Fraunhofer
ISE

FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

Annual Report 2012

Cover:
The continuing success of concentrator technology was recognised in 2012 by the award of the Deutscher Umweltpreis (German Environmental Prize). Dr Andreas Bett from Fraunhofer ISE and Hansjörg Lerchenmüller from Soitec Solar were honoured for their services to research and industry by the Deutsche Bundesstiftung Umwelt. Concentrator photovoltaics applies lens-based optical systems, which concentrate the solar radiation by a factor of 500 onto very small, extremely efficient solar cells of III-V semiconductors. Andreas Bett continues to work with more than 50 colleagues at Fraunhofer ISE on improving the efficiency of multi-junction solar cells and optimising the configuration of concentrator modules. Soitec Solar has successfully transferred the concept of concentrator systems to industrial production and is one of the global leaders in this field today. The Deutscher Umweltpreis was presented by the German President, Joachim Gauck. In 2011 the topic of concentrator photovoltaics was already one of the finalists of the Deutscher Zukunftspreis.

FOREWORD

2012 proved to be a difficult year for the solar industry. Set off by overcapacity and intensified international competition, the dramatic price drop of PV modules brought economic difficulties especially to the German market. Unfortunately policy makers failed to give clear signals and guidelines for the consequent transition from fossil and nuclear fuels to renewable energy sources, as agreed upon in 2011. Rather, the longstanding dispute over a revision of the Renewable Energy Act (EEG) lasted until midyear and triggered investment uncertainties. The winding up and sale of renowned and long-standing German market players followed. Moreover, in their present state, most production systems in Europe are not capable of manufacturing photovoltaic modules at the current low market prices. New photovoltaic factories with the most modern technology will have an annual production capacity ranging from one to five gigawatts. Our present task is to set the appropriate conditions that will enable German producers of photovoltaic manufacturing equipment to offer PV production facilities on this multi gigawatt scale.

Nonetheless the energy transformation remains a big task for the entire nation and provides Germany with a unique chance as international trail blazer. With its broad spectrum of research themes, Fraunhofer ISE is active in almost all areas which are relevant for achieving a CO_2-free energy supply. As the largest solar research institute in Europe, we are working in the areas of photovoltaics, solar thermal energy, energy efficiency, energy system technology and energy storage. With our wide range of research activities, our many years of experience and naturally with our highly competent and motivated staff, Fraunhofer ISE looks back at 2012 as an economically successful year rich in content.

We are especially proud that Dr Andreas Bett of Fraunhofer ISE and Hansjörg Lerchenmüller of Soitec Solar received the German Environmental Prize 2012 for their joint achievements in solar technology. This award also demonstrates appreciation for the field of concentrator photovoltaics, a technology suitable for sun-rich countries where large solar power stations produce electricity on the large scale. This technology that began on a small scale in the research laboratory of Dr Andreas Bett at Fraunhofer ISE is today marketed on the industrial level by Soitec Solar and contributes to the energy transformation on the international level.

We are increasingly using our wide ranging expertise to take a comprehensive look at the future energy supply. At Fraunhofer ISE intense work is being carried out to develop a comprehensive first-of-its-kind model of the German energy system and its transformation through to an energy supply based completely on renewable energy sources. In 2012, Dr Hans-Martin Henning and Andreas Palzer presented first results of this break-through study. In their simulations using hourly time series, they investigated a plausible future energy system in Germany based entirely on renewable energy sources. New is the comprehensive approach which considers both the electricity and the heat sectors and also reductions in energy consumption due to building renovation measures. In the simulations optimisations are performed to determine an economic optimum from the many potential combinations of different technologies and efficiency increasing measures.

To give research on CO_2-free energy systems a stronger voice internationally, Fraunhofer ISE signed a Memorandum of Understanding (MoU) with two other leading solar research

institutes in July 2012. With this MoU, the Global Alliance of Solar Energy Research Institutes (GA-SERI) was founded. This alliance intends to strengthen the co-operation and the scientific exchange between Fraunhofer ISE, the National Renewable Energy Laboratory NREL of the US Department of Energy (USA) and the National Institute of Advanced Industrial Science and Technology AIST (Japan). Two scientists from each institute are to spend time as visiting researchers at each of the other institutes in the alliance.

The energy transformation in Germany requires efforts from the whole of society, and it is encouraging to see the increasing amount of discussions, sometimes heated, being carried out on this topic. Unfortunately the data used often show gaps. To increase the information flow, Fraunhofer ISE continually compiles the relevant data and facts on photovoltaics and makes it available on its website. These data are updated on a regular basis and can be downloaded in an easy-to-understand form. In 2012 we came out with a new study called "Stromgestehungskosten von erneuerbaren Energien" (Electricity production costs of renewable energies). This study clearly shows how competitive renewable energies have become. Due to increased efficiencies and reduced costs, the electricity production costs of photovoltaics even in Germany are meanwhile less than the electricity rates paid by the end customer. Structurally, Fraunhofer ISE also carried out steps to better accompany the energy transformation process. With the introduction of a new market area "Smart Energy Cities", we orient ourselves towards one of the large research tasks at present. To this purpose, the title of the annual international conference "Solar Summit Freiburg 2012 – Highlights and Trends in Solar Energy" was "The Future Sustainable City". On 18–19 October 2012 about 300 participants discussed themes related to sustainable city development in the Freiburg Konzerthaus. In addition, various experts presented overviews on the state-of-the-art of solar research.

The importance of suitable storage solutions to balance out the fluctuating yields from renewable energy sources cannot be overemphasized. With this is in mind, the German Energy Storage Association (Bundesverband Energiespeicher BVES) was established in the fall of 2012 and I assumed the office of Founding President of the BVES. The goal of the association is to promote networking among the growing branch of energy storage companies in order to accelerate the market growth. In Dusseldorf, both Fraunhofer ISE and the Fraunhofer Energy Alliance attended the trade fair "Energy Storage", which took place for the first time in 2012. Synergy and networking is also the emphasis of the newly founded Fraunhofer Alliance Batteries. Fraunhofer ISE, meanwhile one of the leading research institutes on stationary and mobile batteries, is an active member in this alliance.

In 2012, the inauguration of our new solar hydrogen filling station at Fraunhofer ISE brought our research in hydrogen technology and intelligent energy systems a decisive step further. The publically accessible filling station serves not only as a research platform but also as an important corner stone in the hydrogen filling station network under development in Baden-Wuerttemberg. The aspired transformation of Germany's energy system sees hydrogen as a long-term storage medium as well as a fuel in the mobility sector. At the filling station, electrolysers convert the electricity generated by wind or solar energy into hydrogen. Only 3 minutes are needed to fill up the fuel cell cars who visit the filling station. With a full tank, a driving distance of over 400 km can be achieved.

With the new facilities added in 2012, we continue to expand the Institute's capacity at the Freiburg location. In 2013 we plan to inaugurate and move into a new building for the fields of solar thermal technology and applied optics and functional surfaces. With more space for laboratories and equipment,

we will be able to expand our research in these areas. With this expansion, Fraunhofer ISE contributes its part in creating the "Sustainable Energy Valley" in Freiburg. This flagship project was jointly initiated by the State of Baden-Wuerttemberg and the Fraunhofer-Gesellschaft to advance the sