available everywhere within the short to medium term, liquid fuels are often reformed on board the vehicle. Figure 1 illustrates this type of system with the gas purification (CO removal) needed for PEM fuel cells.

The reformer produces gas containing hydrogen and about 10 vol. % CO. The CO conversion step initially reduces the proportion of CO, which is damaging to a fuel cell, to about 0.5 vol. %, and the CO fine purification step reduces it further with selective oxidation to 10 - 50 ppm.

We are also developing the reforming process for liquid fuels further for other applications - some of them in association with high-temperature fuel cells (SOFC, MCFC):
- to drive electric boats, trains and trams,
- as auxiliary power units (APU) for electricity aboard cars, buses, trucks and aeroplanes
- as (stationary) domestic power supplies at isolated locations (replacing oil heating and diesel generators for electricity generation).

The availability and presence of infrastructure determine the choice of fuel. Thus, in addition to the technically simpler process of methanol reforming, we are working more intensively on reforming the following fuels:
- petrol (for motors and APU's in vehicles)
- diesel (particularly for APU's in buses and trucks)
- kerosene (for aeroplanes)
- biogenic fuels (rapeseed oil, bioethanol)

For the various applications, the reforming reaction can take place in three different variations:
- as steam reforming: catalytic racking of the hydrocarbons with water vapour,
- with partial oxidation: substoichiometric combustion,
- with autothermal reforming as a combination of the processes listed above.

In steam reforming, the endothermic reforming reaction and the combustion reaction, which supplies the energy required, occur in separate zones. We use or develop various concepts for combustion (flame burner, radiative burner, catalytically coated burner), which operate with pre-mixed or separate gas inputs.

Partial oxidation allows cold starts within seconds and can respond to changing loads very rapidly. These are essential pre-requisites for mobile applications. A further advantage is that this process operates without any water input.

In autothermal reformers, both reactions run in a single reaction zone and are coupled directly to each other. The heat needed for reforming is generated by the substoichiometric combustion which occurs in parallel.

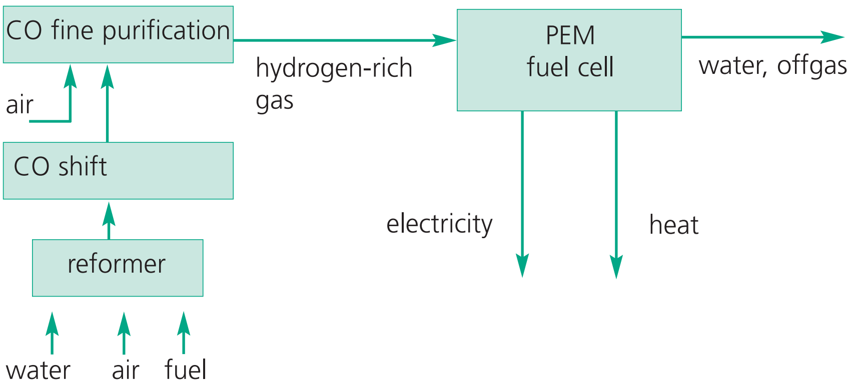
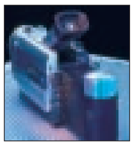


Fig. 1: Reforming liquid fuels for PEM fuel cells; offgas contains CO_2, N_2 and traces of H_2.



Depending on the composition of the different liquid fuels, the ideal efficiency values for hydrogen production are between 88 % and 96 %. This is shown for autothermal reforming without heat losses as an example in fig. 2. The fuels are represented in a simplified form by the H/C ratio of their components. Our experimental results with honeycomb catalysts (fig. 3) already approach the maximum possible reaction yield very closely. We will achieve higher efficiency values by minimising the heat losses and optimising the reactor geometry and catalysts.

However, the sulphur content of current fuels (petrol, diesel) reduces the catalyst activity considerably. The conversion efficiency increases strongly when more sulphur is removed (fig. 4). Petrol with reduced sulphur content (less than 10 ppm), corresponding to future guidelines, is ideally suited for reforming.

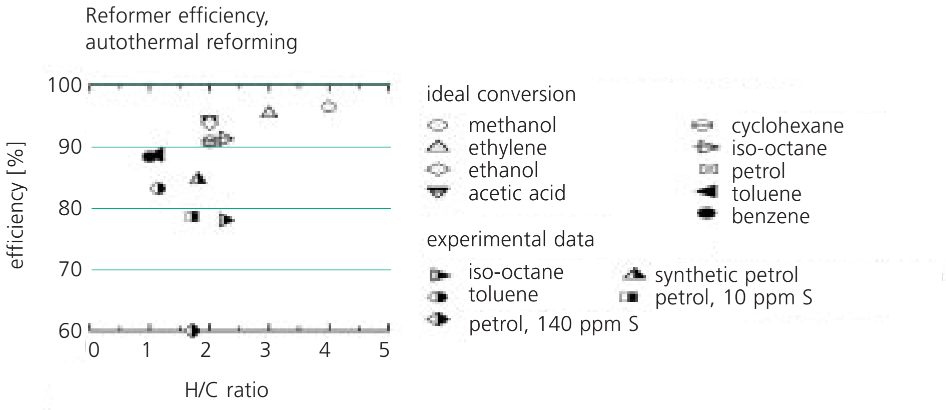


Fig. 2: Ideal efficiency values (adiabatic, without heat losses) for hydrogen produced by reforming different liquid fuels, which are characterised by the H/C ratio of their components. S is the symbol for sulphur.

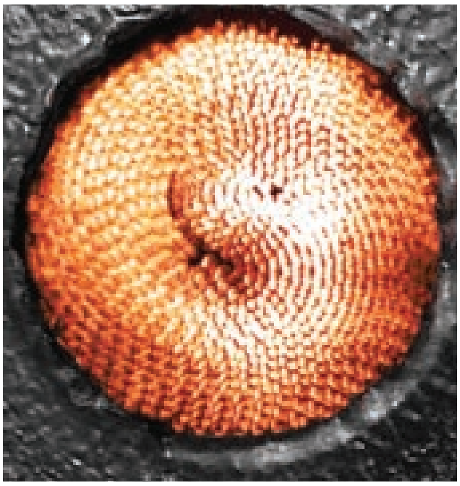


Fig. 3: Honeycomb catalyst for reforming liquid fuels (internal diameter 30 mm).

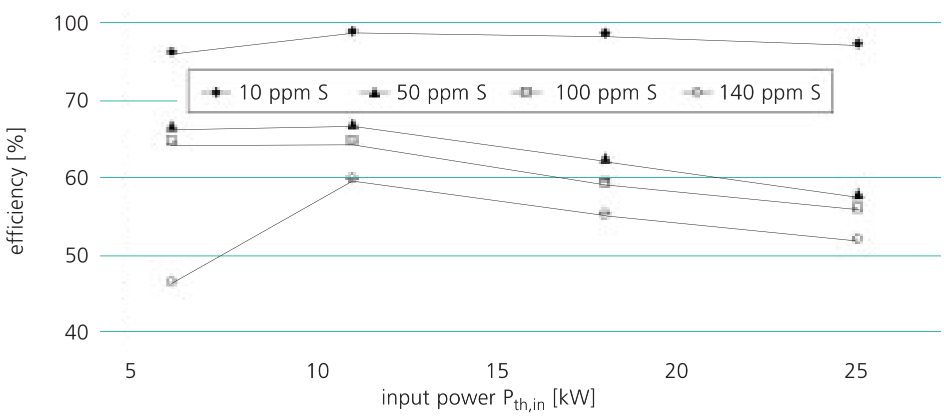
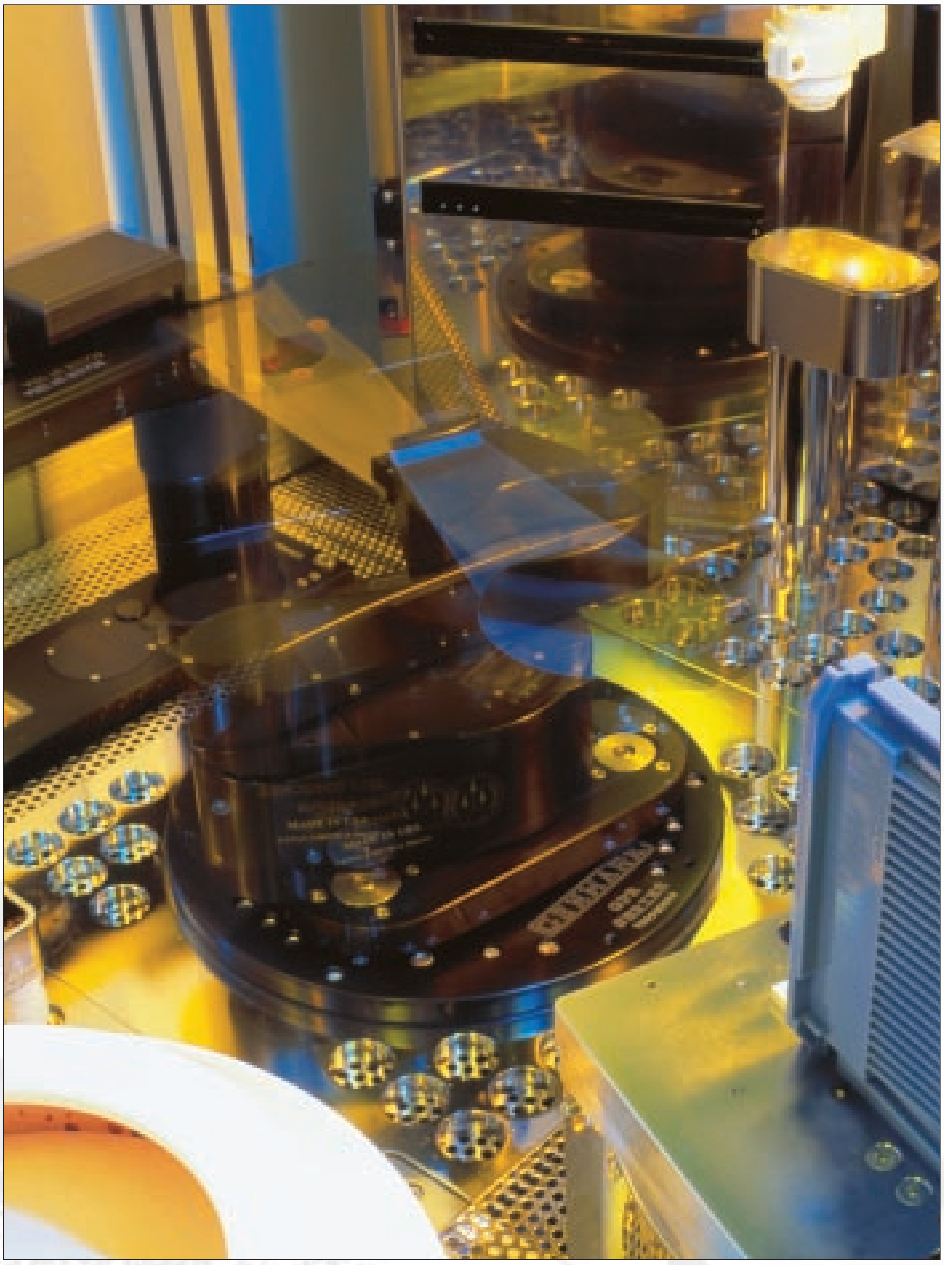
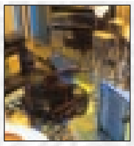


Fig. 4: Effect of the sulphur content on the conversion efficiency for autothermal reforming of petrol, as a function of the input thermal power P.



Robot in the automatic lacquering system for silicon wafers in the clean room at Fraunhofer ISE. This system is part of the pilot line to produce highly efficient silicon solar cells.



More than 90 % of the solar cells manufactured throughout the world are of crystalline silicon. The cost/performance ratio, their long-term stability and potential for further cost reduction indicate that this material will continue to dominate the market for the next 10 years. The silicon wafers will become thinner and thinner, but with appropriately adapted cell structures, the efficiency values will remain constantly high.

III-V semiconductors such as gallium arsenide form the second materials class which we are investigating. It is still associated with a niche market, which can be summarised by the keywords, space and special applications, and optical concentrators.
In both areas, research is approaching the commercial application yet more closely.

- In our Laboratory and Service Centre in Gelsenkirchen, we can work under production conditions in the laboratory. Industry can transfer the results directly to production, without interrupting it for investigations.
- Using a laser-assisted procedure, which has been registered for a patent, we have prepared high efficiency solar cells for industrial series production.
- We can process 70 µm thin wafers with conventional procedures to achieve solar cells with efficiency values of 20.5 %.
- By using a thermography camera and lock-in technology, we can characterise crystalline silicon wafers more than 100 times faster than previously.
- For thin-film crystalline silicon solar cells, we are investigating the physical principles and developing production technology, e.g. for silicon ribbon substrates.
- We are working on radiation-resistant tandem III-V cells for space applications. For terrestrial applications, we are developing an economically attractive procedure to produce the Fresnel lenses in optical concentrator modules and are constructing complete modules for outdoor applications.

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Novel and Highly Efficient Solar Cell Structures for Crystalline Silicon

For economic reasons, solar cells from silicon wafers still need to become thinner and more efficient. Thus, new solar cell structures were developed at Fraunhofer ISE, which also make high efficiency values possible with material of medium quality. Using a patented, laser-assisted procedure, high-efficiency solar cell structures can be produced in industrial series, which previously could only be prepared in the laboratory.

Stefan Glunz, Ralf Preu,
Jochen Dicker, Franz J. Kamerewerd, Joachim Knobloch, Daniel Kray, Antonio Leimenstoll, Ralf Lüdemann, Daniela Oßwald, Tobias Rehrl, Stefan Rein*, Elisabeth Schäffer, Eric Schneiderlöchner, Wilhelm Warta, Gerhard Willeke

There is still a major gap between laboratory cells, with record efficiency values exceeding 20 %, and commercial solar cells. The main reason is the complexity of the cell structures which are needed to achieve high efficiency. At Fraunhofer ISE, a decisive step has now been made to simplify these structures. This will also make them interesting for industrial production.

The back surface of solar cells with highest efficiency values is coated with a thin, electrically non-conductive layer of silicon oxide or nitride. This coating is perforated at a few points. Subsequently, the metallic back surface electrode for the cell is evaporated over the whole area. Most of the metal is located on the non-conductive layer; the silicon is contacted directly only at a few points (fig. 1).

This back surface configuration has major advantages compared with the conventional metal contact covering the complete area. On the one hand, it is highly reflective, so that long-wavelength light which penetrates deep into the wafer is reflected back into it. On the other hand, it allows optimal passivation of the back surface, so there is a high probability that charge carriers which reach it do not recombine there. These two properties are of fundamental importance, particularly for thin cells, if high efficiency values are to be reached. Reduction of the cell thickness and industrial implementation of processes leading to high efficiency are the essential pre-conditions for reducing production costs.

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Now, a new process has been developed at Fraunhofer ISE, which makes production of this advanced back surface structure very simple. As before, the dielectric layer is first deposited on the back surface. However, the next step is immediately to deposit the aluminium electrode over the whole surface. Finally, a laser is used to "fire" the aluminium through the dielectric layer at the points needed as contacts (fig. 2).

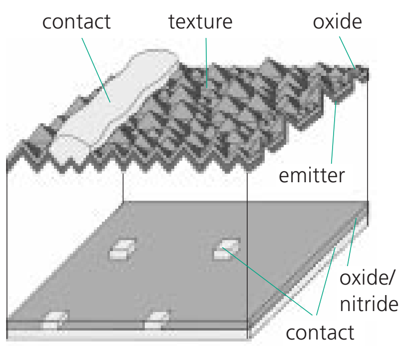


Fig. 1: High-efficiency solar cell with back-surface point contacts.

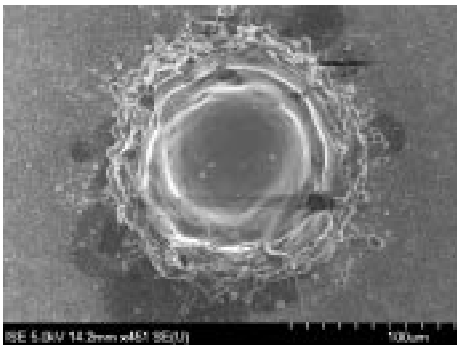
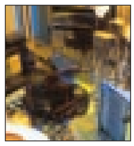


Fig. 2: "Laser fired contact" point on the back surface.



This explains the name of the new method for "laser fired contacts", for which Fraunhofer ISE has filed a patent claim [1]. As the laser step is very rapid, the processing speed and simplicity enter new dimensions. We have already optimised the process to the extent that efficiency values exceeding 21 % can be achieved reliably - a value comparable to that obtained with the original complex processing steps. The new method has thus aroused great interest within the photovoltaic industry.

When solar cells are connected to form a module, it would be very much simpler if the p and n contacts were both on the same side of the cell, instead of being on the front and the back, as at present. Back contact solar cells offer this advantage. In addition, these cells avoid shading losses due to front contacts.

However, as the pn junction is located at the surface away from the light source, practically all of the charge carriers generated by the light have to diffuse through the entire cell. This is not significant for high-quality material with long diffusion lengths. We have already achieved efficiency values exceeding 22 % with this cell concept. As the back surface of this cell type is not completely covered with contact areas, it is also well suited to application as a bifacial solar cell, which can be illuminated from both sides. With this approach, we have produced the first cell in the world which has an efficiency value of more than 20 % for illumination from either side.

Nevertheless, if material with shorter diffusion lengths is used, the concept for the back surface contact must be modified. A laser is used to drill holes through the wafer. Then emitters are introduced by gas phase diffusion from both sides of the wafer, which are thus electrically connected to each other via the walls of the holes (fig. 3, top). In this way, the charge carriers collected at the front pn junction can flow along the hole walls to the back surface of the cell and then to the contacts. Figure 3 shows clearly that the efficiency remains high even for short diffusion lengths with this so-called emitter wrap-through (EWT) structure, whereas it falls drastically for "pure" back contact cells.

We have already prepared an EWT cell with an efficiency value of 21.4 % using FZ Si. The large potential of this structure is demonstrated much more impressively by material of medium quality: We achieved a short-circuit current of 40.6 mAcm^{-2} on 235 μm thick Cz Si, although the material has a diffusion length of only 187 μm. With conventional structures, this current could only be achieved with material where the diffusion lengths were three or four times longer.

[1] R. Preu, E. Schneiderlöchner, S. Glunz and R. Lüdemann, patent claim filed.

*University of Freiburg, Freiburger Materialforschungszentrum FMF

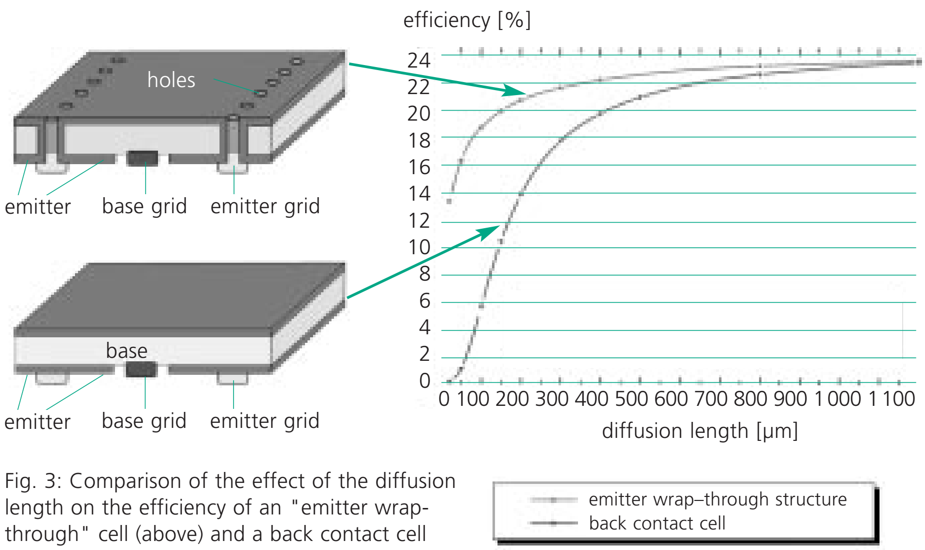
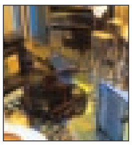


Fig. 3: Comparison of the effect of the diffusion length on the efficiency of an "emitter wrap-through" cell (above) and a back contact cell (below).



Progress towards Short Processing Times

In comparison to monocrystalline cells, the efficiency value of multicrystalline cells is 2 – 3 percentage points lower, depending on the quality of the original wafers. This is true both for laboratory cells and for industrially manufactured cells. The lower efficiency value is attributed to the high density of dislocations and grain boundaries, and an inherently higher degree of contamination with (metallic) impurities. Optimal processing can improve multicrystalline material, in some cases to the point that it closely approaches monocrystalline material.

Christophe Ballif, Dietmar Borchert, Harald Lautenschlager, Elisabeth Schäffer, Christian Schetter, **Roland Schindler**, Wilhelm Warta

One approach to improve mc solar cells involves gettering steps, in which impurities are removed from the interior of the solar cell. However, this is usually associated with long processing times, which are difficult to integrate into industrial production.

The simple solar cell process developed and applied in the past at Fraunhofer ISE achieves the same result. In it, the gettering step takes place simultaneously with the diffusion. This is in accordance with the solar cell industry's aim of reducing processing times further.

For this reason, it is also desirable to shift the temperature window for diffusion toward higher temperatures. This shortens the diffusion time and increases the turnover in the diffusion oven.

The upper limit to the diffusion temperature is determined by the interaction between crystal defects and impurities, which affect the charge carrier lifetime in the material. It is known that very high temperatures reduce the charge carrier lifetime in most multicrystalline materials. The high-temperature behaviour also depends on the crystallisation procedure applied.

Figure 1 shows an example of the dependence of the charge carrier lifetime on the diffusion temperature. In general, the higher the process temperature, the shorter the charge carrier lifetime. The silicon was in the form of a block; the charge carrier lifetime also depends on the position of the material in the block.

Fortunately, most of the lifetime reduction caused by the high temperatures can be compensated by remote plasma hydrogen passivation (RPHP). This is shown in fig. 2, taking the open circuit voltage of solar cells before anti-reflective coating as an example.

We carried out systematic investigations with multicrystalline material from different manufacturers and demonstrated that higher temperatures can indeed be used for phosphorus diffusion, if the cell technology including metallisation is adapted appropriately. In this way, we have approached the goal of shorter process times and higher turnover more closely.

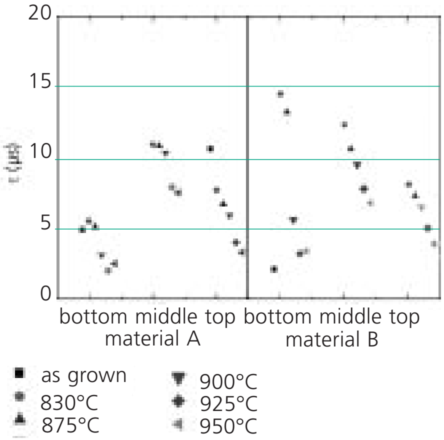


Fig. 1: The minority charge carrier lifetime τ decreases with the diffusion temperature for both materials investigated (A, B; see the legend for the temperatures). The extent of the decrease depends on the position (bottom, middle, top) of the material in the silicon block.

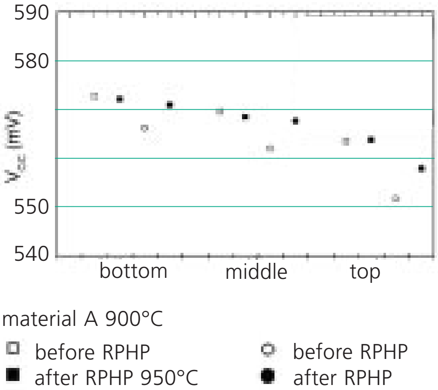
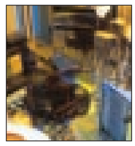


Fig. 2: Open circuit voltage V_{oc} of solar cells before and after hydrogen passivation. Passivation raises the open circuit voltage significantly. The absolute value of the open circuit voltage depends on the position (bottom, middle, top) of the material in the silicon block.



New Equipment for R&D of Crystalline Silicon Thin-Film Solar Cells

Efficient research on crystalline silicon thin-film solar cells is possible only with appropriate equipment. We have developed equipment to produce silicon ribbon substrates and thin silicon films which are specially tailored to the needs of R&D.

Sandra Bau, Achim Eyer, Fridolin Haas, Albert Hurrle, Thomas Kieliba, **Stefan Reber**, Norbert Schillinger

The crystalline silicon thin-film solar cell (fig. 1) is an approach to reduce the cost of solar cells significantly in the future. Supporting arguments include the drastically reduced consumption of expensive, high-quality silicon, and complete elimination of the time-consuming sawing step in conventional wafer production. Nevertheless, much research work is still needed before the crystalline silicon thin-film solar cell is ready for the market. The tools needed are not always commercially available. For example, there was not any moderately priced equipment to produce the silicon substrates or silicon films needed for this type of solar cell. We now supply this equipment, primarily to R&D groups.

We have already been working for years on equipment to produce silicon substrates according to the SSP (silicon sheets from powder) process. During the past year, we concentrated on making it simpler to use. The result is the "SSP120", with which ribbons up to 100 mm wide and more than 1 m long can be produced from silicon powder. By using different silicon powders and process parameters, the user can make ribbons on a routine basis, or carry out R&D directly on the silicon substrates – ideal for research institutions. The system turnover is also oriented to the needs of R&D, so that we can avoid expensive handling devices. This reduces the system price to a minimum.

As with the SSP equipment, we also have years of experience with chemical vapour deposition (CVD) of silicon films. Here again, we have developed equipment which is specifically adapted to the requirements of research on crystalline silicon thin-film solar cells. The most recent product is the "RTCVD160". Using this equipment, silicon films can be deposited onto substrates from trichlorosilane at temperatures around 1200 °C. Great flexibility in the choice of processing parameters is a major advantage of the compact RTCVD160 unit. For instance, all substrate dimensions up to a width of 125 mm and a length of 300 mm can be coated. Depending on the choice of temperature and substrate, the resulting silicon film can have a fine crystalline structure or grow epitaxially as a high-quality, low-defect crystal. Of course, the doping profile of the film is computer-controlled and can be varied freely and continuously over a wide range. The substrates are heated optically, ensuring short processing times which allow several experiments per day.

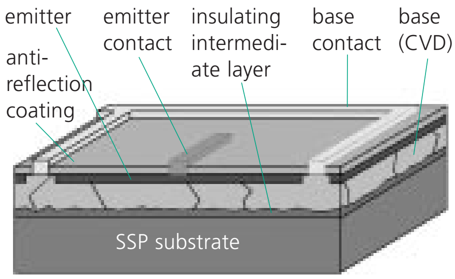


Fig. 1: Schematic diagram of a crystalline silicon thin-film solar cell on a silicon ribbon substrate.

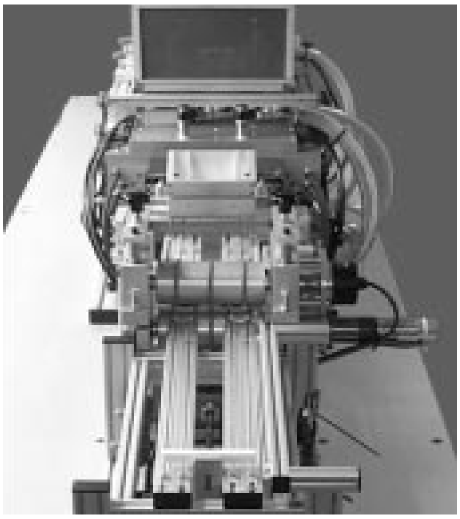
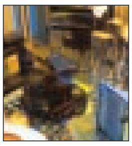


Fig. 2: Equipment to produce silicon ribbon substrates according to the SSP procedure.

Fig. 3: Equipment to deposit silicon films by the CVD process.



III-V Solar Cells and Epitaxy

In our work on III-V materials, we are aiming to achieve efficiency values up to 35 %. To this end, we apply MOVPE, LPE and gas phase diffusion technology to create pn junctions in different combinations of materials. In addition, we develop highly concentrating, optical concentrator systems.

Carsten Agert, Carsten Baur, Rolf Beckert, **Andreas W. Bett**, Frank Dimroth, Mathias Hein, Vladimir Hinkov, Gerrit Lange, Gergö Létay*, Matthias Meusel*, Sascha van Riesen, Ute Schubert, Gerald Siefer

Development of highly efficient multi-junction solar cells

Theoretical efficiency values of up to 30 % have been calculated for solar cells with one pn junction; 26 % has been achieved with a GaAs solar cell. New approaches must be taken to attain still higher efficiency values. One route which appears promising for the near future is the development of multi-junction solar cells, in which several solar cells are connected "optically" in series.

We are investigating two possible configurations: monolithic triple cells based on $Ga_{0.49}In_{0.51}P/Ga_{0.95}In_{0.05}As/Ge$ and mechanically stacked triple cells based on $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ - GaSb. We grow the monolithic cell structures on a substrate by applying metal-organic gas phase epitaxy (MOVPE). The resulting cells are connected not only optically but also electrically in series. In the mechanically stacked cell, we use a monolithic tandem cell as the top cell, which is also grown epitaxially, on a GaAs substrate. We treat the back surface of this cell so that light which has not been absorbed is transmitted, and is thus available for the lower, IR-sensitive GaSb cell (fig. 1). The GaSb cell structure is produced with Zn gas phase diffusion.

In parallel, we are working with MOVPE to produce more complex structures - monolithic IR-sensitive tandem cells - of AlGaAsSb/GaSb. With these structures, we could then produce quadruple solar cells, for which efficiency values up to 40 % have been predicted.

For the mechanically stacked triple solar cell, we have achieved a record efficiency value of 33.5% for a concentration of 308x solar intensity (fig. 1).

The first monolithic triple cells of $Ga_{0.49}In_{0.51}P/Ga_{0.95}In_{0.05}As/Ge$ were produced. Figure 2 shows the measured external quantum efficiency of such a cell. The IR response due to the active bottom cell of Ge is clearly visible.

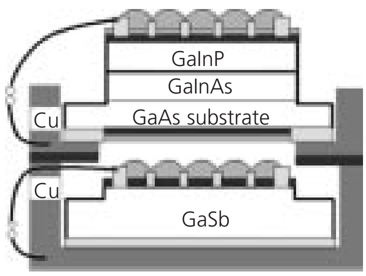


Fig. 1: Schematic diagram of the mechanically stacked triple solar cell of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ - GaSb. With this triple solar cell, we achieved a world record efficiency value of 33.5 % for a concentration of 308x solar intensity (AM1.5d, 25 °C).

From the cell to a concentrator system

In order to test applications of the tandem solar cells of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ developed at Fraunhofer ISE last year, we are developing concentrator modules employing Fresnel lenses, in co-operation with the Ioffe Institute in St. Petersburg in Russia. The optical lenses are made by impressing Fresnel structures into a 2 mm thick silicone film on glass. We also develop encapsulation methods for the concentrator modules and mechanical tracking units to follow the sun. The aim of this work is to construct a durable, highly concentrating concentrator module, which has high module efficiency values in outdoor tests. Over the past years, modules with a concentration factor of 120 and efficiency values up to 24.8 % have been constructed. In addition to demonstrating long-term stability, our current work aims to increase the concentration factor to 500x. To achieve this higher concentration, new Fresnel structures were developed and the solar cell diameter was reduced to 2 mm. The first test modules are being produced and measured at the time of writing.

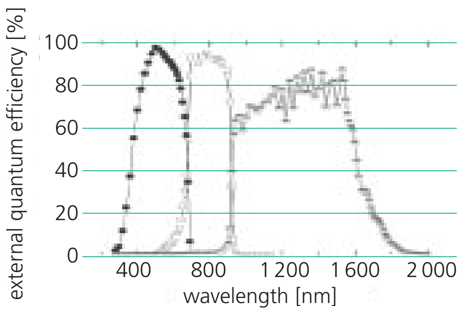
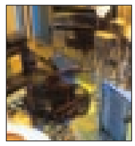


Fig. 2: External quantum efficiency of a monolithic triple cell of $Ga_{0.49}In_{0.51}P/Ga_{0.95}In_{0.05}As/Ge$. Appropriate measurement technology allows the contributions of the individual cells to be shown.

* University of Freiburg, Freiburger Materialforschungszentrum FMF



Analysis of Spatially Distributed Losses in Silicon Solar Cells

The spatial distribution of losses in solar cells often gives decisive indications of possibilities to improve the material and solar cell production technology. In a long-term programme, we are developing models and experimental methods to make this useful information source accessible for production.

Oliver Bartels, Jochen Dicker, Manuel Esterle, Jörg Isenberg*, Stephan Riepe, **Wilhelm Warta**

The reasons that the conversion efficiency value of commercially manufactured silicon solar cells is far from the 20 % exceeded with laboratory cells are related on the one hand to the input material used: Instead of the FZ silicon normally found in laboratories, the industry uses Czochralski silicon or, more commonly in recent years, multicrystalline material which has solidified as a block. For both types of material, but particularly in multi-crystalline silicon, the material quality fluctuates strongly and furthermore, it changes again during solar cell production.

On the other hand, industrial production differs from high-efficiency cell production in applying procedures with a high turnover such as screen printing. These fast processes easily lead to additional losses such as short circuits at the cell edges, which are very inhomogeneously distributed.

It is often not possible to identify underlying causes clearly when global solar cell parameters are analysed, because different, inhomogeneously distributed effects are superimposed. By contrast, details of the spatial distribution of loss factors often indicate their causes.

We already use imaging methods to characterise solar cells and wafers. Now, we have set up a new version of the equipment we had developed for spectrally resolved measurement of short circuit current (SR-LBIC), to be used by an industrial client and the Laboratory and Service Centre in Gelsenkirchen. Its new features include: room for solar cells with dimensions up to 30 x 30 cm^2; improved laser diode optics; measurement of the diffuse reflectance, the internal quantum yield and the effective diffusion length, also for textured cell surfaces.

We have tested improved analytical procedures to separate the effects of the bulk and the back surface of the cell. Their applicability is limited by very stringent demands on the measurement accuracy.
One method we have developed to measure the distribution of recombination losses uses the absorption of infrared radiation by optically generated excess charge carriers (MFCA: modulated free carrier absorption).
We can use it also to investigate partially processed wafers. This method is superior to conventional microwave PCD e.g. for highly doped silicon. For instance, in a recently completed European research project (ARTIST), MFCA was the only method which could be used to measure the charge carrier lifetimes for cheap, highly doped input material. However, the previous equipment operated with sequential measurement, which led to measurement times of several hours for appropriate spatial resolution and large-area solar cells.

To make this measurement principle accessible for broad industrial application, the measurement speed had to be increased significantly.
We succeeded by using an IR camera. The distribution of the charge carrier density is recorded directly as an image (CDI: carrier density imaging), and then processed to give an image of the carrier lifetime distribution (fig. 1). A rough impression can be gained within seconds, and an image with a good signal-to-noise ratio is obtained in less than a minute (fig. 2). This is orders of magnitude faster than a sequential measurement of comparable quality with the widespread microwave PCD method.

By applying lock-in technology, we were able to increase the sensitivity such that the lifetimes usually found in industrial solar cells can be measured. In this method, we generate the charge carriers with a rapidly switchable, high-power laser diode.

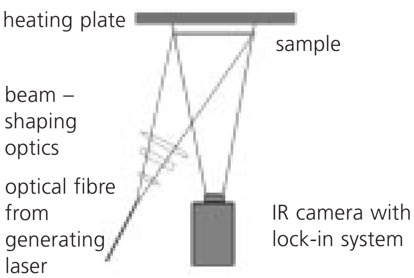


Fig. 1: Principle of the CDI measurement technology.

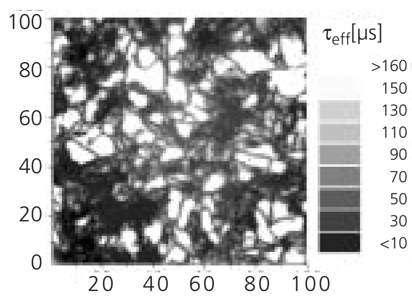


Fig. 2: Lifetime distribution image obtained with the new CDI measurement technology. The scales of the x and y axes are in mm.

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Expert Consortium: Innovative and Rational Production Processes for Silicon Photovoltaic Modules - SOLPRO III

Under the leadership of Fraunhofer ISE and Fraunhofer IPT, Aachen, a "round table" of manufacturers and suppliers to the photovoltaic industry was created to evaluate innovative technology for photovoltaic production. The project was supported by BMWi.

Daniel Biro, Dietmar Borchert,
Gernot Emanuel*, Dominik Huljic,
Sascha Klappert*, **Ralf Lüdemann**,
Stefan Peters, Ralf Preu,
Eric Schneiderlöchner, Dirk Untiedt**

The relatively high costs for photovoltaic electricity still hinder this zero-emission energy source from becoming generally economically competitive. Within this context, the German Federal Ministry of Economics and Technology BMWi funded the project on "Expert Consortium: Innovative and Rational Production Processes for Silicon Photovoltaic Modules - SOLPRO III", which successfully concluded on 31.10.2001 after a period of two years.

The aim of the project was to apply an integrated approach that examined the entire processing chain from silicon to the completed module, and identify potential in production to optimise the efficiency and reduce production costs. This is intended to stabilise and expand the economic viability of photovoltaics on a long-term basis.

We assembled a consortium of wafer, cell and module manufacturers, machine, component and system producers and an energy utility, so that expertise on all aspects of the production chain was represented at the "round table". Altogether 15 enterprises participated in the joint research. The project was scientifically supported and co-ordinated by the Fraunhofer Institute for Production Technology IPT in Aachen and Fraunhofer ISE. The expertise of the two institutes on rational production concepts and development of solar cell processes was complementary, and formed the basis for successful project work and the results achieved.

The co-operation among the participants ranged from the development of innovative production concepts to experimental investigations at all stages along the cell and module production lines. Studies of economic viability and estimated potential took market conditions into account. These included an analysis of promising technology such as laser processing and sputtering in photovoltaics. The following topics were treated in ten subprojects:

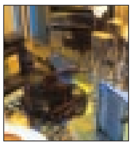
- integrated cell and module production from thin wafers
- application areas for printing technology in solar cell production
- substitution of wet chemistry by plasma technology
- laser applications in production
- fully automatic processing
- processing thin wafers
- front surface metallisation for more efficient solar cells
- texturing processes for multicrystalline silicon
- materials flow analysis

The participants identified optimisation potential for the production of solar cells and modules. They include both measures to increase the efficiency value and to reduce costs; some of them were already applied during the project. In addition, actions for the companies involved were recommended for the short, medium and long term, and new application areas were identified. The positive co-operation between the various companies is being continued beyond the end of the consortium with bilateral projects.

Representation of all stages of production, combined with the research competence of the participating Fraunhofer institutes, was primarily responsible for the success of the interdisciplinary joint research and its market relevance. The expert consortium was an important instrument for technology assessment and for transferring developments from the laboratory to industrial application.

Further information can be found in the Internet under: www.solpro.de.

* University of Freiburg, Freiburger Materialforschungszentrum FMF
** Fraunhofer Institute for Production Technology IPT, Aachen



Laboratory and Service Centre in Gelsenkirchen

In-line processes with a high turnover of 1200 to 1500 wafers per hour represent a very promising approach to greatly reduce the costs of manufacturing solar cells. In our Laboratory and Service Centre in Gelsenkirchen, we give manufacturers the opportunity to test and optimise such processes in the laboratory under conditions similar to those in production. The results can then be transferred directly to production. Support is provided with appropriate measurement technology to characterise both substrates and complete solar cells.

Christophe Ballif, **Dietmar Borchert**, Helge Ehrhard, Ricardo Guerrero, Ali Kenanoglu, Stefan Müller, Stefan Peters, Alexander Poddey, Roland Schindler, Wilhelm Warta, Gerhard Willeke, Janez Zemva, Thomas Zerres

In-line processes represent a new challenge to research in the laboratory. The Laboratory and Service Centre in Gelsenkirchen is devoting an increasing amount of attention to them.

We have set up a pilot line for multicrystalline silicon so as to provide optimal support to the solar cell manufacturers. Solar cells with dimensions up to 150 x 150 mm^2 can be produced there according to the following standard process: wet etching to remove sawing damage, emitter diffusion from doped SiO_2 emulsions in an in-line diffusion furnace, etching of the phosphorus glass, plasma deposition of an anti-reflective silicon nitride coating, screen printing of the front and back contacts and firing of the contacts in an in-line sintering furnace.

One special feature of the production line is the in-line diffusion furnace. The furnace operates with continuous cord transport having a small thermal mass. Low-mass transport and optical heating of the substrates means that short heating times and rapid cooling ramps are possible, so that diffusion processes can be better adapted to the material properties in in-line systems. In addition, the furnace is equipped with an integrated RTP (rapid thermal processing) module, which can produce temperature ramps of 50 to 100 Ks^{-1}. In particular, materials such as EFG (edge-defined film-fed growth) and RGS (ribbon growth on substrate) can profit from the introduction of RTP processes. Our aim is to integrate RTP processes into in-line production units.

The anti-reflective silicon nitride coating is deposited in a parallel-plate system. The deposition area is 450 x 450 mm^2, the excitation frequency is 13.56 MHz. Not only deposition processes but also etching processes can be carried out in this unit.

To characterise multicrystalline silicon, we measured the microwave reflection from wafers deliberately taken from the base and uppermost zone of a block-cast column. This material is not usually supplied to cell manufacturers. We identified iron as the main contaminant in the base region. With phosphorus diffusion, we were able to lengthen the charge carrier lifetimes in the material to the extent that good solar cells could be made from it.

We have expanded our measurement equipment with a device to rapidly determine the sheet resistance over large areas. Compared to conventional systems, it reduces the measurement time by up to 90 %. Whereas they have one sensor with four pins, the new device has 100 small sensors, each with four pins, mounted on a base plate. The sample must be brought in contact with the device only once to obtain 100 measurement points. There are hardly any restrictions on the number of measurement points or their configuration on the base plate. The larger the number of measurement points needed, the greater is the advantage presented by the new device.

Fig. 1: Production of solar cells with in-line processes.

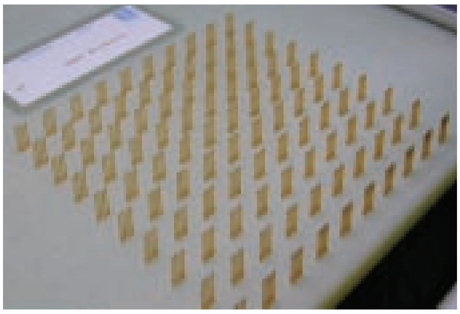
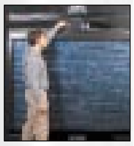


Fig. 2: Base plate with 100 sensors for large-area measurement of sheet resistance over an area of 150 x 150 mm^2.

ISE CalLab – Precision Measurement for Photovoltaics

Precision measurement of a 3 m^2 solar module with a rated power of 290 W.



The characterisation of solar cells and photovoltaic modules plays a decisive role not only in research and development but also for production. It is just as indispensable for the comparison of products as for the dimensioning and authorisation of photovoltaic systems.

The Photovoltaic Calibration Laboratory at Fraunhofer ISE (ISE CalLab) is one of the internationally leading laboratories in measurement technology for photovoltaics - with continuing quality assurance guaranteed by measurement comparisons and harmonisation with the Physikalisch-Technische Bundesanstalt (National Standards Laboratory) in Braunschweig. Not only internationally renowned manufacturers, but also the TÜV Rheinland have their reference cells measured by ISE CalLab.

The success of the calibration laboratory is based on the fundamental aim of the Fraunhofer Society to combine research and applications: The scientific know-how is constantly kept up to date by research at Fraunhofer ISE, and almost 20 years of experience with photovoltaic systems brings in the practical side. The orientation of ISE CalLab towards application is also demonstrated by its home page, http://www.callab.de. It provides information on technical details, gives prices and allows orders to be placed on-line.

One special feature of ISE CalLab is its bandwidth: The samples can be commercial silicon solar cells, dye-sensitised solar cells, thin-film technology or multiple-junction cells for 1000-fold concentration or even complete photovoltaic modules. Researchers from all over the world come to Freiburg with their new developments, for a measurement result from ISE CalLab is internationally recognised at conferences and in the scientific journals.

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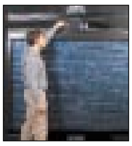


Flashlamp Measurement Technology to Determine Efficiency of Concentrator Solar Cells

The calibration laboratory for solar cells and modules at Fraunhofer ISE (CalLab) is equipped with sophisticated equipment for flashlamp measurements, with which modules can be measured on a routine basis for other groups within the institute or external clients. An important new application for this measurement technology is the characterisation of solar cells intended for use in optical concentrator systems.

Klaus Kiefer, Matthias Meusel, Frank Neuberger, Gerald Siefer, **Wilhelm Warta**, Jürgen Weber

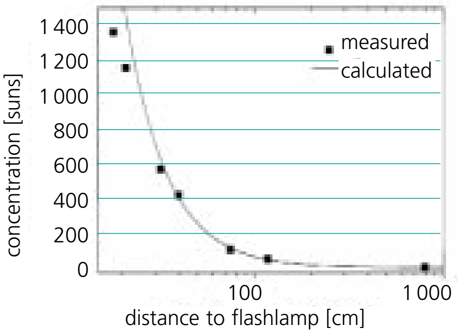


Fig. 1: Illumination intensities which can be attained with the CalLab flashlamp.

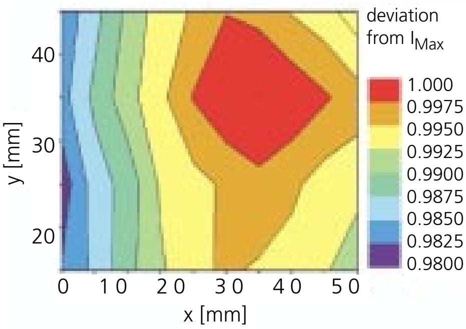


Fig. 2: Homogeneity of the incident illumination for an intensity of 400 suns.

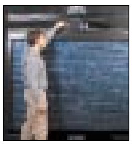
Concentrator systems have a large potential to reduce costs for photovoltaic electricity: On the one hand, the required area of solar cells is reduced by the concentration factor, on the other hand, the efficiency value increases slightly with increasing concentration. Until now, the commercial availability of such systems was restricted. Accordingly, internationally recognised standards to determine the efficiency of concentrator systems do not yet exist. In a project funded by the EU, we are co-operating with IES in Madrid, JRC in Ispra, RWE Solar in Heilbronn and ITER in Tenerife to prepare the foundations for a future measurement standard. Fraunhofer ISE is working on questions associated with the use of artificial light sources for measuring the concentrator cells. To this purpose, we analysed the relevant properties of our flashlamp and measurement equipment.

First we investigated the illumination intensity which can be achieved with the set-up. Figure 1 shows the measured light intensity versus the distance to the lamp filament (points), compared to a simple inverse square dependence. Deviations from the expected values occur at high concentration factors; measurements with a concentration of up to 1 400x suns are possible.

The homogeneity of the light intensity is better than 2 % over the measurement plane of 2.4 x 2.4 m^2 for 1 sun. We have also measured the spatial distribution of the illumination intensity for different intensities. Figure 2 shows the result for 400 suns. For all of the solar cell dimensions considered, we determined that at typical concentration factors for the cell considered, sufficiently large areas with a homogeneity better than 2 % were available.

Another question is the quality of the flashlamp spectrum compared to the standard spectrum. This is a particularly critical point for stacked cells intended for concentrator applications. Investigations on cells produced by Fraunhofer ISE revealed large errors when the spectrum deviates from the standard.

Using a rapid-response diode-array spectral radiometer, we measured the spectral distribution of our flashlamp, and found that it depended on the age of the flashlamps. However, these variations are within the bandwidth specified for a Class A simulator. We are now able to specify the lamp spectrum accurately by applying a model for the age-dependent spectral changes. A specific spectrum can be chosen as required from a range of lamps of differing ages.



Module Calibration - An Efficient Method for Quality Assurance

The booming photovoltaic market in Germany has increased the demand for module measurements enormously. An increasing number of wholesalers and installation companies is commissioning us to characterise random samples taken from large module orders in our flashlamp laboratory or outdoors, to check the specifications given by the manufacturers. The technical facilities for both types of measurement services are ideal in our new building. Our staff has also grown, so that we can provide optimal service to our clients.

Klaus Kiefer, Frank Neuberger, Wilhelm Warta, Jürgen Weber

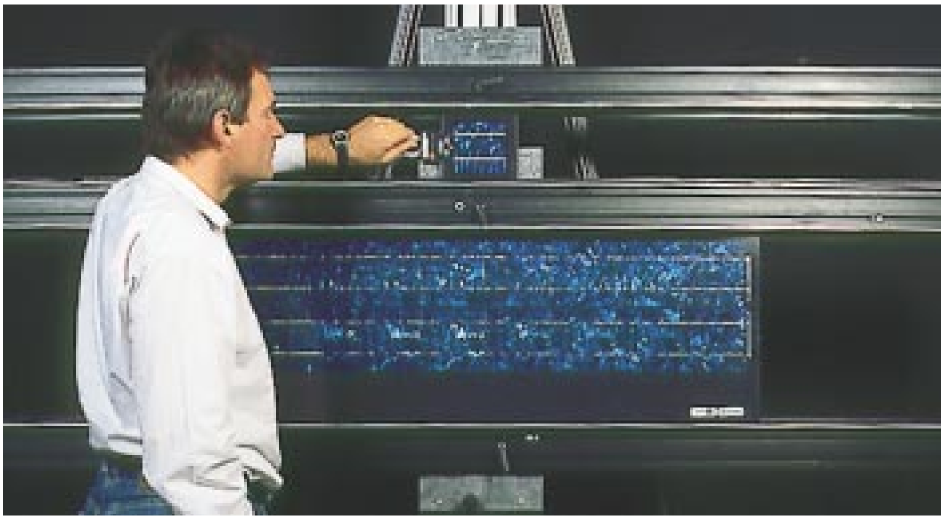


Fig. 1: Measurement of a photovoltaic roofing tile unit.

Our expertise

Thanks to our long years of practical experience in PV measurement technology, we can offer our clients:

- reliable measurement results, which are guaranteed by regular participation in round-robin tests with other internationally recognised measurement laboratories
- compliance with international standards in all calibration steps and in the use of reference elements and measurement facilities
- continuous further development of the measurement procedures in accordance with research activities at Fraunhofer ISE
- rapid, non-bureaucratic processing
- strict confidentiality guaranteed
- regular maintenance and testing of our measurement equipment
- intensive and competent advice on individual measurement requirements

Our services

We characterise PV modules of all constructions up to dimensions of 2 x 2 m^2:

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

Our measurement facilities

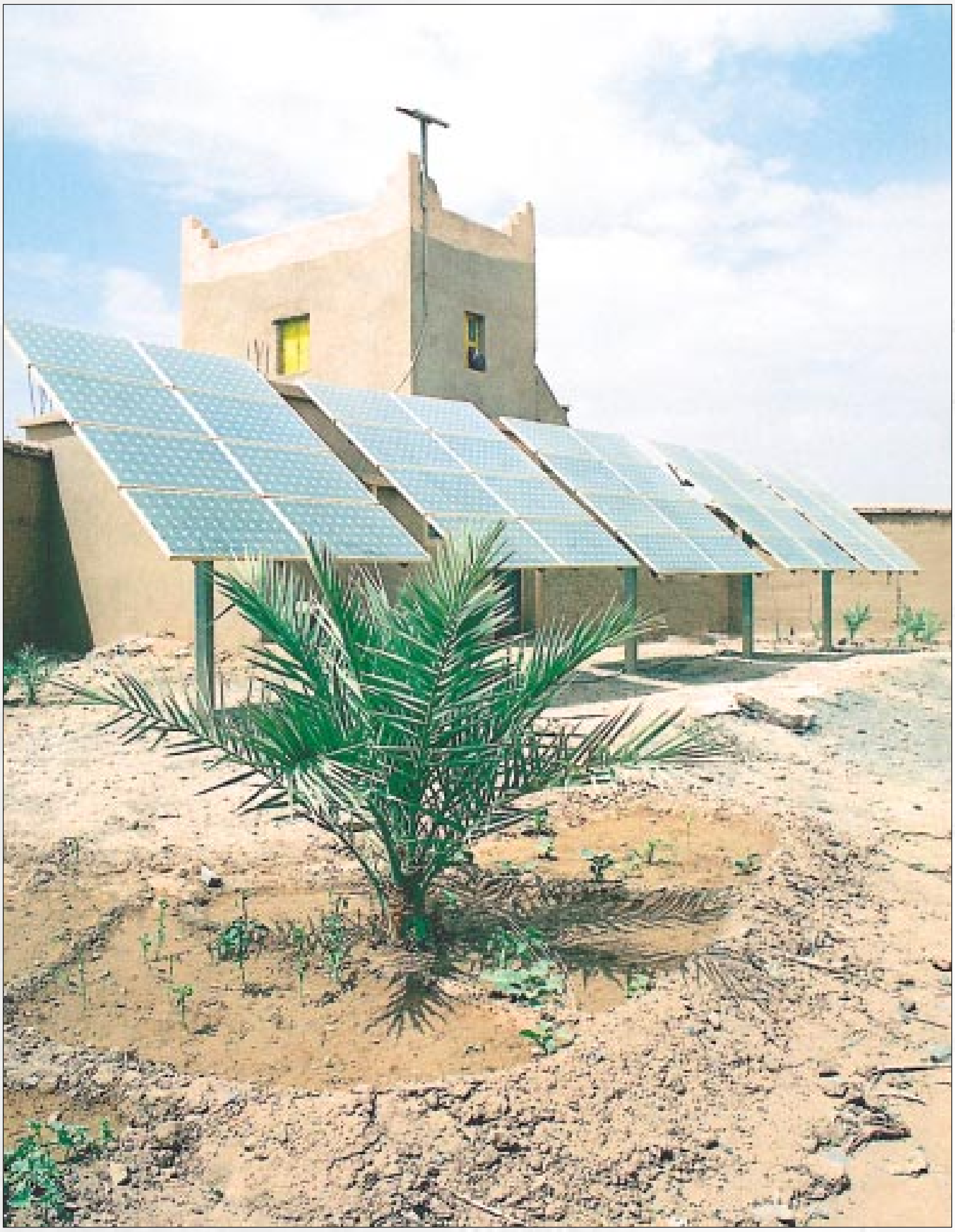
ISE CalLab is equipped with high-quality measurement facilities to meet demanding measurement challenges.

- class A steady-state solar simulator (AM 1.5; AM 0)
- simulator with three light sources
- concentrating solar simulator (up to 1 200 suns)
- pulsed solar simulator (AM 1.5)
- outdoor measurement stand
- filter monochromator (300 nm to 1 400 nm)
- grating monochromator (300 nm to 1 800 nm)
- various spectroradiometers

Internet

For more detailed information, simply consult our Internet site at http://www.callab.de. From there, you can also easily place measurement orders by e-mail.

Off-Grid Power Supply and Storage Systems



Photovoltaic pumping station for drinking water and irrigation in the village of Ifert, Morocco. Another photovoltaic array for the drinking water disinfection unit is mounted on the roof (see article on p. 78).

Whether power is needed for a telecommunications repeater in German mountains or for light in a mud hut in Morocco: Photovoltaics is often the cheapest alternative if there is not a grid nearby. This is equally valid for the two thousand million people in threshold and developing countries and for the 400 000 houses in European mountainous regions.

In addition to Solar Home Systems, which with their rated power of 50 W_p represent the smallest "ray of hope" for rural areas in developing countries, we have been investigating photovoltaic systems of 1 - 20 kW_p with increasing intensity for off-grid power supply. They make additional commercial activities or the operation of a clinic feasible. With regard to energy economics, they are interesting as the smallest unit in a decentralised, inter-connected grid. In grid-independent village power supplies, distribution of the electricity is a contentious issue. Our approach of developing the technology together with the local users, always taking social and economic aspects into account, has proven to be beneficial here. This is equally true for mountaineering lodges, where we have provided advice on planning, energy concepts and monitoring, in some cases for more than a decade now.

The conventional lead-acid battery is still the workhorse of photovoltaic systems technology. We develop new products for the battery industry and optimised charging procedures for solar applications. This results not only in higher usable storage capacities and efficiency values, but also extended lifetimes and thus reduced costs. Quickly obtainable information on the battery lifetime is very important both for the battery manufacturers and for the system users.

Clean drinking water is becoming an increasingly high priority. It determines not only the well-being of the consumers, but also the economic strength of a country. Often surface water is drunk without further treatment, with two thousand million cases of illness annually being the direct result. Photovoltaics can provide cheap electricity for pumping and treating water. We also develop disinfection and desalination technology which is appropriate for decentralised water purification.

The corresponding market is worth several thousand million US dollars. We are active in promoting quality assurance and sustainable market development. In this capacity, we advise governments around the world and accompany market introduction programmes with our technical, sociological and economic expertise. In the "Club for Rural Electrification", we co-operate with industrial partners to strengthen German photovoltaic exports.

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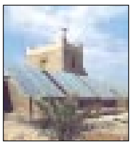


"Club zur ländlichen Elektrifizierung C.L.E" - Association of German Industrial Companies to Develop the Market for Rural Electrification

A questionnaire sent out by Fraunhofer ISE in April 2000 revealed that the German photovoltaic and systems technology branch had considerable need for a common strategy to penetrate the market for rural electrification. As a result, 16 companies founded the "Club zur ländlichen Elektrifizierung C.L.E." in September 2000. Fraunhofer ISE is the coordinator for C.L.E., which already has a membership of 20.

Rana Adib, **Dirk Uwe Sauer**,
Silke Drescher*, Klaus Preiser

Already 20 German companies, ranging from module manufacturers through system developers to installation and finance companies, have combined to co-operate in the "Club zur ländlichen Elektrifizierung C.L.E.". Their common goal is to penetrate the markets for rural electrification. C.L.E. is aiming to achieve a sustainable PV economy in Germany. To this end, C.L.E. intends to establish permanent structures in developing countries which will enable stable export markets for German solar companies. C.L.E. is a broadly based export initiative, in which German photovoltaic businesses will improve the boundary conditions for photovoltaic export and implement decentralised power supply concepts.

C.L.E. brings together the complete spectrum of expertise on rural electrification represented by the member companies. This allows comprehensive and coherent presentation in the strategically significant solar markets - down to marketing of the internationally recognised quality seal, "Made in Germany".

In addition, by acting as a consortium, C.L.E. enables its members, mostly small and medium-sized enterprises, to compete successfully on the global market.

At the same time, C.L.E. sees itself as a representative of the photovoltaic branch to German bodies responsible for promoting export, in matters concerning rural electrification. These are primarily the German Federal Ministries of Economic Co-operation and Development BMZ, and of Economics and Technology BMWi, the Society for Technical Co-operation GTZ, the Kreditanstalt für Wiederaufbau KfW and the Export Council for Renewable Energy, which is currently being established. Essential goals include improved information flow, adequate inclusion of German companies in projects in developing countries and support for German companies in penetrating markets e.g. by close connection with developmental aid projects or credit guarantee mechanisms.

An important aspect is that the export promotion instruments be appropriately adapted to the markets for rural electrification. 10 000 Solar Home Systems, each worth 1 000 euros, require a different form of support to a hydroelectric power station with a value of 10 million euros. Creation of relevant boundary conditions in the target countries (taxes, customs, etc.) is also a topic of discussion.

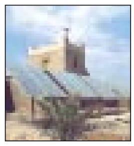
C.L.E. has already had important meetings with the ministries and will co-operate with them closely to further improve the boundary conditions for exporting technology for rural electrification.

C.L.E. also aims to bring together companies with different products, so that they can combine in submitting quotes for system or electrification solutions. In joint actions, market information will be obtained and studies on particular markets or countries prepared, partners in the target countries identified through trading companies or participation in trade fairs, and quality standards introduced, which are based on those already existing on the market.

Close co-operation with the associations representing the German solar industry is fully expected by C.L.E. The legal form for C.L.E. was finalised at the end of 2001.

Further members are welcome. Information about the goals of C.L.E. and its members can be found in the Internet under www.cle-export.de.

*free-lance



Rural Energy Supply Models - How can Rural Customers be Reached?

A basic question for market-orientated rural electrification is how to bring the power supply systems and services to the final customers. We have categorised and characterised marketing and infrastructure models as a service to industry, government institutions and financing agents.

Rana Adib, Klaus Preiser

Renewable energy is viewed as a good and natural solution to supply energy to rural households in developing and threshold countries. The key actors have now chosen a market-orientated approach for providing energy to the population which does not yet have access to electricity - more than two thousand million people around the world. As not much experience has been gained yet with such large projects, there are still numerous issues to be clarified.

We co-operated with the International Solar Energy Society ISES to produce the widely noted study on "Rural Energy Supply Models (RESuM)". Its aim is to support actors such as governments, businesses and financing institutions in their activities concerning rural electrification.

The study fills gaps in knowledge of appropriate power supply models for rural areas in developing countries. It provides information about establishing the various distribution and dissemination models and summarises experience with these models. The information is available in a structured form at a specially developed Internet site.

A market-orientated and market-controlled approach can be combined with sustainable electrification politics with the help of the study. The results allow us to advise companies and financial institutions during the market introduction phase, and to work with them in preparing the optimal marketing strategy.

The following model categories were identified and defined: cash, credit, leasing and service. The reader is offered a structured overview of the corresponding power supply models, their characteristics, advantages and disadvantages. Information is provided about contractual agreements between the system and/or service provider and the final customer. The study also investigates business procedures such as advertisement and installation. The structured analysis is supported by practical examples for each type of power supply model.

As an example, we present results from the "fee for service" model in the following section (fig. 2).

In the "fee for service" model, the customer pays a regular contribution for an agreed, fixed energy service. The service price is determined by the hardware costs plus dealers' margins, financing costs and costs for installation, insurance and maintenance. Infrastructure is necessary for sales, installation, maintenance and insurance. The models assumes long operating periods.

The following problems and risks arise for the service provider:
- high costs for the infrastructure
- repair costs and the question of responsibility in the case of system failure
- storage of spare parts for long periods of time
- lack of technical facilities to monitor overuse by the customer.

Nevertheless, the "fee for service" model has a very high potential for opening markets also among poor households, as the customers are not burdened with high initial investment costs.

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety funded the study.

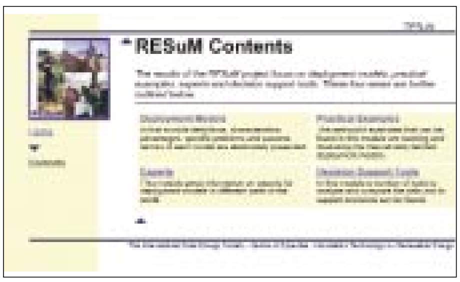


Fig. 1: Interactive Internet site (http:\\resum.ises.org)

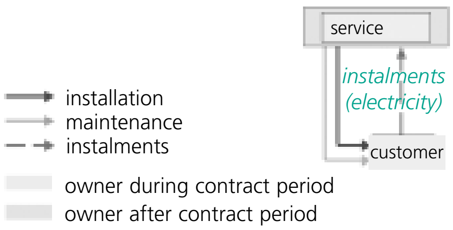


Fig. 2: "Fee for service" model for operation and financing.

Concepts for Combining Decentralised Water and Power Supply Systems based on Regenerative Energy in Rural Areas of the Maghreb Region

Rural water and energy supplies were provided only very slowly in the past in threshold and developing countries. Thus, more than one thousand million people still do not have acceptable access to water and power supplies. Energy and water supplies are closely connected to each other, as energy must be expended to pump and treat water. We co-operate with local partners to develop technical and organisational concepts which will allow water provision to be combined better with rural electrification.

Rana Adib, Christian Brennig,
Silke Drescher*, Dirk Uwe Sauer
Martin Wegmann

The technological development of off-grid, decentralised power and water supply in developing countries is an important aspect of improving living conditions in the target countries on a permanent basis. Appropriate financing and management models for the introduced systems guarantee long-term infrastructure in rural regions.

This is the starting point for the EU-funded "JARUWA" project, which we are running jointly with our Moroccan partner in the Maghreb Region. Economists and engineers are developing concepts together, which take account not only of technical issues but also organisational and financial aspects of combined rural infrastructure for water and power supply, which are based on regenerative energy. A special feature is identification of synergetic advantages which result from introducing and managing the water and power supply systems jointly.

Within the project, we have chosen Morocco as the country to be studied, as governmental programmes to improve the water supply (PAGER) and the power supply (PERG) are already running in rural areas, so that initial experience has already been gained. Decentralised supply approaches with renewable energy sources are explicitly supported in these programmes.

We compared and combined the two programmes on the basis of their classification criteria for villages which will not be connected to the national electricity grid. We used these criteria to identify suitable villages for case examples, and described their needs in more detail after conducting field investigations. At the same time, we discussed implementation and management approaches for rural water and power supplies with the responsible representatives from politics, research and economics.

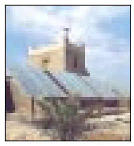
The interim results revealed that water and power supplies have been introduced independently of each other in Morocco up to now. Existing synergetic opportunities are not exploited, although many criteria for the systems are similar.

There are various approaches which can be appropriate for maintaining and managing the systems. The "community management" approach, in which the users themselves are responsible for smooth running of the system, operates on different principles to the "service concept". The latter relies on the involvement of private commercially organised bodies (individuals or companies), which guarantee reliable system operation for a fee.

Our plans to use the results of the study as the basis for discussion in an international workshop, with participants from Europe and the Maghreb, have been encouraged by the considerable interest shown in our activities. The workshop aims to promote exchange of concepts and experience in the north-south and south-south directions. The results are intended to strengthen co-operation between the Maghreb States and the EU in the rural infrastructure sector, and to further promote the use of solar energy in the sunny Maghreb States.

Fig. 1: PV-powered water supply in Efert, Morocco, with an integrated disinfection plant. In future, a miniature electricity grid based on photovoltaics should also be installed in the village.

*free-lance



Energy Planning Guidelines for Mountain Lodges

Renewable energy is an ideal alternative to diesel generators for supplying electricity to mountain lodges. We have summarised the most important points for successful conversion in a set of planning guidelines.

Georg Bopp, Klaus Kiefer,
Dirk Uwe Sauer

The planning guidelines help to determine the energy demand and set up an environmentally acceptable power supply for mountain lodges and shelter huts. They are addressed both to owners and operators (e.g. wardens and leaseholders) and also to engineering offices and system planners. They are intended to support all involved in the planning process, and thus contribute to the development of high-quality power supply concepts.

The guidelines are based on our experience with more than 45 photovoltaically powered, off-grid houses and mountain lodges. This has shown that the first step is to determine the existing energy consumption and ways of reducing it.

The standard method to calculate the potential for saving electricity uses consumption measurements and calculations for the individual project concerned. As a supplement, for the first time we have proposed three methods based on energy coefficients. The coefficients were derived from 15 systems which have already been measured. We analysed the data for correlations between the electricity consumption and the amount of installed equipment, number of guests, table capacity, number of beds, the menu, length of the ascent to the lodge and the water consumption. With the assumption that most of the appliances used are from the energy efficiency class A, finally three reliable correlations were identified. As an example, fig. 1 shows the correlation between energy demand and the number of guests for large lodges, which have more than 4 000 overnight guests per season or are open the whole year.

For this category of lodge, the energy demand can be calculated quickly and sufficiently accurately using the coefficient for "energy consumption per guest", without the need for measuring consumption.

Once the energy-saving potential has been determined, the guidelines show how the remaining energy demand can be met in an environmentally acceptable way using regenerative energy sources, taking the particular boundary conditions in the mountains into account.

A corresponding decision diagram includes e.g. photovoltaic systems, heat/electricity co-generation plants fuelled with rapeseed oil, solar collector systems for domestic hot water and tiled stoves fuelled with wood pellets. Using this diagram, the reader can develop a consistent overall concept.

To validate the assumptions, we prepared an energy concept for the Göppinger Lodge of the German Mountaineering Club DAV, thereby proving the practicability of the guidelines.

The guidelines were financed by the German Environmental Foundation DBU. It has initiated a funding programme for exemplary, environmentally acceptable supply and disposal services for off-grid mountain lodges. This includes measures for power and water supply, and disposal of garbage and waste water. To make a grant application with the DBU, a detailed analysis of the existing situation and presentation of the concept are required. The guidelines simplify this step considerably.

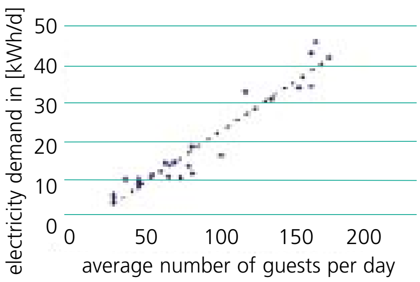
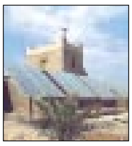


Fig. 1: Average daily energy demand as a function of the average daily number of guests.

Fig. 2: The energy planning guidelines were validated for the first time for the Göppinger Lodge.



Development of Test Procedures for Storage Batteries in Stand-Alone Power Supply Systems

There are no suitable test procedures available today which can reliably determine the lifetime of batteries in stand-alone power supplies. We are developing procedures to characterise batteries according to their application conditions. In addition, we are working on procedures for accelerated ageing tests.

Dirk Uwe Sauer, Pascal Fischer, Rudi Kaiser, Hans-Georg Puls

Batteries are responsible for a large share of the costs in stand-alone power supplies. The lifetime of the batteries depends very much on two factors:

- choice of the optimal battery type or appropriate battery technology
- setting of the operating conditions

However, there are not yet any test procedures which can reliably determine the lifetime of batteries in stand-alone power supplies within a short testing time. This is partly because the operating conditions are influenced decisively by the application, the location and the system configuration.

In addition, many ageing effects occur in parallel in batteries, which are not all intensified by the same factor in accelerated ageing tests. Therefore, the results cannot be rescaled to normal battery operating conditions. Even under accelerating conditions, ageing tests on good batteries last for at least one year; if real operating conditions are applied, 5 to 8 years must pass before reliable results become available.

We are working in two projects on procedures which allow the lifetime behaviour of batteries in stand-alone power supplies to be characterised.

In the "BENCHMARKING" project (which started in January 2002), we are co-operating with leading institutes from Europe, USA and Australia to characterise and classify the operating conditions of batteries. Data from real systems are analysed and used to determine the stress profiles on the batteries. A typical testing cycle will be developed for each class of operating conditions. This can be used to conduct non-accelerated ageing tests, which give a reliable lifetime value for the tested battery in the corresponding class of operating conditions. Further, the aim is to develop accelerated testing cycles, which also reproduce the operating conditions as closely as possible.

The development in the "ACTUS" project goes a step further. There, a novel procedure for accelerated ageing tests of lead-acid batteries is being developed together with industrial companies and partners specialised in the electrochemistry of batteries. It consists of a combination of electrochemical tests and lifetime simulation of the ageing behaviour of lead-acid batteries in a system. Specific electrochemical or physical tests are to be developed for each of the different ageing mechanisms, which will be used to characterise the test object's vulnerability to ageing. None of the tests should last longer than three months. After three months, characteristic values for the various ageing effects will be available. We use these data to determine the parameters for a detailed, physico-chemical ageing model of the battery. We can use this to simulate the lifetime under different operating conditions. Determination of the characteristic values once will thus allow quick calculation of the lifetime which can be expected. At the same time, the results will be verified within the project with non-accelerated ageing tests.

Both projects are funded by the EU.

Fraunhofer ISE is also participating in the "INVESTIRE" network, which is led by CEA-GENEC, Aix-en-Provence and funded by the EU. 35 partners will document the current status of all types of storage technology for stand-alone power supplies, and evaluate their potential for development. We are responsible for determining the operating conditions in different application classes.

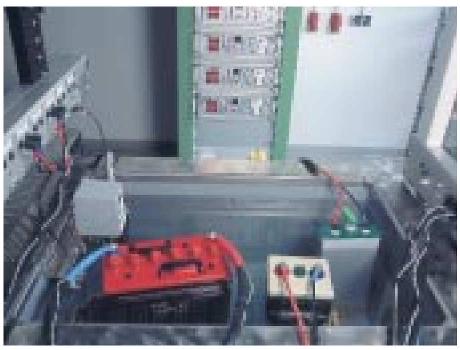
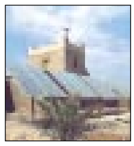


Fig. 1: We have a total of more than 50 battery testing circuits for short-term and long-term electrical characterisation, with current ranges between 20 mA and 300 A and voltages between 1 V and 500 V. Three water baths and two temperature-controlled cabinets are available to keep the battery temperature at the required value.



Product Development of a Photovoltaically Powered Water Purification System

One thousand million people are living without access to electricity or clean drinking water. Water purification technology must be adapted to the conditions in regions remote from the grid if these people are to have a sustainable supply of drinking water.

Jochen Benz, **Georg Bopp**,
Markus Brandl, Orlando Parodi,
Ulrike Seibert, Andreas Steinhüser

In rural areas of developing countries, there is often neither a connection to a public electricity grid nor a supply of clean drinking water. Off-grid, decentralised systems are suitable to supply hygienically acceptable drinking water to these areas. We therefore develop concepts for photovoltaically powered systems for purifying drinking water.

Together with the SolarFabrik GmbH, we developed a stand-alone water purification system specially for application in developing countries.

During field investigations in Morocco, one of the target countries, we found out that potential customers wanted a combination of water pumping and water purification. These two features of the system led to the product name, WATERpps (water pumping and purification system).

The basic concept of WATERpps has the following elements:
- pumping of domestic water and purification of drinking water
- water supply for 25 to 50 persons
- drinking water purification by microfilters from Katadyn, Switzerland
- stand-alone photovoltaic power supply
- compact and robust construction
- user friendly
- cheap to produce

In implementing it, we observed the conditions in detail where the system will be used. For instance, the WATERpps prototype has excellent features concerning transportability. The compact housing unit allows the system to be transported safely to the planned installation site, which may well be very remote. The hinged construction makes installation simple. A microbiological risk for the drinking water can arise only if the filter is subjected to stagnation conditions for longer periods (risk of clogging growth). An active protective device warns against this state. Automatic pump switch-off and a simple energy storage display prevent energy from being wasted.

During the product development process, we carried out various long-term tests of the system. To this purpose, we set up a universally applicable test stand for water purification systems. We can use it also to characterise other types of water purification systems.

The work was funded within the BMWi programme on "Photovoltaics for appliances and small systems."

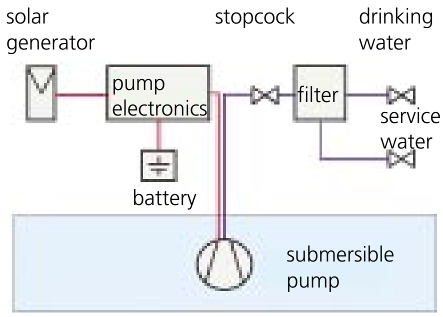
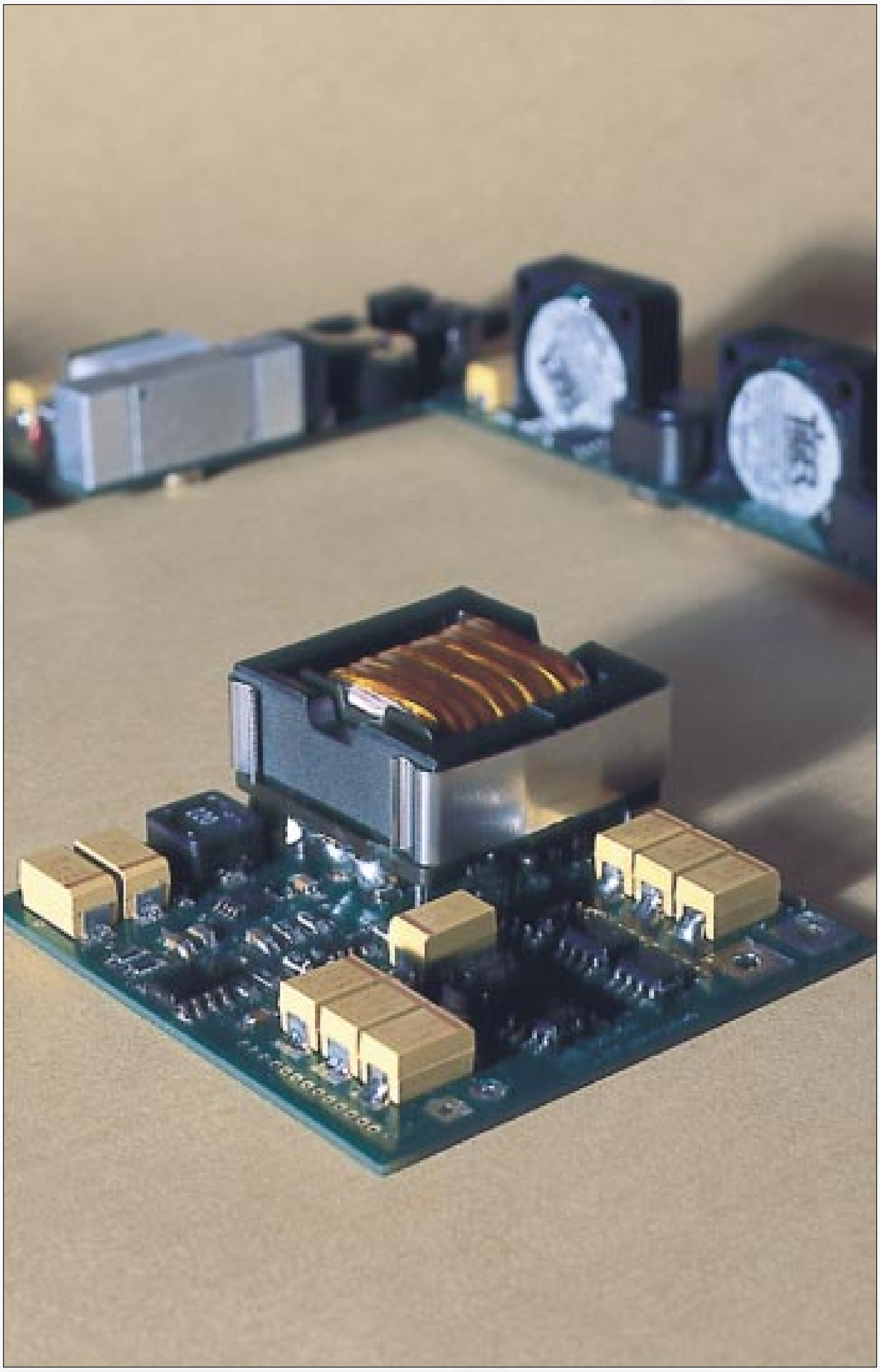


Fig. 1: System diagram of WATERpps.

Fig. 2: WATERpps prototype.

Fig. 3: The WATERpps prototype ready for transportation.



The operating point of fuel cells or solar cells can be flexibly adapted to the load by using highly efficient DC/DC converters. The photo shows a converter which supplies 10 W power from a fuel cell to a notebook with an efficiency exceeding 91 % for an input voltage of only 1 V (see article on p. 84).

Products which are powered by the sun are more convenient, save battery costs or replace expensive grid connections. Already in 2001, there were more than four thousand million portable electronic appliances such as radios, mobile phones, camcorders or palmtops. Industrial applications of photovoltaics include decentralised facilities for telecommunications, information technology and traffic direction.

Each application has its own specifications for the power supply. For telecommunications, it is 100 % availability, which we can guarantee with hybrid systems. In the consumer sector, the trend is towards smaller and more powerful devices. Our answer to that is miniaturisation and efficiency, for good appliances demand excellent components: High-efficiency solar cells, sophisticated energy management, low-power electronic components, surface mounted devices (SMD), optimised battery periphery.

Solar power supplies are characterised by high flexibility and efficiency, so we adapt the electronics to each specific application. For instance, we have paved the way to a completely new family of products with our DC/DC converter for very high currents and extremely low input voltages. Another example is our energy management system, which efficiently combines very diverse electricity generators, loads and storage units. It "learns" from the user behaviour and can be adapted to very different applications. Using it, even stand-alone power supplies with seasonal storage and 10 years of maintenance-free operation have become feasible.

In addition to scientific competence, our second asset is the practical experience we have gained over 20 years of co-operation with manufacturers and users. After all, it is not the concept but the market success which is decisive. We promote comprehensive quality assurance - not only at the Institute, but also in national and international bodies - to ensure high-quality components and systems.

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Customised Power Electronics for Fuel Cell Systems

If portable devices such as notebooks and camcorders draw their power from miniature fuel cells instead of conventional batteries, the duration of operation and thus their usefulness increases considerably. We adapt the connection of the energy converter to the appliance according to the individual specifications.

Jochen Benz, **Bruno Burger**,
Jürgen Ketterer, Heribert Schmidt

Conventional batteries or other voltage sources cannot be directly replaced by fuel cells of any size, due to their specific electrical characteristics. To ensure reliable and efficient operation, an adaptation must be made, employing modern power electronics and sophisticated control strategies. The fuel cell is then started in a controlled mode, operated at its optimum working point and protected against damage due to overloading.

As voltage converters with these properties are not available on the market, we have developed customised DC/DC converters for various clients. The power ranges from a few watts to kilowatts. All efficiency values are well above 90 %. In addition to the voltage conversion, we have integrated other features which are important for a fuel cell system, particularly for the low power range, such as:
- controls to regulate the system start without an external voltage source
- control of the hydrogen pressure
- controls for ventilation to regulate the water content.

Integration into portable appliances creates particular challenges concerning the construction form and dimensions. We were able to meet these by using miniature components and innovative configurations.

1st example: Camcorder
Here, we replaced the standard battery by a compact unit consisting of a hydrogen tank and a fuel cell.
A highly efficient, miniaturised DC/DC converter adapts the output voltage to the specifications of the appliance (fig. 1). In addition, the circuit controls the pressure of the input gas and regulates the start of fuel cell operation.

2nd example: Personal digital assistant (PDA)
The PDA, where the keyboard and display are combined, represents the next step in miniaturisation from a notebook. A long-term power supply is essential for this device with its primarily mobile application. Fuel cells are excellent for this purpose.

For this application, we developed a converter with a large transformation ratio and a high efficiency value (fig. 2). This meant that we could reduce the number of cells in the fuel cell stack and thus the volume required.

3rd example: Telecommunications
We developed a DC/DC converter, which combines a fuel cell and a battery, as part of the stand-alone power supply (photovoltaics and fuel cell) for a transmitter designed for use in rural telephone networks. It features integrated controls to protect the fuel cell against overloading. On the input side, it monitors the current and voltage of the fuel cell stack and controls the output power according to specifications. The converter recognises possible deviations or transient interruptions and takes them into account. The efficiency value of more than 95 % saves energy resources.

The "FIRST" telecommunications project is funded by the EU.

Input power	300 W
Input voltage	16 V – 25 V
Output voltage (48 V battery)	40 V – 60 V
Rated efficiency value	95 %

Table 1: Technical specifications of the converter for telecommunications.

Fig. 1: DC/DC converter for a fuel-cell camcorder. The efficiency value is 97 %. In addition, the circuit includes the hydrogen valve and a button cell for the starting phase. The circuit board is 50 mm long.

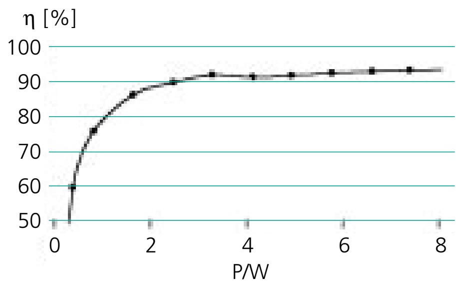

Fig. 2: Efficiency profile of a DC/DC converter for a fuel-cell PDA. Input voltage 1 V - 3 V, output voltage 8 V, power 8 W.

Powerful Electronics for Hybrid Power Supply Systems for Telecommunications Facilities

We design and construct the controls for autonomous power supply systems based on a photovoltaic generator, a fuel cell with an optional electrolyser and a 12-month hydrogen storage unit.

Jochen Benz, Bruno Burger,
Jürgen Ketterer, Michael Neutz,
Dirk Uwe Sauer, Heribert Schmidt

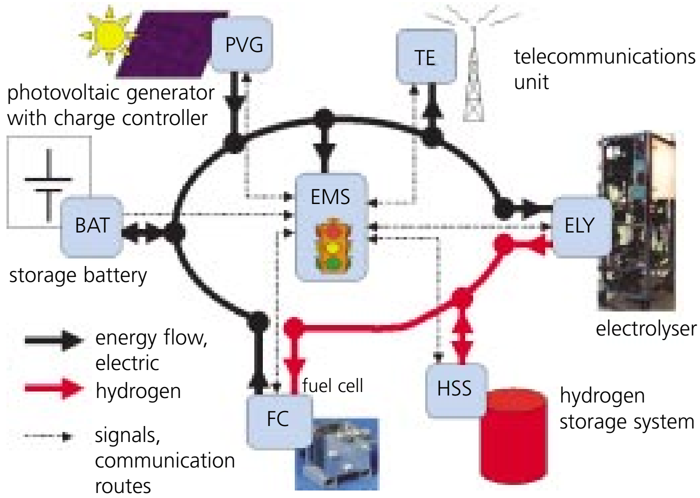

Fig. 1: Block circuit diagram of the discussed hybrid system for telecommunications facilities.

Hybrid systems with photovoltaics and an auxiliary generator are a good option for supplying power to transmitters, as they are often located at remote sites with difficult access. Expensive installation of electricity cables can be avoided or complicated fuel transport can be reduced. The auxiliary generator guarantees supply reliability even during periods with little or no sunshine, while the major share of the demand is met by the photovoltaics. Complete independence from external sources can be achieved with an additional seasonal energy storage unit (fig. 1). Supply reliability is decisive for telecommunications systems. Modern electronics and software are essential to ensure that the economic and lifetime boundary conditions are met. The central control unit for the system is a microcontroller-based energy management system (EMS), which monitors and controls all energy flows (fig. 2). In an EU-funded project, we are testing modular concepts for commercial applications. The most recent results from systems simulation and storage system research are taken into account.

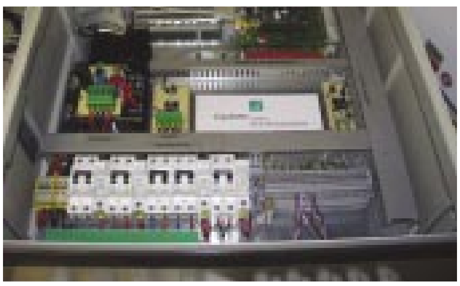

Fig. 2: Electronics of the energy management system to control hybrid systems.

Determining the battery state of charge

One central quantity for operation management is the state of charge of the battery. We determine it with an algorithm which automatically adjusts the parameters for the underlying battery model during operation. Appropriately adapted precision sensors ensure that the results are sufficiently accurate.

Seasonal hydrogen storage unit

The electrolyser needs half an hour to initialise before it can convert excess power from the photovoltaic generator into hydrogen. The energy management system recognises stable insolation periods, when it is worth operating the electrolyser. The EMS monitors the filling of the metal hydride storage unit and determines the amount of gas stored. In darker periods during the winter months, it starts the fuel cell to maintain the power supply at the level needed.

Safety and defect detection

The EMS continually checks the system components and gives notification of any defects by radio to a central station, before the power supply falls too low.
The electric controls for the gas valves of the fuel cell were designed so that faults in the electronics itself can be recognised and unwanted gas escape can be prevented in all cases.

Modular concept

In constructing the hardware, which is also reflected in the operation management software, we designed the units to be as independent as possible. They are coupled via an energy bus and connected to the central unit with a communications interface. A safety loop is foreseen as an option. This means that a developed system can be modified simply and adapted to other boundary conditions. A PV-fuel cell system based on this concept was installed in Madrid in June, 2001. Experience from this field test is influencing the development of the system with seasonal storage, which will be commissioned early in 2002.

Photovoltaics for Appliances and Small Systems

An increasing number of appliances and small systems are operated independently of a central power supply. Often a grid connection is not feasible or too expensive. A photovoltaic power supply is a good option. We support small and medium-sized enterprises in exploiting the wide range of innovative potential offered by photovoltaics for new products

Sergej Aingorn, Jochen Benz, Rudi Kaiser, Frank Kreuz, Norbert Pfanner, **Werner Roth**, Dirk Uwe Sauer, Heribert Schmidt, Andreas Steinhüser

Traffic direction system

Particularly along the federal motorways, traffic direction systems with prismatic displays are being installed in increasing numbers. The displays consist of rotatable, prismatic segments, and are usually connected to the 230 V grid. Together with the company, via traffic controlling gmbh, we have developed a stand-alone system with cable-free data transfer and intelligent sensors. The system has a photovoltaic power supply and consists of a 3-facetted prismatic display in an aluminium frame, which can display three traffic signs. In addition to the mechanical drive system for the prisms, the frame houses the circuit board for the controls, a GSM radio modem and the charge controller. A planar GSM antenna is mounted on the frame. An infrared sensor to measure the road surface temperature, an anemometer or a radar detector for speed control could also be added to the system.

Fig. 1: Photovoltaically powered prismatic display: Rapidly installed, requiring little maintenance and simple to control via the mobile telephone network. (Source: via traffic controlling gmbh).

The solar-powered prismatic display is primarily intended for traffic direction in built-up areas (fig. 1). A timer, remote controls or sensor-based control can be used to select the different traffic signs.

Solar powered outdoor lights

In addition to street and footpath lighting, accent lighting is often needed at locations away from the public electricity grid (fig. 2). We have co-operated with Moonlight GmbH to develop, construct and test a stand-alone photovoltaic power supply system for spherical and hemispherical lamps.

We investigated various types of lighting technology to achieve energy-efficient and homogeneous illumination of the spheres. For spherical lamps of up to 35 cm diameter, a light was developed with super-bright LED's in combination with a constant current source. Larger lamps are equipped with compact fluorescent lights. In lamps with several light sources, operation is optimised by a control unit which automatically switches the lights on and off according to the state of charge.

Southern countries, with high ambient temperatures, represent one of the main regions where photovoltaically powered accent lighting is applied. For these applications, we have equipped the switch box (fig. 3) with a heat exchanger to cool the battery. The heat exchanger is powered by the

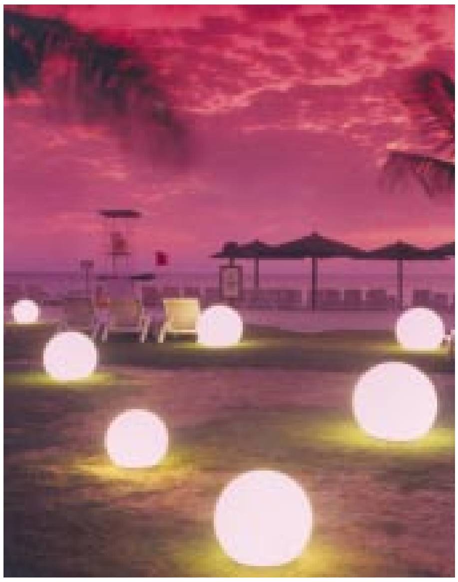

Fig. 2: Beach lighting with spherical lamps. (Source: Moonlight GmbH).

excess energy available when the solar radiation intensity is high. This measure extends the battery lifetime significantly.

Maintenance-free, stand-alone power supply

Stand-alone power supplies are used for e.g. transponders, sensors and telematics systems, and allow maintenance-free and reliable operation over very long periods of time.
If the power demand is very low, primary batteries can also be used for operation over several years.
However, as soon as the consumption is higher and off-grid operation is required, a stand-alone power supply with a photovoltaic generator is the first choice. As the energy supply and demand do not generally coincide, a rechargeable battery is also needed. It should have a high efficiency value, be very reliable and have a long lifetime.

Often, these specifications can not be met by one type of storage technology alone. This applies particularly if the solar irradiation is subject to strong seasonal variation. Then energy must be stored in summer and be available for use in winter. In addition, the power supply must be very reliable. For instance, if the rechargeable batteries are discharged completely, a warning signal is sent to the central control station, and further reliable operation is guaranteed with an emergency reserve.

Our concept is very flexible and allows diverse battery types, loads and photovoltaic generators to be operated in parallel (fig. 4).

As all components are connected to a common DC bus, its voltage can fluctuate within a wide range. A capacitor stabilises the voltage of the DC bus, so that a continuous current supply to the load is guaranteed even during switching processes. The load is supplied with constant voltage via a DC/DC converter. Almost any number of rechargeable batteries can be connected to the DC bus. A primary battery is connected via a diode to the DC bus and only supplies energy when the voltage on the DC bus is lower than the voltage of the primary battery. The overall concept ensures that this can happen only when all of the rechargeable batteries are completely discharged. In this concept, the primary battery has the lowest voltage level of all the storage units. Its lifetime should be equal to at least twice the time between two maintenance checks, and its self-discharge should be minimal. We aim for 10 years of operation without maintenance for the complete system.
A patent claim for the concept has been filed. The German Federal Ministry of Economics and Technology BMWi funded this work within its programme on "Photovoltaics for appliances and small systems".

Fig. 3: Switch box to house the energy storage unit and control electronics. The heat exchanger to cool the batteries can be seen on the roof. It is powered with excess electricity from the photovoltaic generator.

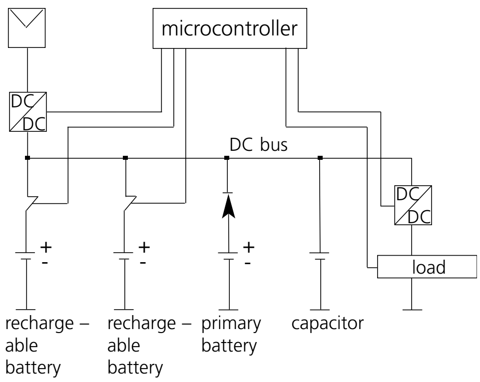

Fig. 4: Block circuit diagram of a system for seasonal storage of energy, with a lifetime goal of ten years.

Grid-Connected Electricity Systems

Yield measurement of a solar power plant for the RWE utility in Essen (see article on p. 92).

The 100 000 Roofs Programme and the Renewable Energy Law have stimulated a rapid upswing for grid-connected photovoltaics in Germany. We accompany market introduction programmes of this type and accept responsibility for planning, dimensioning, authorisation and monitoring of the systems. With payments of 0.99 DM/kWh for electricity supplied to the grid, careful planning for an optimal yield is certainly warranted. Ten years of monitoring have taught us where weaknesses can be expected and how they can be remedied quickly.

The range of services which we can offer to our clients is as comprehensive as the knowledge base underlying it: We monitor the quality of modules as soon as they are delivered in our flashlamp laboratory. The next stage is the authorisation inspection on site. After that, we do not stop observing the system: remote monitoring with data transfer each night and differentiated alarm levels, accurate analysis every day and presentation of the system data in Internet, evaluation of the results and consultancy. We also have an inexpensive solution for small systems: The satellite-supported SAT Watch offers guaranteed monitoring of the yields from private systems, without additional installation and operating costs.

Not only operators, but also manufacturers profit from our experience. The best example is given by inverters: During the 1 000 Roofs Programme, we identified numerous breakdowns with our monitoring. We discussed the causes of faults together with the manufacturers. Now, inverters are characterised by an operating availability of 99 %, and have become an export success.

A strong increase in the number of enquiries from architects and civil engineers indicates that photovoltaics is developing swiftly in its role as an element of solar building. PV modules fulfil many different functions in buildings, including aesthetic purposes, daylighting and shading, as well as electricity generation. We identify the desired solution with simulation programs.

In co-operation with industrial partners, we are working toward the intelligent electricity grid of the future, which will allow a large proportion of renewable energy to be incorporated. Many complementary generators drawing on PV, wind, water and biomass, together with storage and control elements, will ensure that the electricity customer does not notice the transition to a sustainable energy economy, because the convenience and reliability of the grid will remained unchanged.

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Optimisation of Advanced Photovoltaic Applications on Buildings - the New Institute Premises as an Example

Four photovoltaic systems with a rated power of about 20 kW_p were incorporated into the new premises for Fraunhofer ISE. These systems are fully integrated into the building by their construction, design and energy contribution. More generally, we apply sophisticated system design and detailed knowledge of the products to integrate even exotic photovoltaic applications into buildings, and ensure that they operate reliably and efficiently.

Sören Andersen* , Sebastian Herkel, Klaus Kiefer, **Hermann Laukamp**, Karsten Voss

Fig. 1: A 2.4 kW_p photovoltaic generator is integrated into the end façade of the access tract.

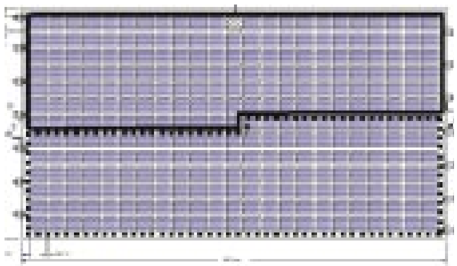

Fig. 2: Schematic drawing of a module for the access tract façade, with two electrically isolated submodules. An asymmetric wiring plan allows all cells to be connected, despite the odd number of rows and columns. Specifications: 299 cells, 400 W_p, 2 x (87 V, 3 A). (Source: Flabeg Solar).

Fig. 3: A view up into the top of the atrium.

Integrating photovoltaic systems into buildings demands careful consideration of expectations regarding design and yield of the systems. Two of the systems on the new institute premises illustrate how a good electric yield can be achieved while clear aesthetic and town planning boundary conditions are observed.

End façade of the access tract

The architects chose large modules with the dimensions of the building's basic gridula, app. 2.5 x 1.8 m^2. The number of rows and columns is odd, so that certain gaps between the cells are retained for visibility. The façade is partly shaded. These conditions, and the size of the modules, led the module manufacturers to suggest that one row and one column of cells remain unconnected.

Our response was to design an asymmetric wiring plan for the module (fig. 2), and to divide the system vertically into fine strings. Each module is subdivided into two electrically isolated submodules. One string consists of three submodules connected in series, and a total of four strings operate together with two inverters. This solution results in a regular appearance and supplies 12 % more electricity than the solution with unconnected cells.

Saw-toothed roof over the atrium

When the sun is very low in the sky, the front panels partly shade the back ones (fig. 4). Therefore, we divided each module into three, electrically

*Architects Dissing+Weitling, Copenhagen

isolated submodules (fig. 5), and wired these to form horizontal strings. In this way, only submodules with the same irradiation conditions are connected in series, so that mismatch losses are minimised. The yield is around 8 % higher than for conventional wiring.

Energy concept

Altogether, around 20 kW_p of photovoltaics is installed on the new building for Fraunhofer ISE. With an annual yield of 15 MWh, this approximately meets the demand for electric lighting in the offices (fig. 6).

The photovoltaic systems on our new premises will be described and published as a case study in the IEA-PVPS Task 7 on "PV in the Built Environment" (www.task7.org). Our participation in Task 7 is financially supported by BMWi. The European Union financially supported the systems within the "Thermie" programme.

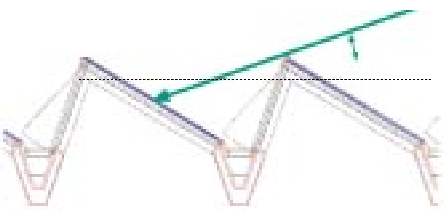

Fig. 4: The front panels of the saw-toothed roof partly shade the back ones.

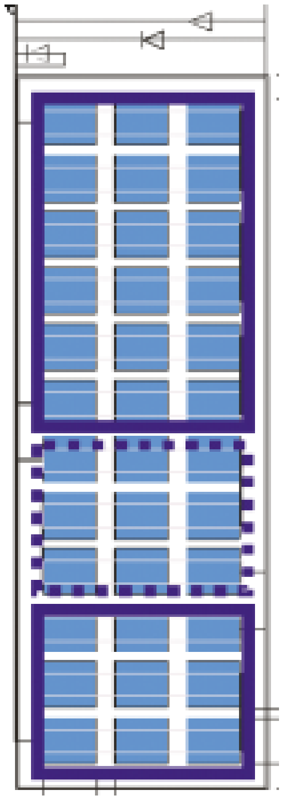

Fig. 5: The atrium roof modules are subdivided into three electrically isolated submodules, which are then connected horizontally. (Source: St. Gobain Glass Solar).

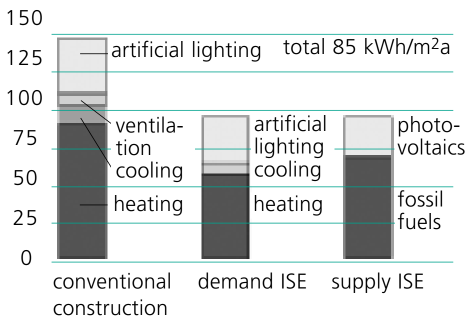

Fig. 6: Primary energy demand and energy supply for the new building (centre and right), compared to the energy demand of a conventionally planned office building (left). Units: primary energy equivalents.

Fig. 7: The new ISE premises viewed from the south-east.

Monitoring – a Broad Service Offer

Measurement, analysis and communication are the strengths of our monitoring service for photovoltaic systems. We design, install and operate complete measurement systems of all sizes. We apply our wide experience to analyse and interpret the results. Transparent, rapid presentation of the results in appropriate publications or in the Internet is also part of our service package.

Alfons Armbruster*, Thomas Erge, Volker U. Hoffmann, Frank Neuberger, Wolfgang Heydenreich**, **Klaus Kiefer**, Christian Reise, Eberhard Rössler**

Scientific support for market introduction programmes

Since starting in this field, we have thoroughly investigated about 3000 systems. The references for our monitoring are summarised in table 1.

Project	Commissioned by
1000-Dächer	BMBF
Sonne i. d. Schule	BMWi
SonneOnline	E.ON Energie AG
600 Kirchendächer	Deutsche Bundesstiftung Umwelt DBU
Umwelttarif	RWE Power AG
Regiostrom	Badenova AG
Euralp	Deutscher Alpenverein DAV
100 Passivhäuser	Energie Baden-Württemberg EnBW

Table 1: Examples of monitoring projects, which we are currently running or have completed.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg
**free-lance

Figure 1 illustrates how widely the yields from photovoltaic systems can diverge within Germany, taking 1999 as an example. The annual system yields from different projects are classified into different ranges. Although 1999 was a year with a high solar irradiation total, half of the systems from the 1000 Roofs Programme generated less than 700 kWh/kW_p. This is very much less than the expected yield of 800 kWh/kW_p.

Only a few systems in the "Umwelttarif" and "SONNEonline" programmes yielded less than 700 kWh/kWp. Here, we had taken appropriate quality assurance measures in the initial stages of the programmes. In detail, these were:

- careful selection of sites to avoid partial shading of the photovoltaic generator
- sample measurements of individual modules in the calibration laboratory of Fraunhofer ISE
- authorisation inspection of installed systems, including a test of the generator performance
- continuous acquisition of operation data

As an example, figure 2 shows measured I/V characteristic curves for a solar generator found in practice. The blue characteristic curve indicates a string with defect modules.

The initiative entitled "Church congregations for solar energy", supported by the Bundesstiftung Umwelt,

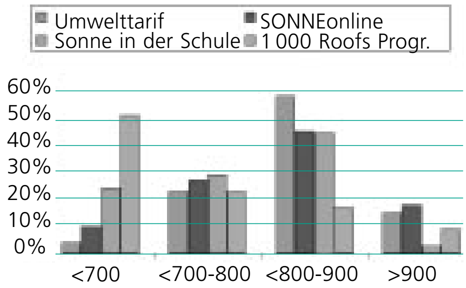

Fig. 1: Annual yield of individual photovoltaic projects for 1999. The system yields are given in kWh per kW_p installed rated power for the photovoltaic generator.

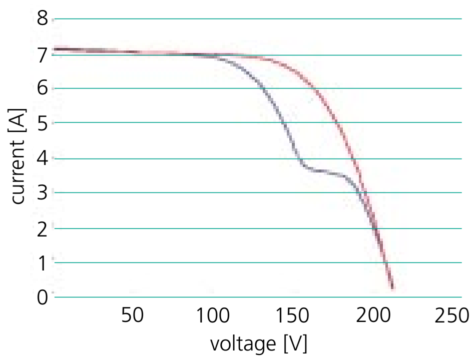

Fig. 2: Example of I-V characteristic curves for the strings of a generator. The expected curve is plotted in red; the blue curve is from a string with defect modules.

Fig. 3: The system belonging to the Catholic Students' Congregation in Berlin has a specific annual yield of 680 kWh/kW_p, which is considerably lower than the average.

also shows how important quality assurance is in the current stage of market introduction for grid-connected photovoltaic systems.
By monitoring the yield data on a monthly basis, we identify systems with a low yield and search for the causes. For example, partial shading is the main reason for the annual yield of a system in Berlin being more than 10 % less than predicted.

Quality assurance for system manufacturers and installers

With the current price of 0.99 DM per kWh for photovoltaic electricity fed into the grid, good system design and quality also brings financial benefits for system operators. An increasing number of industrial clients make use of the services offered by Fraunhofer ISE. Some selected examples follow.

SAT Watch for Shell Siemens

On commission to Shell Siemens, Fraunhofer ISE monitors the yield of all newly installed Shell photovoltaic systems by satellite. After installation, Shell Solar informs Fraunhofer ISE once of the technical and site specifications of the system, as well as the orientation and tilt angle of the solar modules. We obtain the monthly irradiation values for any desired site by analysing the image data from the METEOSAT satellite. By combining the two sets of information, we can calculate the monthly yields with our programs. The values are sent each month to the system operators by SMS, email, fax or postcard. In this way, the operators can easily determine whether their systems are delivering the yield expected. If deviations occur, the client consults the specialist company responsible for the system.

System yield data from RWE Solar in Internet

The RWE Solar company wants to make the measurement results from photovoltaic systems based on different ASE module technology accessible to their customers and contract partners. We co-operated with the company to develop a concept which allows customers to inform themselves daily about the performance of the ASE products.
As an example, figure 5 shows the variation of the daily energy yield in kWh/kW$_p$ and the daily irradiation total during the month of August, 2001. (See also www.solar-monitoring.de/tessag).

"Karlsruher Sonnendach" of the Karlsruhe city utility

The "Karlsruher Sonnendach" (sunroof) is an initiative taken by citizens of Karlsruhe and the municipal utility. In the preparatory phase, we advised the utility on system planning, call for quotes and selection of installation partners. After commissioning, we carried out an authorisation inspection. To ensure that the "Karlsruher Sonnendach" generates as much electricity as possible, we also monitor its operation continuously with automated data transfer via the telephone network. In 2000, the system achieved a yield of 985 kWh per kW$_p$, exceeding predictions by 10 percent.

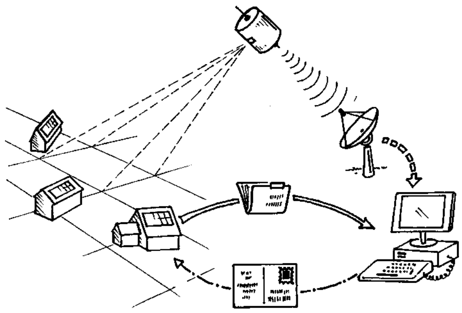

Fig. 4: Operating principle of SAT Watch.

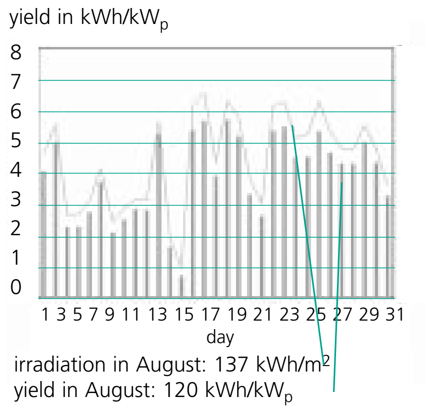

Fig. 5: Monthly graph from August 2001 for the RWE system in Alfhausen. The line plot shows the fluctuations in the daily solar irradiation. The columns indicate the daily yields.

Fig. 6: "Karlsruher Sonnendach" with a rated power of 50 kW$_p$.

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

Visiting Scientists

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Research area: solar cell characterisation

Prof. Manfred von Mende
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1.10.2001-28.2.2002
Research area: solar building

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Research area: micro-energy technology

Prof. Valeri Rumyantsev
A.S. Ioffe Physico-Technical Institute
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Research area: III-V concentrator module development

Dr Nicolay Sadchikov
A.S. Ioffe Physico-Technical Institute
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16.6.2001-14.9.2001
Research area: III-V concentrator module development

Participation in National and International Associations

Bundesministerium für Wirtschaft und Technologie BMWi
- Lenkungsausschuss “Solar optimiertes Bauen«

Deutsche Elektrotechnische Kommission DKE
- Komitee 221: Elektrische Anlagen von Gebäuden
- Komitee 373: Photovoltaische Solarenergiesysteme
- Komitee 384: Brennstoffzellen

Deutsche Gesellschaft für Chemisches Apparatewesen, Chemische Technik und Biotechnologie Dechema e.v.
- Arbeitsausschuss “Elektrochemische Prozesse«

Deutsche Gesellschaft für Galvano- und Oberflächentechnik DGO
- Fachausschuss “Mikrosysteme und Oberflächentechnik”

Deutsche Gesellschaft für Psychologie
- Fachausschuss Umweltpsychologie

Deutsche Gesellschaft für Sonnenenergie DGS
- Vorstand der Sektion Südbaden

Deutsche Elektrotechnische Kommission DKE
- Komitee 384: Brennstoffzellen

Deutsche Physikalische Gesellschaft
- Arbeitskreis Energie

Deutscher Wasserstoff-Verein

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

European Fuel Cell Group

European Renewable Energy Centres EUREC Agency
- President

Fachinstitut Gebäude-Klima FGK
- Arbeitskreis Sorptionsgestützte Klimatisierung

Fachverband Transparente Wärmedämmung
- Fachausschuss “Produktkennwerte”

Forschungsallianz “Brennstoffzellen”, Baden-Württemberg

Forschungsverbund Sonnenenergie FVS
- Direktorium Hahn-Meitner-Institut HMI
- Wissenschaftlicher Beirat

German Advisory Council on Global Change
- Member

Institut für Solare Energieversorgungstechnik ISET
- Wissenschaftlicher Beirat

International Solar Energy Society ISES
- Board of Directors

International Solar Energy Society Europe ISES-Europe
- Governing Board

Nationales Symposium Photovoltaische Solarenergie
- Wissenschaftlicher Beirat

ISO/TC 197 Hydrogen Technologies
- Normenausschuss Gastechnik (NA Gas)

Verein Deutscher Elektrotechniker
- ETG-Fachausschuss “Brennstoffzellen”

Verein Deutscher Ingenieure, VDI-Gesellschaft Energietechnik
- Fachausschuss “Regenerative Energien”

Verein Deutscher Ingenieure VDI-Gesellschaft Energietechnik
- Fachausschuss “Brennstoffzellen”

VMPA- Verband der Materialprüfämter e.V.
- Sektorgruppe “Türen, Fenster und Glasprodukte”

Zeitschrift “Physikalische Blätter”, Wiley-VCH
- Kuratorium

Zentrum für Solarenergie und Wasserstoff ZSW, Stuttgart
- Kuratorium

Congresses, Conferences and Seminars organised by the Institute

OTTI Energie-Kolleg Regensburg
7. Symposium Innovative Lichttechnik
Staffelstein, Kloster Banz, 25./26.1.2001

OTTI Energie-Kolleg Regensburg
16. Symposium Photovoltaische Solarenergie
Staffelstein, Kloster Banz, 14.-16.3.2001

OTTI Energie-Kolleg Regensburg
11. Symposium Thermische Solarenergie
Staffelstein, Kloster Banz, 9.-11.5.2001

Solarbau 2001
Symposium Neubau Deutsches Technikmuseum
Berlin, 24./25.6.2001

Intersolar Freiburg
Technologie Seminar
Freiburg, 6.-8.7.2001

OTTI Energie-Kolleg Regensburg
Fachseminar Netzgekoppelte Photovoltaik-Anlagen
Freiburg, 27./28.6.2001

Forschungsverbund Sonnenenergie
Jahrestagung
Potsdam, 20./21.9.2001

OTTI Energie-Kolleg Regensburg
Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme
Freiburg, 25./26.9.2001

8th International Workshop on Space Solar Cell Calibration and Measurement Techniques
Freiburg, 17.–19.10.2001

17th European Photovoltaic Solar Energy Conference
Munich, 22.–26.10.2001

Lecture Courses and Seminars

Dr. Bruno Burger
Leistungselektronische Systeme für regenerative Energiequellen
Vorlesung WS 01/02
Universität Karlsruhe

Prof. Joachim Luther
Photovoltaische Energiewandlung
Vorlesung SS 01
Aktuelle Fragen der Sonnenenergiekonversion
Seminar SS 01
Thermische Solarenergiewandlung
Vorlesung WS 01/02
Aktuelle Fragen der Sonnenenergiekonversion
Seminar WS 01/02
Universität Freiburg, Fakultät für Physik

Prof. Roland Schindler
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Dr. Heribert Schmidt
Photovoltaik Systemtechnik
Vorlesung SS 01
Universität Karlsruhe

Priv. Doz. Dr. Gerhard Willeke
Halbleiter für Bauelemente und alternative Energien
Seminar SS 01
Universität Konstanz, Fachbereich Physik

Priv. Doz. Dr. Volker Wittwer
Innovative Energiesysteme
Vorlesung SS 01
Innovative Energiesysteme
Seminar WS 01/02
Universität Freiburg, Fakultät für angewandte Wissenschaften, Bereich Mikrosystemtechnik

Trade Fairs and Exhibitions

5. Passivhaus Tagung und Ausstellung für energieeffizientes Bauen im CongressCentrum Böblingen, 16.-18.2.2001

Industrieausstellung im Rahmen des 16. Symposiums Photovoltaische Solarenergie
Staffelstein, Kloster Banz, 14.-16.3.2001

European Coatings Show
Joint stand of the WISA and INNOFASS projects.
Nürnberg, 2.-4.4.2001

Hanover Trade Fair, 2001
- Joint stand of the "Nanofab" project
- Participation in the joint stand on "Hydrogen Technology"
  Hanover, 23.-28.4.2001

Intersolar 2001
Freiburg, 6.-8.7.2001

17th European Photovoltaic Solar Energy Conference and Exhibition
Munich, 22.-26.10.2001

Patents

Patent Applications

Dr Benedikt Bläsi, Vokmar Boerner,
Dr Andreas Gombert, Michael Niggemann
"Device for anisotropic light scattering and procedure to produce the device"

Axel Heitzler, Dr Christopher Hebling, Andreas Schmitz
"Fuel cell system and procedure to control pressure in fuel cell systems"

Prof. Adolf Goetzberger, Dr Manuel Goller, Michael Müller
"Optical element like a linear Fresnel lens and application of the optical element for glare control"

Dr Andreas Hinsch, Dr Andreas Georg, Michael Niggemann
"Procedure to produce polymer solar cells on porous substrate films"

Dr Peter Nitz, Dr Andreas Gombert,
Dr Benedikt Bläsi, Christopher Bühler
"Insulating glazing with integrated solar control and light-redirecting system with partial view (based on prismatically structured surfaces) and procedure to produce such a system"

Patents Granted

Dr Harry Wirth
"Thermal light switch (TLS)"

Dr Andreas Gombert, Jörg Jungjohann
"Light redirecting element"

Dr Andreas Georg, Wolfgang Graf, Prof. Konstantin Ledjeff-Hey, Dr Volker Wittwer
"Catalytic, transparent heating element"

Marcel Lorenz, Dr Armin Zastrow
"Photoconductive triode"

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

Dr Hans-Martin Henning, Michael Hermann, Carsten Hindenburg, Peter Schossig
"Active thermal component with phase-change material"

Dr Harry Wirth, Dr Volker Wittwer
"Tracking translucent solar shading device with concentrator function"

Doctoral Theses

Carsten Agert
"MOVPE of GaSb-based Materials and Solar Cell structures"
Doctoral thesis, University of Marburg
Marburg, 2001

Simone Baumgärtner
"Herstellung und Charakterisierung hochporöser Titandioxid-Schichten. Einfluss ihrer Struktur auf optische und elektrische Eigenschaften von Farbstoffsolarzellen"
(Production and characterisation of highly porous titanium dioxide films. Effect of their structure on optical and electrical properties of dye-sensitised solar cells)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Rolf Beckert
"Charakterisierung von Infrarot-empfindlichen Photovoltaikzellen"
(Characterisation of infrared-sensitive photovoltaic cells)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Andreas Bühring
"Theoretische und experimentelle Untersuchungen zum Einsatz von Lüftungs-Kompaktgeräten mit integrierter Kompressionswärmepumpe"
(Theoretical and experimental investigations on the application of compact ventilation units with an integrated compression heat pump)
Doctoral thesis, Technical University of Hamburg-Harburg
Hamburg-Harburg, 2001

Rainer Kern
"Untersuchungen zur Langzeitstabilität von Farbstoffsolarzellen mittels optischer und elektrischer Impedanzspektroskopie"
(Investigations of the long-term stability of dye-sensitised solar cells with optical and electrical impedance spectroscopy)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Christian Peter
"Physikalische Charakterisierung optisch schaltender Fenster auf der Basis photoelektrochemischer elektrochromer Systeme"
(Physical characterisation of optically switching windows based on photoelectrochemical electrochromic systems)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Christoph F. Reinhart
"Daylight availability and manual lighting control in office buildings - simulation studies and analysis of measurements"
Doctoral thesis, University of Karlsruhe
Karlsruhe, 2001

Steffen Schattner
"Die elektromagnetische Verträglichkeit und der Blitzschutz von Photovoltaik-Anlagen"
(The electromagnetic compatibility and lightning protection of photovoltaic systems)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Matthias Zenker
"Thermophotovoltaische Konversion von Verbrennungswärme"
(Thermophotovoltaic conversion of combustion heat)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Walter Zimmermann
"Kristalline Silicium-Dünnschichtsolarzellen auf SSP Substraten"
(Crystalline silicon thin-film solar cells on SSP substrates)
Doctoral thesis, University of Freiburg
Freiburg, 2001

Press Releases

www.ise.fhg.de/english/press/pi_2001/index.html

1.3.2001
Prof. Joachim Luther appointed to the "German Advisory Council on Global Change"

9.4.2001
Camcorder fueled with hydrogen

14.5.2001
Lightweight walls provide climate control
New building material with micro-encapsulated phase change materials

21.6.2001
Solar air-conditioning – solar energy provides heat, cooling and controlled air humidity
Fraunhofer ISE is designing the first autonomous solar air-conditioning system in Germany

22.6.2001
Solar eclipse at the press of a button –
Gaschromic windows for modern solar control

15.10.2001
Advances in solar cells
New procedures at Fraunhofer ISE

15.10.2001
Rural Energy Supply Models focus of recent study
RESuM results now available on the Internet

3.12.2001
A building for the sun: Fraunhofer ISE officially opened its new premises
Two decades of solar research in Freiburg:
Europe's largest solar research institute turned 20

New Commercial Enterprise

Holotools GmbH
12.9.2001
Wiesentalstr. 29,
79100 Freiburg

Lectures

Lectures with published manuscripts are listed under "Publications".

Agert, C.
"Alternative Aluminiumquellen für die MOVPE von (AlGa)(AsSb) im Multiwafer Planetenreaktor«, DGKK-Tagung, Bad Dürkheim, 11.12.2000

Agert, C.
"MOVPE von GaSb-basierenden III/V-Halbleitern«, Ferdinand-Braun-Institut, Berlin, 15.12.2000

Agert, C.
"MOVPE von GaSb-basierenden III/V-Halbleitern im Planetenreaktor«, Hahn-Meitner-Institut, Berlin, 25.1.2001

Agert, C.
"MOVPE antimonhaltiger Verbindungshalbleiter«, Hahn-Meitner-Institut, Berlin, 26.1.2001

Agert, C.
"MOVPE of Antimonides at Fraunhofer ISE«, TU Berlin, Berlin, 29.1.2001

Agert, C.; Bett, A.W.; Hinkov. V.;
"Growth of (AlGa)(AsSb) in a Multiwafer Planetary MOVPE Reactor«, 9th European Workshop on MOVPE (EW-MOVPE IX), Wrexham, North Wales/ United Kingdom, 10.-13.6.2001, Poster

Ballif, C.; Peters, S.; Borchert, D.; Schultz, O.; Biro, D.; Willeke, G.
"Lifetime Measurements of Various Silicon Structures«, Photovoltaic Devices: High Efficiency Solar Cells, Tomar, Portugal, 8.-13.9.2001, Poster

Bett, A.W.
"III-V-Konzentratorsolarzellen-Herstellung und Anwendung«, Hahn-Meitner-Institut, Berlin, 13.12.2000

Bett, A.W.; Sulima, O.V.[1]
"State of the Art of TPV, Market and Perspective«, 4th International Conference Mid Infrared Optoelectronics Materials and Devices MIOMD, Montpellier, France, 1.-4.4.2001
([1]: Astropower Inc., Newark, DE, USA)

Bett A.W.
"Multi-Band-Gap Solar Cells and Their Applications«, Workshop The Path to Ultra High Efficient Solar Cells, Ispra, Italy, 15.-16.11.2001

Bläsi, B.
"Mikrostrukturierte funktionale Oberflächen – holographische Herstellung, Replikationsverfahren und Anwendungen«, Seminar zur Oberflächentechnik, Universität Bonn, Bonn, 30.11.2001

Bopp, G.; Schattner, S.
"Einfluss der Anlagenkomponenten auf die EMV«, Fachseminar EMV und Blitzschutz in Photovoltaik-Anlagen, OTTI-Technologie-Kolleg, Freiburg, 15.-16.2.2001

Bopp, G.
"Gefährdungspotential des Blitzes«, Fachseminar EMV und Blitzschutz in Photovoltaik-Anlagen, OTTI-Technologie-Kolleg, Freiburg, 15.-16.2.2001

Bopp, G.
"Netzverhalten, Wartungsaufwand und Kosten von PV-Hybridsystemen«, Internationales Fachseminar der DBU, Benediktbeuern, 2.-3.3.2001

Bopp, G.; Dohlen, K. von
"Normkonforme Einbindung von PV-Anlagen in Gebäude mit und ohne äußeren Blitzschutz«, Fachseminar Blitzschutz für Solarthermie und Photovoltaik, Cölbe, 22.11.2001

Bopp, G.
"Gefährdungspotential des Blitzes« Fachseminar Blitzschutz für Solarthermie und Photovoltaik, Cölbe, 22.11.2001

Bühring, A.; Bundy, S.; Dittmar, C.; Greuel, B.; Guter, W.; Schmid, T.; Seigel, B.
"Entwicklung von Lüftungs-Kompaktgeräten für Passivhäuser«, 5. Passivhaus Tagung, Böblingen, 16.-18.2.2001, Poster

Bühring, A.
"Lüftungs-Kompaktgeräte: Erfahrungen und Messergebnisse bei Passivhäusern«, Sonderschau Wohnungslüftung des Fachinstituts Gebäude-Klima auf der ISH, Frankfurt a/M, 28.3.2001

Bühring, A.
"Lüftungs-Kompaktgeräte für Solar-Passivhäuser«, Wochner Passivhauskongress, Balingen, 12.7.2001

Bühring, A.
"Lüftungs-Kompaktgeräte für Solar-Passivhäuser: Vom Konzeptentwurf über Anlagensimulation und Teststandmessungen bis zu Feldversuch und Markteinführung«, Graduierten Kolleg Energiebereitstellung aus regenerativen Energiequellen der DFG, Chemnitz, 28.8.2001

Bühring, A.
"Das Solar-Passivhaus: Hoher Komfort bei niedrigen Betriebskosten«, VDI Mittelrhein-Koblenz, Koblenz, 25.9.2001

Bühring, A.; Schmitz, G.[1]
"Theoretische und experimentelle Untersuchungen zum Einsatz von Lüftungs-Kompaktgeräten mit integrierter Kompressionswärmepumpe«, Thermodynamik Kolloquium, Würzburg, 8.-9.10.2001
([1]: TU Hamburg-Harburg, Hamburg)

Dimroth, F.; Chapman, D.C.[1]; Shurtleff, J.K.[1]; Stringfellow, G.B.[1]
"Surfactant Effects on the Growth of GaAs:N and B:GaAs«, Proceedings 9th European Workshop on MOVPE (EW-MOVPE IX), Wrexham, North Wales/ United Kingdom, 10.-13.6.2001, Poster
([1]: University of Utah, Salt Lake City, U.S.A.)

Georg, A.; Hauch, A.[1]; Opara Krasovec, U.[2]; Orel, B.[2]
"New Photoelectrochromic Device«, UPS 01, Unconventional Photoactive Systems, Les Diablerets, Switzerland, 4.-8.9.2001, Poster
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: National Institute of Chemistry, Ljubljana, Slovenia)

Gladkov, P.S.[1]; Sulima, O.V.[2]; Bett, A.W.
"Surface Preparation Dependent Photoluminescence Properties of Bulk GaSb Substrates«, 4th International Conference Mid Infrared Optoelectronics Materials and Devices MIOMD, Montpellier, France, 1.-4.4.2001, Poster
([1]: Academy of Sciences of Czech Republic, Prague, Czech Republic)
([2]: AstroPower Inc., Newark, DE, USA)

Gombert, A.
"Selbstreinigende Oberflächen durch Mikrostrukturierung mit Blick auf Anwendungen der Holz- und Möbelindustrie«, Interzum 2001, Köln 19.5.2001

Gombert, A.
"Mikrostrukturierte Oberflächen mit optischen Funktionen«, Süddeutsches Kunststoffzentrum, Würzburg, 30.-31.5.2001

Hebling, Chr.
"Mikrobrennstoffzelle als Alternative zur Batterie«, Bewag-Workshop Brennstoffzelle, Berlin, 21.3.2001

Hebling, Chr.
"Solar Cells and Fuel Cells as Power Sources for Portable Electronic Devices«, Batteries 2001, Paris, France, 17.-19.4.2001

Hebling, Chr.; Heinzel, A.; Groos, U.
"Technology and Markets of Portable Fuel Cells«, 7th Grove Fuel Cell Symposium, London, United Kingdom, 11.-13.9.2001

Hebling, Chr.
"Solar Cells and Fuel Cells as Power Sources for Portable Electronic Devices«, Power 2001, Anaheim, CA, USA, 30.9.-3.10.2001

Hebling, Chr.
"Fuel Cells for the Low Power Range – Technology and Markets«, Monthly Materials Colloquium, Eindhoven, the Netherlands, 7.11.2001

Hebling, Chr.
"Fuel Cells for Portable and Stationary Power Generation«, Environmental Forum Seeking Quality Life through Sustainable Development, Freiburg, 5.-6.12.2001

Hebling, Chr.
"Solar Energy and Fuel Cells«, Environmental Forum Seeking Quality Life through Sustainable Development, Freiburg, 5.-6.12.2001

Henning, H.-M.
"Kühlung mit offenen und geschlossenen Adsorptionsverfahren und Einbindung von Solarenergie zum Antrieb der Prozesse«, Workshop Innovative Technologien zur Kälteerzeugung und Klimatisierung, Ulm, 18.7.2001

Henning, H.-M.
"Solare Klimatisierung. Solare Wärme – aktuelle Technologien, wachsende Märkte, neue Förderinstrumente«, Haus der Wirtschaft, Stuttgart, 26.7.2001

Henning, H.-M.; Schossig, P.
"Encapsulated Phase-Change-Materials Integrated in Construction Materials«, ZAE-Symposium Heat und Cold Storage, Garching, 4.-5.10.2001

Henning, H.-M.; Scheuble, K.
"Modellierung und messtechnische Bewertung einer Adsorptionskältemaschine in einer solarthermisch unterstützten Kälteanlage«, NEW-Forum, Fachhochschule Offenburg, Offenburg, 15.11.2001, Poster

Hindenburg, C.
"Solare sorptionsgestützte Klimatisierung – ein aussichtsreicher neuer Markt für die Solarthermie?!«, Fraunhofer ISE Technologie-Seminar, Intersolar, Freiburg, 6.-8.7.2001

Hoffmann, V.U.
"Stand und Zwischenergebnisse des 100.000-Dächer-Solarstrom-Programms«, 4. Solartag Sachsen, Dresden, 7.-8.4.2001

Hoffmann, V.U.
"Stand und Perspektiven der Photovoltaik«, 4. Solartag Sachsen, Dresden, 7.-8.4.2001

Hoffmann, V.U.
"Stand und Ergebnisse des Vorhabens Sonne in der Schule«, 4. Solartag Sachsen, Dresden, 7.-8.4.2001

Hoffmann, V.U.
"Einträgliche Anlagenerträge«, Tagung zur Förderinitiative Kirchengemeinden für die Sonnenenergie, Hoisbüttel bei Hamburg, 28.-29.6.2001

Hoffmann, V.U.
"Einträgliche Anlagenerträge«, Tagung zur Förderinitiative Kirchengemeinden für die Sonnenenergie der DBU, Ostritz, 11.-12.9.2001

Hoffmann, V.U.
"Phtovoltaik und ihre technologischen Entwicklungstendenzen«, Symposium Viktor Kaplan und die Zukunft, Mürzzuschlag, Austria, 3.-6.10.2001

Hoffmann, V.U.
"Einträgliche Anlagenerträge«, Tagung zur Förderinitiative Kirchengemeinden für die Sonnenenergie der DBU, Münster, 16.-17.10.2001

Huljic, D.M.; Castillo, C.C.; Willeke, G.
"Bestimmung des Übergangswiderstandes zwischen siebgedruckten Dickfilmkontakten und n-dotierten Siliciumschichten«, AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001

Huljic, D.M.; Hirth, E.; Lüdemann, R.; Willeke, G.
"Large Area Crystalline Silicon Solar Cells with Pad Printed Front Side Metallisation«, 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, Poster

Huljic, D.M.; Craff Castillo, C.; Kray, D.; Lüdemann, R.
"Behaviour of PECVD Silicon Nitride Antireflection and Passivation Layers in Rapid Thermal Firing Through Processes«, Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, Poster

Hurrle, A.; Faller, F.; Schillinger, N.
"Großflächige Silicium-CVD-Abscheidung für kristalline Silicium-Dünnschicht-Solarzellen«, Tagung Spezielle Probleme der Festkörperphysik, Albert-Ludwigs-Universität Freiburg, Freiburg 19.1.2001

Kiefer, K.
"Solare Stromerzeugung heute und morgen«, Infoveranstaltung Kundenzentrum Stadtwerke Karlsruhe, Karlsruhe, 4.4.2001

Kiefer, K.
"Bundesweite Analyse der Betriebsergebnisse von PV-Anlagen«, Berliner Energie Tage, Berlin, 14.6.2001

Köhl, M.
"Singulett-Sauerstoff: Erzeugung und Wechselwirkung mit Wasser«, Workshop Singulett Sauerstoff und Wasser, Glottertal, 15.3.2001

Köhl, M.
"Singulett-Sauerstoff: Erzeugung und Wechselwirkung mit Wasser«, Kolloquium des Leibniz-Instituts für Gewässerökologie und Binnenfischerei, Berlin, 26.04.2001

Köhl, M.
"Pre-Normative Research within IEA-SHC Task27«, Seminar Innovation and Quality in Solar-Thermal Application, INETI, Lisbon, Portugal, 19.11.2001

Köhl, M.
"Einflussmöglichkeiten auf Energiehaushalt und Betauung von Gebäuden«, Workshop Innovative Fassaden, Würzburg, 4.12.2001

Köhl, M.
"Der Einfluss von photosensibilisiert generiertem Singulettsauerstoff auf die physiko-chemischen Eigenschaften von Wasser – erste Ergebnisse und Hypothesen«, Schwerpunktkolloquium zur Makromolekül- und Vielteilchenphysik, Berlin, 17.12.2001

Kray, D.
"High-Efficiency Flexible Solar Cells«, Thin Semiconductor Devices – Manufacturing and Applications, Munich, 3.-4.12.2001

Létay, G.[1]; Wettling, W.; Bett, A.W.
"Wirkungsgradlimit für Photovoltaikzellen«, 10. Internes Kolloquium des Freiburger Materialforschungszentrums, Breisach, 9.-10.11.2001
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Lüdemann, R.
"The Status of Dry Processing in Silicon Solar Cell Technology", Flemish-Hungarian Workshop on Advanced Concepts for Low Thermal Budget Processing of Crystalline Silicon Solar Cells, IMEC, Leuven, Belgium, 13.-14.3.2001

Lüdemann, R.
"Low Thermal Budget Processing of Silicon Solar Cells – the RTP Approach", Flemish-Hungarian Workshop on Advanced Concepts for Low Thermal Budget Processing of Crystalline Silicon Solar Cells, IMEC, Leuven, Belgium, 13.-14.3.2001

Lüdemann, R.
"Silicium-Photovoltaik: Ein Beispiel für interdisziplinäre physikalische Forschung", Institut für Angewandte Physik, Universität Karlsruhe, Karlsruhe, 11.5.2001

Luther, J.
"Stromerzeugung mit Solarzellen", Shell Solarfabrik, Gelsenkirchen, 26.1.2001

Luther, J.
"Photovoltaik – Strom aus Sonnenenergie: Status, Entwicklungschancen, Visionen", Jahrestagung Kerntechnik 2001, Dresden, 15.-17.5.2001

Luther, J.
"Solare Fassaden – Gebäudeklimatisierung und Tageslichttechnik", Fachseminar der Deutschen Gesellschaft e.V. für Solare Fassaden und Bedachungen, Intersolar, Freiburg, 6.-8.7.2001

Luther, J.
"Renewable Energies in Residential Buildings and Integration of Domestic Energy Systems into Main Energy Systems", Conference of the European Commission, Brussels, Belgium, 25.-26.9.2001

Luther, J.
"Photovoltaische Stromerzeugung", Universität Kassel, Kassel, 8.11.2001

Luther, J.
"Forschung für den Markt – Photovoltaik und solares Bauen", 2. Forum Solarpraxis, Berlin, 15.-17.11.2001

Kaiser, R.; Bohlen, O.; Sauer, D.U.
"Ladeintegriertes Batteriemanagement mit automatischer Ladezustands- und Kapazitätsbestimmung", 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, Poster

Meusel, M.; Bett, A.W.; Baur, C.; Beckert, R.; Dimroth, F.; Letay, G.; Hein, M.; Riesen, S. van; Schubert, U.; Siefer, G.; Sulima, O.V.[1]; Tibbits, T.N.D.
"Development of High-Efficiency Mechanically Stacked GaInP/GaInAs-GaSb Triple-Junction Concentrator Solar Cells", 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001
([1]: AstroPower, Inc., Newark, DE, USA)

Peters, S.; Radt, V.; Preu, R.; Huljic, D.; Schindler, R.
"Oberflächenpassivierung kristalliner Silicium-Solarzellen mittels Rapid Thermal Processing", AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001

Peters, S.; Ballif, Chr.; Borchert, D.; Radt, V.; Preu, R.; Willeke, G.
"Rapid Thermal Oxidation for Surface Passivation of Silicon Solar Cells", Photovoltaic Devices: High Efficiency Solar Cells, Tomar, Portugal, 8.-13.9.2001, Poster

Preiser, K.
"Stand und Perspektiven der Photovoltaik-Systemtechnik aus Sicht der angewandten Forschung", Fraunhofer ISE-Technologie-Seminar, Intersolar, Freiburg, 6.-8.7.2001

Radt, V.; Peters, S.; Schindler, R.
"Rasches thermisches Prozessieren von multikristallinen Silicium-solarzellen", AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001

Rein, S.; Warta, W.; Glunz, S.W.
"Investigation of Carrier Lifetime in P-Type Czochralski-Silicon (Cz-Si): Specific Limitations and Realistic Prediction of Cell Performance", AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001

Rehrl, T.; Rein, S.; Warta, W.; Glunz, S.W.
"Temperature-Dependent Lifetime Spectroscopy (TDLS) in Silicon for Solar Cells", AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001

Riesen, S. van; Bett, A.W.
"Photovoltaik-Zellen für die Laserleistungsübertragung", AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001, Poster

Riesen, S. van; Schubert, U.; Bett, A.W.
"GaAs Photovoltaic Cells for Laser Power Beaming at High Power Densities", 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, Poster

Rommel, M.; Lustig, K.; Pitz-Paal, R.
"Stand der Technik und neue Entwicklungen bei thermischen Solaranlagen", Konferenz Solarthermie – Auslegung, Anwendung, technische Regeln, Gelsenkirchen, 7.3.2001

Rommel, M.
"Stand der Technik und Entwicklung bei thermischen Solaranlagen", Fraunhofer ISE Technologie-Seminar, Intersolar, Freiburg, 6.-8.7.2001

Roth, W.
"Solarprodukte für den privaten Gebrauch", Volkshochschule Offenburg, Offenburg, 23.3.2001

Russ, Chr.
"Ergebnisse der Sanierung von Typenschulen in den neuen Bundesländern am Beispiel der Schulen Leipzig, Wurzen und Erfurt", Informationsaustausch im Förderprogramm ENSAN, Dresden, 13.2.2001

Russ, Chr.
"Energieeffiziente Sanierung von Typenschulen-Vermittlung von Ergebnissen und Erfahrungen aus der Sanierung von Typenschulen in den neuen Bundesländern", Workshop des Finanzministeriums des Freistaates Thüringen im Rahmen des Schul-Bauprogramms, Erfurt, 11.4.2001

Sauer, D.U.; Schmidt, H.; Kuhmann, J.
"Elektrische Energiespeicher und Laderegler für Geräte und Kleinsysteme", Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001

Schmid, T.; Russ, Chr.; Bühring, A.
"Lüftungskompaktgeräte in Passivhäusern", Konferenz Die Lüftungsanlage in der Praxis, Vienna, Austria, 9.11.2001

Schmitz, A.; Müller, M.[1]; Müller, C.[1]; Hahn, R.[2]; Schumacher, J.O.; Hebling, Chr.
"Optimisation of Electrical Losses in Microstructured Fuel Cells", 7th Grove Fuel Cell Symposium, London, United Kingdom, 11.-13.9.2001, Poster
([1]: Institut für Mikrosystemtechnik IMTEK, Freiburg)
([2]: Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM, Berlin)

Schossig, P.; Henning, H.-M.
"Mikroverkapselte Phasenwechselmaterialien in Wandverbundsystemen", Workshop Wärmespeicherung, Köln, 28.-29.5.2001

Schumacher, J.O.; Hakenjos, A.; Tonn, D.; Herrmann, A.; Schmitz, A.; Hebling, Chr.
"Water Balance Characterisation of a PEM Fuel Cell Using Impedance Spectroscopy and an Empirically Verified Fuel Cell Model", 7th Grove Fuel Cell Symposium, London, United Kingdom, 11.-13.9.2001, Poster

Schweizer-Ries, P.; Vogt, G.; Casper, C.
"Die gemeinschaftliche Nutzung einer Stromanlage aus Umwelt- und organisatorischer Sicht: das Beispiel Rambla del Agua/ Spanien", Tagung der Fachgruppe Umweltpsychologie, Kassel, 20.-23.9.2001

Schweizer-Ries, P.
"Combined Project on Multi-User Solar Hybrid Grids (MSG)", Integration of Renewable Energy Sources and Distributed Generation in Energy Systems, Brussels, Belgium, 25.-26.9.2001

Steinhüser, A.
"Präsentation des Fraunhofer-Instituts für Solare Energiesysteme ISE und der Abteilung Elektrische Energiesysteme", 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001

Steinhüser, A.
"Computerunterstützte Auslegung und Simulation von Photovoltaik-Kleinsystemen", Vorlesungsreihe Photovoltaik-Systemtechnik, Universität Karlsruhe, Karlsruhe, 29.5.2001

Steinhüser, A.
"Simulationsprogramme", Fachseminar Netzgekoppelte Photovoltaik-Anlagen, OTTI-Energie-Kolleg, Freiburg, 27.-28.6.2001

Steinhüser, A.
"Photovoltaik-Kleingeräte, Photovoltaik-Kleinsysteme und Solar Home Systeme", Vorlesungsreihe Phtotovoltaik-Systemtechnik, Universität Karlsruhe, Karlsruhe, 25.7.2001

Steinhüser, A.
"Grundlagen zur Nutzung der Sonnenenergie", Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001

Steinhüser, A.
"Aspekte zur Entwicklung von photovoltaisch versorgten Geräten", Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001

Steinhüser, A.
"Kompakte Photovoltaik-Hybridsysteme", Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001

Steinhüser, A.
"Computerunterstützte Auslegung und Simulation von Photovoltaik-Kleinsystemen", Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001

Steinhüser, A.
"Simulationsprogramme", Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001

Vetter, M.
"Systeme zur thermischen Solarenergienutzung. Neue Anwendungsgebiete und aktuelle Entwicklungen", 6. Deutsch-Türkisches Energiesymposium Erneuerbare Energiequellen und Umweltschutz, Izmir, Turkey, 21.-24.6.2001

Wienold, J.
"Solarenergie als Bestandteil der modernen Haustechnik", Informationsveranstaltung Klimaschutz in Emmendingen – Neue Geschäftsfelder für das Handwerk: Altbaumodernisierung und Solarenergie, Emmendingen-Kaiserstuhl, 17.10.2001

Willeke, G.
"Solarzellentechnologien – Stand der Entwicklung und Perspektiven", Fraunhofer ISE-Technologie-Seminar, Intersolar, Freiburg, 6.-8.7.2001

Wilson, H.R.[1]
"Glazing – Transparent Component for Energy-Saving Architecture", Summer Academy on Multi-Family Solar Housing, Freiburg, 20.7.2001
([1]: Interpane E&BmbH, Lauenförde)

Wittwer, Chr.
"Simulation solarthermischer Systeme", 14. Arbeitstreffen Simulation solarer Energiesysteme, Oldenburg, 18.-19.6.2001

Wittwer, Chr.; Hube, W.; Schossig, P.
"ColSim – a New Simulation Environment for Complex System Analysis and Controllers", Building Simulation 2001, Rio de Janeiro, Brasil, 13.-15.8.2001

Publications

Afjei, T.; Bühring, A.; Dürig, M.; Huber, A.; Kelle, P.; Shafai, E.; Widmer, P.; Zweifel, G.
"Kostengünstige Wärmepumpenheizung für Niedrigenergiehäuser: Technisches Handbuch: Grundlagen, Planungsvorgehen und Beispiele – Schlussbericht", Nr. 200126 ENET-Publikationen, Arbon, Switzerland, 2001

Agert, C.; Beckert, R.; Hinkov, V.; Sulima, O.V.[1]; Bett, A.W.
"Novel Device Structures for Infrared Solar Cells Based on GaSb: PN-Homojunctions, PN-Heterojunctions and Tandem Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: AstroPower, Inc., Newark, DE, USA)

Agert, C.; Lanyi, P.; Bett, A.W.
"MOVPE of GaSb, (AlGa)Sb and (AlGa)(AsSb) in a Multiwafer Planetary Reactor", in: Journal of Crystal Growth, 225 (2001), 426-430

Agert, C.; Gladkov, P.S.[1]; Bett, A.W.
"Origin of the Photoluminescence Line at 0.8 eV in Undoped and Si-Doped GaSb Grown by MOVPE", in: Semiconductor, Science and Technology, in press
([1]: Academy of Sciences of the Czech Republic, Prague, Czech Republic)

Aschaber, J.; Schumacher, J.O.; Schlemmer, Chr.; Boerner, V.; Hebling, Chr.; Luther, J.
"Modelling of a Thermophototlaic System for Different Micro-structured Tungsten Surfaces as Selective Emitters", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Ballif, Chr.; Peters, S.; Borchert, D.
"Lifetime Mapping of Solar Cells and Control of the Effective Surface Recombination Velocity by Application of a Bias Voltage", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Ballif, Chr.; Peters, S.; Borchert, D.; Isenberg, J.; Schindler, R.; Warta, W.; Willeke, G.; Hässler, Chr.[1]
"Lifetime Investigations of Degradation Effects in Processed Multicrystalline Silicon Wafers", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]. Bayer AG, Krefeld)

Bau, S.; Denter, J.; Schillinger, N.; Hurrle, A.
"Herstellung von Si-Schichten mittels CVD für kristalline Si-Dünnschichtsolarzellen", Tagungsband AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001, 209

Bau, S.; Kieliba, T.; Oßwald, D.; Hurrle, A.
"Chemical Vapor Deposition of Silicon on Ceramic Substrates for Crystalline Silicon Thin-Film Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Baumgärtner, S.[1]; Sastrawan, R.[1]; Schubert, M.[1]; Ferber, J.[1]; Luther, J.
"Influence of TiO_2 Properties and Tert-Butylpyridine Addition on Electron Lifetime and Diffusion Coefficients in Dye-Sensitized Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Beckert, R.; Meusel, M.; Siefer, G.; Warta, W.; Bett, A.W.
"Determination of Absolute External Quantum Efficiency of Monolithic Triple Junction Solar Cells", Proceedings 12th International Photovoltaic Science and Engineering Conference PVSEC, Cheju Island, Korea, 11.-15.6.2001, 577-578

Benz, J.
"Energiemanagement für autonome Photovoltaik-Systeme", Seminarband Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001, 373-389

Betcke, J.W.H.[1]; Dijk, V. van; Wiezer, F.[2]; Reise, Chr.; Wiemken, E.; Dufner, H.[3]; Toggweiler, P.[4]; Heinemann, D.[5]
"PVSAT: Remote Performance Check for Grid Connected PV Systems Using Satellite Data", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Utrecht Universität, Utrecht, the Netherlands)
([2]. O.D.E., Utrecht, the Netherlands)
([3]: DFS e.V., Freiburg)
([4]: Enecolo AG, Mönchaltorf, Switzerland)
([5]: Universität Oldenburg, Oldenburg)

Bett, A.W.; Baur, C.; Beckert, R.; Dimroth, F.; Letay, G.; Hein, M.; Meusel, M.; Riesen, S. van; Schubert, U.; Siefer, G.; Sulima, O.V.[1]; Tibbits, T.N.D.
"Development of High Efficiency Mechanically Stacked GaInP/GaInAs-GaSb Triple-Junction Concentrator Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Astro Power, Inc., Newark, DE, USA)

Bett, A.W.
"Multi-Junction Solar Cells: Development and Their Applications", Proceedings Workshop the Path to Ultra High Efficient Solar Cells, Ispra, Italy, 15.-16.11.2001

Beyer, H.G.[1]; Heinemann, D.[2]; Hoyer, C.[2]; Reise, Chr.; Wiemken, E.; Musikowski, H.-D.[3]
"Accuracy of the Estimation of Monthly Performance Figures of Grid-Connected PV Systems Based on Remote Data Sources", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Fachhochschule Magdeburg, Magdeburg)
([2]: Universität Oldenburg, Oldenburg)
([3]: Universität Magdeburg, Magdeburg)

Biro, D.; Preu, R.; Schulz, O.; Peters, S.; Huljic, D.M.; Zickermann, D.; Schindler, R.; Lüdemann, R.; Willeke, G.
"Advanced Diffusion System for Low Contamination In-Line Rapid Thermal Processing of Silicon Solar Cells", Proceedings 12th International Photovoltaic Science and Engineering Conference PVSEC, Cheju Island, Korea, 11.-15.6.2001, 589-590

Biro, D.; Schultz, O.; Preu, R.; Ballif, Chr.; Zickermann, D.; Lüdemann, R.
"Screen Printed Selective Emitters Prepared by Fast Rapid Thermal Diffusion", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Biro, D.; Warta, W.
"Low Temperature Passivation of Silicon Surfaces by Polymer", in: Solar Energy Materials & Solar Cells, Vol. 71, (2002), 369-374

Bläsi, B.; Boerner, V.; Gombert, A.; Kübler, V.; Niggemann, M.; Wittwer, V.
"Functional Surface-Relief Structures Manufactured by Holography and Subsequent Microreplication", Proceedings 2nd Euspen International Conference, Turin, 27.-31.5.2001, 12-15

Bläsi, B.; Lalanne, Ph.[1]; Boerner, V.; Bühler, Chr.; Gombert, A.
"Microstructures in the Refractive-Diffractive Transition Range for Light Management", Proceedings EOS Topical Meeting on Diffractive Optics 2001, Budapest, Hungary, 9.-11.10.2001, 20-21
([1]: Lab. Charles Fabry de l'Institute d'Optique, Centre National de la Recherche Scientifique, Orsay, France)

Boerner, V.; Gombert, A.; Bläsi, B.; Kübler, V.; Meier, M.; Niggemann, M.; Wittwer, V.
"Large Area Surface Microstructures at the Frontier to Commercialisation", Proceedings EOS Topical Meeting on Diffractive Optics 2001, Budapest, Hungary, 9.-11.10.2001, 10-11

Bopp, G.; Pfanner, N.; Preiser, K.; Roth, W.; Schweizer-Ries, P.
"DC-Kleinsysteme zur Basisstromversorgung ländlicher Haushalte", Seminarband Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001, 425-462

Bühring, A.
"Theoretische und experimentelle Untersuchungen zum Einsatz von Lüftungs-Kompaktgeräten mit integrierter Kompressionswärmepumpe", Dissertation an der TU Hamburg-Harburg, Fraunhofer IRB-Verlag, Stuttgart, 2000, ISBN 3-8167-6031-7

Bühring, A.; Russ, Chr.
"Lüftungs-Kompaktgeräte: Messergebnisse, Erfahrungen, Hersteller", Tagungsband 5. Passivhaus Tagung, Böblingen, 16.-18.2.2001, 165-175

Bühring, A.
"Wärmepumpen-Type 176: Komponentenorientierte Simulation vor der ersten Messung, mit mehreren Verflüssigern, Latentwärmenutzung, internem Wärmeübertrager, Vereisung und Abtauung" Tagungsband TRNSYS-Usertag 2001, Stuttgart, 23.2.2001

Bühring, A.; Russ, Chr.
"Lüftungs-Kompaktgeräte für Solar-Passivhäuser: Messergebnisse, Erfahrungen, Marktangebot", Tagungsband 2. Freiburger Praxis-Symposium für Passivhäuser, Freiburg, 6.4.2001

Bühring, A.
"Lüftungskompaktgeräte für Solar-Passivhäuser – Betriebserfahrung und Marktübersicht", Internationale Fachmesse und Kongress Intersolar, Freiburg, 6.-8.7.2001, in: Tagungsband Solares Heizen

Bühring, A.; Heinzel, A.; Fritz, H.-L.[1]; Luther, J.
"Energieversorgung im Niedrigstenergiebau: von der Abluftwärmepumpe mit Solarkopplung zum Brennstoffzellen-Heizgerät", Integration Erneuerbarer Energie in Versorgungsstrukturen, Jahrestagung des Forschungsverbunds Sonnenenergie, Potsdam, 20.-21.9.2001, im Druck
([1]: Maico HaustechnikSysteme, Villingen-Schwenningen)

Dicker, J.; Isenberg, J.[1]; Warta, W.
"Effect of Shunt Distribution on the Overall Solar Cell Performance Investigated by Circuit Simulation", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Freiburger Materialforschungzentrum FMF, Freiburg)

Dimroth, F.; Beckert, R.; Meusel, M.; Schubert, U.; Bett, A.W.
"Metamorphic $Ga_yIn_{1-y}P/Ga_{1-x}In_xAs$ Tandem Solar Cells for Space and for Terrestrial Concentrator Applications at C>1000 Suns", in: Progress in Photovoltaics: Res. Appl. (9/2001), 165-178

Dimroth, F.; Schubert, U.; Bett, A.W.; Kunze, J.[1]; Hilgarth, J.[1]; Nell, M.[1]; Strobl, G.[1]; Bogus, K.[2]; Signorini, C.[2]
"Next Generation GaIn/GaInAs/Ge Triple-Junction Space Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: RWE Solar, Heilbronn)
([2]: ESA-ESTEC, Nordwijk, the Netherlands)

Emanuel, G.; Schneiderlöchner, E.; Stollhof, J.[1]; Gentischer, J.[2]; Preu, R.; Lüdemann, R.
"High Throughput Laser Isolation of Crystalline Silicon Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Haas Laser GmbH + Co. KG, Schramberg)
([2]: ACR GmbH, Niedereschach)

Erge, T.; Kiefer, K.; Hoffmann, V.U.
"The German Experience with Grid-Connected PV-Systems", in: Solar Energy, Vol. 70 (6/2001), 479-487

Erge, T.; Kiefer, K.; Rössler, E.; Beuschel, A.[1]; Schmitz, W.[1]
"Operation Experience of the 120 kWp PV System Butzweilerhof", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Handwerkskammer zu Köln, Köln)

Georg, A.; Hauch, A.[1]; Opara Krasovec, U.[2]; Orel, B.[3]; Wittwer, V.
"New Photoelectrochromic Device", Proceedings UPS 01, Unconventional Photoactive Systems, Les Diablerets, Switzerland, 4.-8.9.2001, in: Journal of Electrochemical Society, in press,
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: National Institute of Chemistry, Ljubljana, Slovenia)

Glunz, S.W.
"Hocheffiziente Solarzellenstrukturen auf kristallinem Silicium", Tagungsband 10. Diskussionstagung Anorganische-Technische Chemie, DECHEMA, Frankfurt/M, 21.-22.2.2001, 15

Glunz, S.W.; Dicker, J.; Kray, D.; Lee, J.Y.; Preu, R.; Rein, S.; Schneiderlöchner, E.; Sölter, J.; Warta, W.; Willeke, G.
"High Efficiency Cell Structures for Medium-Quality Silicon", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001,in press

Glunz, S.W.; Dicker, J.; Altermatt, P.P.[1]
"Band Gap Narrowing in p-Type Base Regions of Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: University of New South Wales, Sydney, Australia)

Glunz, S.; Rein, S.; Warta, W.
"Minority Carrier Lifetime Degradation in Czochralski Silicon", in: Journal of Applied Physics, Vol. 90(5) (2001), 2397-2404

Goetzberger, A.; Luther, J.; Willeke, G.
"Solar Cells: Past, Present and Future", Proceedings 12th International Photovoltaic Science and Engineering Conference PVSEC, Cheju Island, Korea, 11.-15.6.2001, 5-10

Goetzberger, A.
"Solar Cell Materials and Technology: from the Past to the Future", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Goetzberger, A.
"Möglichkeiten und Probleme der Photovoltaik", Nordrhein-Westfälische Akademie der Wissenschaften, Vorträge 11/2001, 21

Goetzberger, A.
"Optical Principles for Daylighting and New Components for Sun Protection", Advances in Solar Energy, Vol. 14, 2001, 1

Häberle, A.[1]; Zahler, Chr.[1]; Lalaing, J. de[2]; Ven, J.[2]; Sureda, M.[2]; Graf, W.; Lerchenmüller, H.; Wittwer, V.
"The Solarmundo Project. Advanced Technology for Solar Thermal Power Generation", Proceedings ISES 2001 Solar World Congress, Adelaide, Australia, 25.11.-2.12.2001, in press
([1]: PSE GmbH, Freiburg)
([2]: Solarmundo N.V., Antwerpen, Belgium)

Hauch, A.[1]; Georg, A.; Baumgärtner, S.; Opara Krasovec, U.[2]; Orel, B.[2]
"New Photoelectrochromic Device", in: Electrochimica Acta, Vol. 46, Issues 13-14 (April/2001), 2131-2136
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: National Institute of Chemistry, Ljubljana, Slovenia)

Hauch, A.[1]; Georg, A.
"Diffusion in the Electrolyte and Charge-Transfer Reaction at the Platinum Electrode in Dye-Sensitized Solar Cells", Electrochimica Acta, Vol. 46, Issue 22 (August/2001), 3457-3466
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Hauch, A.[1]; Georg, A.; Opara Krasovec, U.[2]; Orel, B.[2]
"Photovoltaically Self-Charging Battery", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
(1: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: National Institute of Chemistry, Ljubljana, Slovenia)

Hauch, A.[1]; Georg, A.; Opara Krasovez, U.[2]; Orel, B.[2]
"Photovoltaically Self-Charging Battery", in: Journal of Electrochemical Society, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: National Institute of Chemistry, Ljubljana, Slovenia)

Hauch, A.[1]; Georg, A.; Baumgärtner, S.; Opara Krasovec, U.[2]; Orel, B.[2]
"Comparison of Photoelectrochromic Devices with Different Layer Configurations", in: Journal of Electrochemical Society, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: National Institute of Chemistry, Ljubljana, Slovenia)

Hebling, Chr.
"Simulation, Construction and Characterisation of Small Fuel Cells for Low Power Applications", Proceedings 3rd Annual International Symposium Small Fuel Cells and Battery Technologies for Portable Power Applications, Washington, D.C., USA, 22.-24.4.2001

Hebling, Chr.; Schmidt, H.
"Brennstoffzellen und Solarzellen als geräteintegrierte Stromerzeuger", Design & Elektronik (09/01), 38-41

Hebling, Chr.; Groos, U.
"Brennstoffzellen im kleinen Leistungsbereich", Tagungsband ‚f-cell' – Die Brennstoffzelle, Stuttgart, 15.10.2001

Hebling, Chr.; Heinzel, A.; Zedda, M.
"Portable Brennstoffzellen – ein Überblick über die aktuellen Entwicklungen. Die portablen Anwendungen holen auf.", in: H2Tec (10/2001), 8-11

Hebling, Chr.
"Wasserstoff-Brennstoffzelle: Der vielseitige Leistungsriese: Erste gehäuseintegrierte Lösungen", in: Markt & Technik (43/2001), 30-32

Hein, M.; Bett, A.W.; Dimroth, F.; Siefer, G.
"Characterisation of a High Concentration System with One-Axis-Tracking", Technical Digest, 12th International Photovoltaic Science and Engineering Conference PVSEC, Cheju Island, Korea, 11.-15.6.2001, 303-304

Hein, M.; Meusel, M.; Dimroth, F.; Lange, G.; Siefer, G.; Tibbits, T.N.D.; Bett, A.W.; Andreev, V.M.[1]; Rumyantsev, M.Z.[1]; Shvartz, M.Z.[1]
"Characterisation of a 25 % High-Efficiency Fresnel-Lens-Module with GaInP/GaInAs Tandem Concentrator Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Ioffe Physico-Technical Institute, St. Petersburg, Russia)

Heinzel, A.; Hebling, Chr.; Zedda, M.
"Brennstoffzellen im kleinen Leistungsbereich für portable Anwendungen", Tagungsband Stationäre Brennstoffanlagen-Markteinführung, Heilbronn, 3.-4.4.2001, in press

Henning, H.-M.
"Energetische und wirtschaftliche Aspekte solar unterstützter Klimatisierung", Tagungsband Solare Kühlung in der Praxis, Stuttgart, 23.-24.4.2001, 22-24

Henning, H.-M.; Scheuble, K.; Glaser, H.[1]; Wöfle, D.[2]
"Solare Kälteerzeugung mit Adsorptionskältemaschinen", 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5. 2001, 156-163
([1]: Universitätsklinikum Freiburg, Freiburg)
([2]: Sulzer Infra Baden GmbH, Freiburg)

Henning, H.-M.
"Wärme-Kälte-Kopplung mit Abbzw. Adsorptionskältemaschinen – Teil1", KI Luft- und Kälte (Mai/2001), 230

Henning, H.-M.
"Wärme-Kälte-Kopplung mit Abbzw. Adsorptionskältemaschinen – Teil2", KI Luft- und Kälte (Juni/2001), 277

Henning, H.-M.
"Solare Klimatisierung", Konferenzband, Solare Wärme Konferenz, Stuttgart, 26.6.2001, 41-52

Henning, H.-M.; Hindenburg, C.
"Kühle Räume dank solarer Wärme", in: Erneuerbare Energien (11/2001), 42-45

Henning, H.-M., Hindenburg, C.
"Wann wird solare Kälteerzeugung wirtschaftlich?", in: Erneuerbare Energien (12/2001), 50-52

Henze, N.[1]; Bopp, G.; Degner, T.[2]; Häberlin, H.[2]; Schattner, S.
"Radio Interference on the DC Side of PV Systems, Research Results and Limit of Emissions", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Institut für Solare Energieversorgungstechnik ISET, Kassel)
(2: Berner Fachhochschule, Burgdorf, Switzerland)

Herkel, S.
"Energieeffizienz und regenerative Energie bei Bürogebäuden: das Konzept der schlanken Gebäude", 5. Passivhaus Tagung, Böblingen, 16.-18.2.2001, 145-146

Hindenburg, C.; Henning, H.-M.
"Solar Thermal Energy for Air Conditioning of Buildings", in: Chemie Ingenieur Technik (CIT), 3rd European Congress of Chemical Engineering, Nürnberg, 26.-28.6.2001

Hindenburg, C.; Henning, H.-M.
"Thermische Solarenergie für die Gebäudeklimatisierung", in: BHKS-Almanach 2001, Bonn, 18-23

Hindenburg, C.; Kalwellis, V.; Fuchsberger, B.; Backes, S.; Matekenya, W.
"SSGKTEST – Ein neuer Teststand für solare sorptionsgestützte Klimatisierungssysteme", Tagungsband 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5. 2001, 176-180

Hoffmann, V.U.; Kiefer, K.; Armbruster, A.
"SONNEonline Wissenschaftliche Auswertung für das Jahr 2000" in: www.sonneonline.de

Hoffmann, V.U.
"300 Kirchengemeinden für die Sonnenenergie", Broschüre (Juli/2001)

Hoffmann, V.U.
"Sonne in der Schule", BMWi-Bericht, Broschüre (Juli/2001)

Hube, W.; Wittwer, Chr.
"Betrachtungen zur Heizkennlinie eines Niedrigenergie-Mehrfamilienhauses und ColSim-Erweiterungen zur Untersuchung integraler Regelungen zur Wärmeversorgung" Tagungsband 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5.2001, 214-219

Huljic, D.; Hirth, E.; Lüdemann, R.; Willeke, G.
"Large Area Crystalline Silicon Solar Cells with Pad Printed Front Side Metallisation", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Huljic, D.M.; Mäckel, H.; Craff Castillo, C.; Kray, D.; Ballif, C.; Lüdemann, R.
"Behaviour of PECVD Silicon Nitride Antireflection and Passivation Layers in Rapid Thermal Firing Through Processes", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Isenberg, J.[1]; Dicker, J.; Warta, W.
"Analysis of the Effect on Diffusion Length Distributions on Global Solar Cell Parameters by Simplified 2-D Modeling", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Isenberg, J.[1]; Reber, S.; Warta, W.
"Diffusion Properties of Ion-Implanted Vanadium in PECVD-SiO_2 and PECVD-SiN_X", Journal of the Electrochemical Society, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Kaiser, R.; Bohlen, O.; Sauer, D.U.
"Ladereglerintegriertes Batteriemanagement mit automatischer Ladezustands- und Kapazitätsbestimmung", Tagungsband, 16. Symposium PV-Solarenergie, OTTI-Technologie-Kolleg, Staffelstein, 14.-16.3.2001, 461-466

Kern, R.[1]; Ferber, J.[1]; Hinsch, A.[2]; Kroon, J.[2]; Luther, J.; Meyer, A.[3]; Sastrawan, R.[1]; Uhlendorf, I.[4]
"Investigation of the Long-Term Stability of Dye-Sensitized Solar Cells by Optical and Electrochemical Impedance Spectroscopy", 13th Workshop on Quantum Solar Energy Conversion - QUANSOL 2001, Kirchberg, Austria 11.-17.3.2001, in: www.esqsec.unibe.ch/qu01_pub.htm
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: Netherlands Energy Research Foundation ECN, Petten, the Netherlands)
([3]: Solaronix SA, Aubonne, Switzerland)
([4]: Institut für Angewandte Photovoltaik INAP, Gelsenkirchen)

Kern, R.[1]; Ferber, J.[1]; Hinsch, A.[2]; Kroon, J.[2]; Luther, J.; Meyer, A.[3]; Sastrawan, R.[1]; Uhlendorf, I.[4]
"Long Term Stability of Dye-Sensitised Solar Cells", Proceedings European Material Research Society Spring Meeting, Strasbourg, France, 5.-8.6.2001 ([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: Netherlands Energy Research Foundation ECN, Petten, the Netherlands)
([3]: Solaronix SA, Aubonne, Switzerland)
([4]: Institut für Angewandte Photovoltaik INAP, Gelsenkirchen)

Kiefer, K.; Weber, P.[1]
"Umweltgerechte Energiekonzepte bei Berghütten des DAV – Herangehensweise, Stand und Erfahrungen aus realisierten Förderprojekten, Perspektiven", Tagungsband Internationales Fachseminar der DBU, Benediktbeuren, 2.-3.3.2001 ([1]: Deutscher Alpenverein DAV, Munich)

Kiefer, K.; Hoffmann, V.U.; Becker, G.[1]
"Langzeiterfahrung mit netzgekoppelten PV Anlagen", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 320-327
([1]: Solarenergieförderverein Bayern e.V.; Munich)

Kiefer, K.
"Ertragssicherung und Qualitätskontrolle von netzgekoppelten Photovoltaik-Anlagen", Seminarband Fachseminar Netzgekoppelte Photovoltaik-Anlagen, OTTI-Energie-Kolleg, Freiburg, 27.-28.6.2001, 221-234

Kiefer, K.
"Energiebericht 2000 zum Regiostrom der FEW", Broschüre (Mai/2001)

Kiefer, K.
"Monitoring Bericht 2000 zum Umwelttarif der RWE", Broschüre (Mai/2001)

Kiefer, K.
"Sonne auf den Hütten. Alpenvereinshütten mit solarer Energieversorgung – das Projekt Euralp", Broschüre

Kiefer, K.; Becker, G.[1]
"Architectural Integration of Photovoltaic Systems-Consideration on Aesthetic and Technology of Awared PV Plants in Bavaria", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Solarenergieförderverein Bayern e.V., Munich)

Kieliba, T.; Reber, S.; Bau, S.; Hässler, C.[1]; Stollwerck, G.[1]
"Kristalline Silicium-Dünnschichtsolarzellen auf Si_3N_4-Keramiken", Tagungsband AKF-Frühjahrstagung der Deutschen Physikalischen Gesellschaft, Hamburg, 26.-30.3.2001, 232
([1]: Bayer AG, Krefeld)

Kieliba, T.; Bau, S.; Reber, S.; Oßwald, D.[1]; Eyer, A.[1]; Schober, R.[2]
"Crystalline Silicon Thin-Film Solar Cells on $ZrSiO_4$ Ceramic Substrates", Proceedings 12th International Photovoltaic Science and Engineering Conference PVSEC, Cheju Island, Korea, 11.-15.6.2001, 557-558
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)
([2]: Fraunhofer-Institut für Keramische Technologien und Sinterwerkstoffe IKTS, Dresden)

Kieliba, T.; Bau, S.; Oßwald, D.[1]; Eyer, A.
"Coarse-Grained Si-Films for Crystalline Si Thin-Film Solar Cell Prepared by Zone-Melting Recrystallization", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, München, 22.-26.10.2001, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Köhl, M.
"IEA-SHC Task 27: Performance, Durability and Sustainability of Advanced Windows and Solar Components for Building Envelopes", Tagungsband North Sun 2001, Leiden, the Netherlands, 7.-8.5.2001

Köhl, M.
"Durability of Solar Energy Materials", in: Renewable Energy 24 (2001), 597-607

König, P.; Bopp, G.; Müller, M.; Puls, H.-G.; Sauer, D.U.
"Universelles, standardisiertes Auswertetool für autonome Stromversorgungssysteme –THESA", Tagungsband, 16. Symposium PV-Solarenergie, OTTI-Technologie-Kolleg, Staffelstein, 14.-16.3.2001, 580-586

Kray, D.; Dicker, J.; Rein, S.; Kamerewerd, F.-J.; Oßwald, D.; Schäffer, E.; Glunz, S.W.; Willeke, G.
"High-Efficiency Emitter-Wrap-Through Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Kray, D.; Leimenstoll, A.; Glunz, S.W.; Willeke, G.
"20 % Efficient Flexible Silicon Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Kuhn, T.E.; Platzer, W.J.
"Evaluation of Overheating Protection with Sun-Shading Systems", in: Solar Energy, Vol. 69/1-6, 2000, 59-74

Laukamp, H.
"Strom von der Sonne – Gebäude mit Solarzellen", in: Deutsches Architektenblatt (Juni/2001), 70-75

Laukamp, H.; Herkel, S.; Kiefer, K.; Voss, K.; Andersen, S.[1]
"Architectural Integration of Photovoltaic Systems – The New Premises of Fraunhofer ISE", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Dissing+Weitling, Copenhagen, Denmark)

Lavrencic Stangar, U.[1]; Groselj, N.[1]; Orel. B.[1]; Schmitz, A.; Colomban, Ph.[2]
"Proton-Conducting Sol-Gel Hybrids Containing Heteropoly Acids" in: Solid State Ionics (145/2001), 109-118
([1]: National Institute of Chemistry, Ljubljana, Slovenia)
([2]: Laboratoire de Dynamique, Interactions et Réactivité, Thiais, France)

Lee, J.Y.; Peters, S.; Dicker, J.; Rein, S.; Glunz, S.W.
"Carrier Lifetime Improvement in Czochralski Silicon for Solar Cells by Rapid Thermal Processing", Proceedings 12th International Photovoltaic Science and Engineering Conference PVSEC, Cheju Island, Korea, 11.-15.6.2000, 27-28

Lee, J.Y.; Rein, S.; Glunz, S.W.
"Advanced RTP-Process for the Stable Lifetime in Czochralski Silicon for Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Lee, J.Y.; Peters, S.; Rein, S.; Glunz, S.W.
"Improvement of Charge Carrier Lifetime in p(boron)-type Czochralski Silicon by Rapid Thermal Annealing", in: Progress in Photovoltaics, 9/2001, 417-424, in press

Létay, G.[1]; Bett, A.W.
"EtaOpt – a Program for Calculating Limiting Efficiency and Optimum Bandgap Structure for Multi-Bandgap Solar Cells and TPV Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1] Freiburger Materialforschungszentrum FMF, Freiburg)

Lüdemann, R.; Biro, D.; Peters, S.; Huljic, D.M.; Preu, R.
"Rapid Thermal Processing for High Throughput Silicon Solar Cell Production", Proceedings 11th Workshop on Crystalline Silicon Solar Cells, Estes Park, Colorado, USA, 19.-22.8.2001, 114-121

Lüdemann, R.; Damiani, B.M.[1]; Rohatgi, A.[1]; Willeke, G.
"Multicrystalline Silicon Solar Cells with Back Silicon Texturization", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Georgia Institute of Technology, Atlanta, GA, USA)

Lüdemann, R.; Preu, R.; Willeke, G.
"Innovation in Solar Cell Production Technology", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Lustig, K.; Rommel, M.
"Simulationstechnische Abbildung der Vorgänge in einem Solarsystem während des Stillstands", 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5.2001, 111-115

Luther, J.; Wittwer, V.; Voss, K.
"Energie für Gebäude – solare Technologien und Konzepte", Physikalische Blätter, Heft 11 (November/2001), 39-44

Luther, J.
"Nachhaltige Architektur – der Beitrag der Disziplinen – Sustainable Architecture – the Contribution of the Various Disciplines", Katalog zur Ausstellung Thomas Herzog – Architektur und Technologie – Architecture and Technology (Dezember/2001), 12-15

Luther, J.
"Solares Bauen heute – auf dem Weg zu zukunftsfähigen Wohn- und Bürogebäuden", in: Energie im Wandel. Politik, Technik und Szenarien einer nachhaltigen Energiewirtschaft, FS für J. Nitsch, hrsg. v. O. Langniß, M. Pehnt, Stuttgart 2001, ISBN 3-540-41329-4, 195-212

Mäckel, H.; Huljic, D.M.; Craff Castillo, C.; Lüdemann, R.
"Passivation Quality and Thermal Stability of Silicon Nitride Layers on Silicon and Phosphorus-Diffused Silicon Solar Cell Emitters", Proceedings ISES 2001 Solar World Congress, Adelaide, Australia, 25.11.-2.12.2001, in press

Messenger, S.R.[1]; Walters, R.J.[1]; Summers, G.P.[1]; Bett, A.W.; Dimroth, F.; Baur, C.; Meusel, M.; Takamoto, T.[2]; Agui, T.[2]; Imaizumi, M.[3]; Matsuda, S.[3]
"Radiation Response Analysis of Triple Junction InGaP/inGaAs/Ge Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: U.S. Naval Research Lab., Washington, DC, USA)
([2]: Sharp Corporation, Nara, Japan)
([3]: National Space Development Agency of Japan, Tsukuba, Japan)

Meusel, M.; Adelhelm, R.[1]; Dimroth, F.; Bett, A.W.; Warta, W.
"Spectral Mismatch Correction and Spectrometric Characterisation of Monolithic III-V Multijunction Solar Cells", in: Progress in Photovoltaics, in press
([1]: Astrium GmbH, München)

Niggemann, M.; Bläsi, B.; Bühler, Chr.; Boerner, V.; Gombert, A.; Kübler, V.; Wittwer, V.
"Periodic Microstructures for Large Area Applications Generated by Holography", SPIE's 46th Annual Meeting, International Symposium on Optical Science and Technology, San Diego, CA, USA, 29.7.-3.8.2001, in press

Niggemann, M.; Bläsi, B.; Gombert, A.; Hinsch, A.; Hoppe, H.[1]; Lalanne, P.[2]; Meissner, D.[1]; Wittwer, V.
"Trapping Light in Organic Plastic Solar Cells with Integrated Diffraction Gratings", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Johannes Kepler Universität, Linz, Austria)
([2]: Lab. Charles Fabry de l'Institut d'Optique, Centre National de la Recherche Scientifique, Orsay, France)

Noël, S.[1,2]; Lautenschlager, H.; Muller, J.C.[1]
"Record Rapid Thermal Processed Multicrystalline Silicon Solar Cells", Progress in Photovoltaics (January-February/2001) Vol. 9, No. 1, 41-47
([1]: Laboratoire PHASE, CNRS, Strasbourg, France)
([2]: J.I.P.ELEC, Meylan, France)

Parretta, A.[1]; Schnell, M.; Lüdemann, R.
"Angle-Resolved Reflectance Measurements on Textured Silicon Materials and Devices", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: ENEA Centro Ricerche, Portici, Italy)

Peters, S.; Ballif, Chr.; Borchert, D.; Radt, V.; Schindler, R.; Warta, W.; Willeke, G.; Hässler, Chr.[1]; Lauinger, T.[2]
"Improving the Efficiency of Silicon Ribbon Solar Cells Using Rapid Thermal Proccessing", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]. Bayer AG, Krefeld)
([2]: RWE Solar GmbH, Alzenau)

Peters, S.; Ballif, Chr.; Borchert, D.; Huljic, D.; Lee, J.Y.; Radt, V.; Preu, R.; Schindler, R.; Schneiderlöchner, E.; Warta, W.
"Rapid Thermal Surface Passivation of Silicon Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Pfanner, N.; Roth, W.
"Photovoltaik in der Beleuchtungstechnik", Seminarband Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001, 211-289

Platzer, W.J.
"Measurement of Angular Light and Total Solar Energy Transmittance for Complex Glazings: the ALTSET Project", CEN-Star Workshop, Paris, France, 5.-6.10.2000, in: Rivista della Stazione Sperimentale del Vetro, Vol. 31/1 (2001)

Platzer, W.J.
"Transparent Insulation Materials and Products: a Review", Chapter 2, in: Advances in Solar Energy, Vol. 14 (2001), 33-65, ISBN 0-89553-257-3

Puls, H.-G.; Sauer, D.U.; Bopp, G.
"Least Cost Planning for Autonomous Energy Supply Systems", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Raicu, A.[1]; Wilson, H.R.[2]; Nitz, P.; Platzer, W.; Wittwer, V.; Jahns, E.
"Facade Systems with Variable Solar Control Using Thermotropic Polymer Blends", in: Solar Energy, Vol. 17 (2002), 31-42
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg)
([2]: Interpane E&BmbH, Lauenförde)

Räuber, A.[1]; Wettling, W.
"Die PV-Szene heute – Technologie, Industrie, Markt", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 260-270
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg)

Reber, S.; Dicker, J.; Huljic, D.M.; Bau, S.
"Epitaxy of Emitters for Crystalline Silicon Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Rein, S.; Rehrl, T.; Warta, W.; Glunz, S.W.; Willeke, G.
"Electrical and Thermal Properties of the Metastable Defect in Boron-Doped Czochralski Silicon", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Rein, S.; Rehrl, T.; Warta, W.; Glunz, S.W.
"Temperature Dependent Lifetime Spectroscopy (TDLS) in Silicon", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Rein, S.; Rehrl, T.; Warta, W.; Glunz, S.
"Lifetime Spectroscopy for Defect Characterisation: Systematic Analysis of the Possibilities and Restrictions", in: Journal of Applied Physics, in press

Reinhart, Chr.
"Monitoring and Analysis of the Manual Control Strategies for Artificial Lighting and Venetian Blinds of 20 Users – Experimental Setup and Prelimenary Results", Tagungsband 7. Symposium über Innovative Lichttechnik in Gebäuden, OTTI-Technologie-Kolleg, Staffelstein, 25.-26.1.2001, 208-212

Reinmüller, D.[1]; Adib, R.; Preiser, K.
"Dissemination Models for Rural Energy Supply in Developing Countries – Decision Making Support for Governments, Industry and Financial Institutions", 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: International Solar Energy Society ISES, Freiburg)

Reise, Chr.; Wiemken, E.; Toggweiler, P.[1], Dijk, V. van[2]; Heinemann, D.[3]
"Ertragsberechnung für netzgekoppelte PV-Anlagen: erste Ergebnisse aus der Testphase von PVSAT", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 53-58
([1]: Enecolo AG, Mönchaltorf, Switzerland)
([2]: Utrecht University, Utrecht, the Netherlands)
([3]: Universität Oldenburg, Oldenburg)

Riechel, S.[1]; Lemmer, U.[1]; Feldmann, J.[1]; Berleb, S.[2]; Mückl, A.G.[2]; Brütting, W.; Gombert, A.; Wittwer, V.
"A Very Compact Tunable Solid State Laser Utilizing a Thin Film Organic Seminconductor", Optics Letters (26/2001), 593-595
([1]: Ludwig-Maximilians-Universität Munich, Munich)
([2]: Universität Bayreuth, Bayreuth)

Riechel, S.[1]; Gombert, A.; Lemmer, U.[1]; Feldmann, J.[1]
"Laser Modes in Organic Solid State Distributed Feedback Lasers", in: Applied Physics B 71 (2000), 897-900
([1]: Ludwig-Maximilians-Universität Munich, Munich)

Riepe, S.; Isenberg, J.; Ballif, Chr.; Glunz, S.W.; Warta, W.
"Carrier Density and Lifetime Imaging of Silicon Wafers by Infrared Lock-In Thermography", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Rommel, M.; Lustig, K.; Pitz-Paal, R.[1]
"Stand der Technik und neue Entwicklungen bei thermischen Solaranlagen", in: VDI: Solarthermie – Auslegung, Anwendung, technische Regeln, Wissenschaftspark Gelsenkirchen, 7.3.2001, (VDI-Berichte Nr. 1584, 2001), 1-16 (1: DLR, Köln)

Rommel, M.
"Neue Entwicklungen bei thermischen Solaranlagen", Internationale Fachmesse und Kongress Intersolar, Freiburg, 6.-8.7.2001, in: Tagungsband Solares Heizen

Rosenfeld, J.L.C.[1]; Platzer, W.J.; Dijk, H. van[2]; Maccari, A.[3]
"Modelling the Optical and Thermal Properties of Complex Glazing: Overview of Recent Developments", in: Solar Energy, Vol. 69/1-6 (2000), 1-13
([1]: Technical University of Denmark, Lyngby, Denmark)
([2]: TNO Building and Construction Research, Delft, the Netherlands)
([3]: ENEA Centro Ricerche, Rom, Italy)

Roth, W.; Steinhüser, A.
"Photovoltaik in der Telekommunikation, Telematik und Telemetrie", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 90-97

Roth, W.
"Photovoltaische Energieversorgungssysteme – Prinzipieller Systemaufbau und Einsatzmöglichkeiten", Seminarband Fachseminar Netzgekoppelte Photovoltaik-Anlagen, OTTI-Energie-Kolleg, Freiburg, 27.-28.6.2001, 7-47

Roth, W.
"Photovoltaik zur dezentralen Stromversorgung im Bereich Telekommunikation", Tagungsband von SOLTEC – Tagung für Architekten und Ingenieure, Hameln, 16.-18.8.2001

Roth, W.
"Prinzipieller Systemaufbau, Anwendungsbeispiele und Marktpotential photovoltaisch versorgter Geräte und Kleinsysteme", Seminarband Fachseminar Photovoltaisch versorgte Geräte und Kleinsysteme, OTTI-Energie-Kolleg, Freiburg, 25.-26.9.2001, 1-52

Ruddell, A.J.[1]; Dutton, A.G.[1]; Wenzl, H.[2]; Ropeter, C.[2]; Sauer, D.U.; Merten, J.[3]; Orfanogiannis, C.[4]; Twidell, J.W.[5]; Vezin, P.[6]
"Analysis of Battery Current Microcycles in Autonomous Renewable Energy Systems", in: Power Sources, in press
([1]: Rutherford Appleton Lab., Didcot, United Kingdom)
([2]: Technische Universität Clausthal, Clausthal-Zellerfeld)
([3]: Trama TechnoAmbiental TTA, Barcelona, Spain)
([4]: ESCO, Athens, Greece)
([5]: AMSET Centre, Hornighold, United Kingdom)
([6]: Vergnet, Saran, France)

Russ, Chr.; Kappert, M.
"Sanierung der Regelschule Erfurt", in: EB Energie Effizientes Bauen (1/2001), 46-50

Sastrawan, R.[1]; Kern, R.[1]; Ferber, J.[1]; Luther, J.
"Electrochemical and Optical Impedance Spectroscopy on Dye-Sensitised Solar Cells", Proceedings European Material Research Society Spring Meeting, Strasbourg, France, 5.-8.6.2001
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Schattner, S.; Bopp, G.; Erge, T.; Fischer, R.[1]; Häberlin, H.[1]; Minkner, R.[1]; Venhuizen, R.[2]; Verhoeven, B.[2]
"A New Measurement Technique Ensuring the EMC of Photovoltaic Systems", Proceedings 14th International Zurich Symposium on Electromagnetic Compatibility, Zurich, Switzerland, 20.-22.2.2001
([1]: Berner Fachhochschule, Burgdorf, Switzerland)
([2]: KEMA T & D Power, Arnhem, the Netherlands)

Schmidhuber, H.; Hebling, Chr.
"First Experiences and Measurements with a Solar Powered Personal Digital Assistant (PDA)", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Schmidhuber, H.; Krannich, K.
"Why Using EVA for Modul Encapsulation if there is a Much Better Choice?", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001,in press

Schmidt, H.; Steinhüser, A.; Häberle, A.[1]; Heidler, K.[2]
"Spielerisch die Zukunft begreifen – Hightech Exponate für Aus- und Weiterbildung", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 120-124
([1]: PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg)
([2]: Solar Consulting, Freiburg)

Schmidt, H.; Roth, W.
"Solarzellen und Module: Aufbau und Eigenschaften", Seminarband Fachseminar Netzgekoppelte Photovoltaik-Anlagen, OTTI-Energie-Kolleg, Freiburg, 27.-28.6.2001, 61-102

Schmidt, H.
"Wechselrichter für Photovoltaik-Anlagen" Seminarband Fachseminar Netzgekoppelte Photovoltaik-Anlagen, OTTI-Energie-Kolleg, Freiburg, 27.-28.6.2001, 103-119

Schmidt, H.; Erge, T.; Sauer, D.U.; Weissmüller, G.[1]; Stephanblome, T.[2]; Povh, D.[3]; Boll, M.[4]
"Intelligent Electricity Distribution Grids with Integrated Decentralised Power Generators for the Energy Market of the Future", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Stadtwerke Karlsruhe, Karlsruhe)
([2]: EUS, Gelsenkirchen)
([3]: Siemens, Erlangen)
([4]: Energie Baden-Württemberg EnBW, Stuttgart)

Schmidt, J.[1]; Cuevas, A.[2]; Rein, S.; Glunz, S.W.
"Fill Factor Limitations and Non-Ideal Diode Behaviour of Czochralski Silicon Solar Cells Due to Light-Induced Recombination Centres", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Universität Stuttgart, Stuttgart)
([2]: Australian National University, Canberra, Australia)

Schmidt, J.[1]; Cuevas, A.[2]; Rein, S.; Glunz, S.W.
"Impact of Light-Induced Recombination Centres on the Current Voltage Characteristics of Czochralski Silicon Solar Cells", in: Progress in Photovoltaics, Vol. 9, 2001, 249-255
([1]: Universität Stuttgart, Stuttgart)
([2]: Australian National University, Canberra, Australia)

Schneiderlöchner, E.; Preu, R.; Lüdemann, R.; Glunz, S.W.; Willeke, G.
"Laser Fired Contacts – the Path to Economical High-Efficiency Technology for the Rear Contact of Crystalline Silicon Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Schossig, P.; Henning, H.-M.; Weingarten, G.; Raicu, A.[1]
"Mikroverkapselte Phasenwechselmaterialien in Wandverbundsystemen", Tagungsband 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5.2001, 287-292
([1]: PSE GmbH Forschung Entwicklung Marketing, Freiburg)

Schultz, O.; Biro, D.; Preu, R.; Ballif, Chr.; Zickermann, D.; Lüdemann, R.
"Screen Printed Selective Emitters Prepared by Fats and Rapid Thermal Diffusion", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Schweizer-Ries, P.; Vogt, G.; Casper, C.
"Mensch-Technik-Organisations(MTO)-Analyse von netzunabhängigen Dorfstromanlagen am Beispiel von Rambla del Agua/ Spanien", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 125-130

Schweizer-Ries, P., Djuwita, R.[1]; Ramirez, E.[2]; Hidalgo de Avila, E.[3]; Casper, C.[4]
"Social Interventions to Achieve Success with Off-Grid Village Power Supply Systems", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: University of Indonesia, Jakarta, Indonesia)
([2]: Trama Techno Ambiental TTA, Barcelona, Spain)
([3]: Instituto Nacional de Agricultura INTA, San Juan, Argentina)
([4]: Freelancer for Fraunhofer ISE, Barcelona, Spain

Schweizer-Ries, P.
"Decentralized Energy Use in Mountain Regions: Solar-Electric Stand-Alone Systems", in: Mountain Research and Development, in press

Seigel, B.; Bühring, A.
"Simulation von Wärmeübertragern in Lüftungskompaktgeräten für Passivhäuser mit TRNSYS", TRNSYS-Usertag 2001, Stuttgart, 23.2.2001

Vetter, M.; Wittwer, Chr.
"Simulationsbasierte Entwicklung von Regelungsstrategien zur optimierten Einbindung von erdgasbetriebenen netzgekoppelten Brennstoffzellen-BHKWs in teilsolare Energieversorgungssysteme von Gebäuden", Tagungsband 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5.2001, 413-418

Voss, K.
"Mit Fassaden Solarenergie nutzen", in: Tagungsband Symposium Industriebau, Dresden, 31.1.-1.2.2001

Voss, K.; Kiefer, K.; Reise, Chr.
"Gebäudeenergiekonzepte mit Photovoltaik", Tagungsband 16. Symposium Photovoltaische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 14.-16.3.2001, 172-178

Voss, K.
"Ein Institutsgebäude für ein sonniges Jahrtausend – Der Neubau des Fraunhofer ISE", EB Energie Effizientes Bauen (4/2001), 28-32

Voss, K.
"Schlanke Gebäude – Hohe Arbeitsplatzqualität bei geringem Energieverbrauch", EB Energie Effizientes Bauen (3/2001), 12-17

Voss, K.; Wagner, A.[1]; Löhnert, G.[2]
"Energieeffizienz und Solarenergienutzung im Nichtwohnungsbau. Konzepte und Bauten" Solarbau: MONITOR Journal 2000, 1. Aufl., Freiburg 2001
([1]: Universität Karlsruhe, Karlsruhe)
([2]: sol°id°ar, Berlin)

Wagner, F.[1]; Dobbins, A.[1]; Würfel, U.[1]; Hinsch, A.; Luther, J.
"Solid-State Dye-Sensitised Solar Cells Prepared by Mechanical Pressing: an Initial Study", 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Walkenhorst, O.; Reinhart, Chr.; Timmer, J.[1]
"Jahressimulation des Tageslichtangebotes in Gebäuden auf der Basis von stündlichen und minütlichen Strahlungsdaten", Tagungsband 7. Symposium Innovative Lichttechnik in Gebäuden, OTTI-Energie-Kolleg, Staffelstein, 25.-26.1.2001
([1]: Albert-Ludwigs-Universität, Freiburg)

Wiemken, E.; Beyer, H.G.[1]; Heydenreich, W.; Kiefer, K.
"Power Characteristics of PV Ensembles. Experiences from the Combined Power Production of 100 Grid Connected PV Systems Distributed Over the Area of Germany", in: Solar Energy, Vol. 70 (6/2001), 513-518
([1]: Fachhochschule Magdeburg, Magdeburg)

Wienold, J.; Kuhn, T.E.
"Tageslichtnutzung versus Energie – Gesamtheitliche Bewertung von Tageslicht und Sonneschutzsystemen" in: Tagungsband 7. Symposium Innovative Lichttechnik in Gebäuden, OTTI-Energie-Kolleg, Staffelstein, 25.-26.1.2001, 174-182

Willeke, G.; Kray, D.
"A New Route Towards 50 mm Thin Crystalline Silicon Wafer Solar Cells", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Wittwer, Chr.; Mertins, M.
"Regelungstechnische Modellierung von DEC-Systemen", Tagungsband 11. Symposium Thermische Solarenergie, OTTI-Energie-Kolleg, Staffelstein, 9.-11.5. 2001, 372

Wittwer, Chr.; Hube, W.; Schossig, P.
"ColSim – a New Simulation Environment for Complex System Analysis and Controllers", Proceedings Building Simulation 2001, Rio de Janeiro, Brazil, 13.8-15.8.2001, 237

Wittwer, V.; Graf, W.; Georg, A.
"Gaschromic Glazing with a Large Dynamic Range in Total Energy Transmittance", Proceedings 7th International Conference on Architectural and Automotive Glass, Tampere, Finland, 18.-21.6.2001, 725-728

Wolkenhauer, H.[1]; Henning, H.-M.; Franzke, U.[2]
"Systemkomponenten der solaren Klimatisierung – Teil 1", in: Heizung, Lüftung/ Klima, Haustechnik HLH (10/2001), 26-39
([1]: Klimahaus GmbH, Hamburg)
([2]: Institut für Luft- und Kältetechnik, Dresden)

Wolkenhauer, H.[1]; Henning, H.-M.; Franzke, U.[2]
"Systemkomponenten der solaren Klimatisierung – Teil 2", in: Heizung, Lüftung/ Klima, Haustechnik HLH (11/2001), im Druck
([1]: Klimahaus GmbH, Hamburg)
([2]: Institut für Luft- und Kältetechnik, Dresden)

Würfel, U.[1]; Wagner, J.[1]; Ferber, J.[1]; Luther, J.
"PEDT, a Solid Hole-Conducting Polymer in Dye Solar Cells", European Material Research Society, Spring Meeting, Strasbourg, France, 5.-8.6.2001
([1]: Freiburger Materialforschungszentrum FMF, Freiburg)

Zenker, M.; Heinzel, A.; Stollwerck, G.; Ferber, J.; Luther, J.
"Efficiency and Power Density Potential of Combustion-Driven Thermophotovoltaic Systems Using GaSb Photovoltaic Cells", in: Electronic Devices, Vol. 48 (2/2001), 367-376

Zerres, T.; Ballif, Chr.; Borchert, D.; Peters, S.
"High Speed Mapping of Sheet Resistance on Large Area Wafers: the Fakir System", Proceedings 17th European Photovoltaic Solar Energy Conference and Exhibition, Munich, 22.-26.10.2001, in press

Abbreviations

Ag	silver
Al	aluminium
AlGaAs	aluminium gallium arsenide
AM	air mass
APCVD	atmospheric pressure chemical vapour deposition
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 Reaktor-sicherheit (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BMZ	Bundesministerium für wirt-schaftliche Zusammenarbeit und Entwicklung (German Federal Ministry of Economic Co-operation and Development)
BSF	back surface field
CIS	copper indium diselenide
CNRS	Centre Nationale de la Recherche Scientifique
c-Si	crystalline silicon
CV	capacitance/voltage
CVD	chemical vapour deposition
Cz	Czochralski
DLTS	deep level transient spectroscopy
EBIC	electron beam induced current
EBR	etchback regrowth
ECR	electron cyclotron resonance
EFG	edge-defined film-fed growth
EMC	electromagnetic compatibility
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
kW_p	kilowatt peak
LBIC	light beam induced current
LBSF	local back surface field
LPE	liquid phase epitaxy
mc	multicrystalline
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 photoconductance decay
NOCT	nominal operating cell temperature
PCVD	photocurrent and voltage decay
Pd	palladium
PECVD	plasma enhanced chemical vapour deposition
PEM	polymer membrane
PERC	passivated emitter and rear cell
PV	photovoltaic
RCC	rear contacted cell
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
SME	small and medium-sized enterprises
Si	silicon
SIMOX	separation by implanted oxygen
SiN_x	silicon nitride
SiO_2	silicon dioxide
SIR	simultaneous infiltration and recrystallisation
Sn	tin
SPV	surface photovoltage
SSP	silicon sheets from powder
SR	spectral response
SR-LBIC	spatially resolved light beam induced current
TI	transparent insulation
Ti	titanium
TiO_2	titanium dioxide
TPV	thermophotovoltaics
V_{oc}	open circuit voltage
WPVS	world photovoltaic scale
Zn	zinc
η	efficiency value

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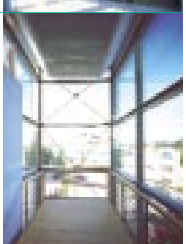

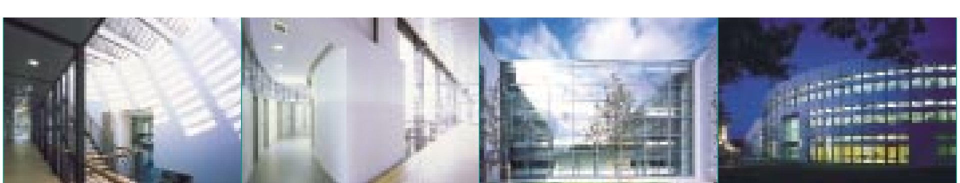

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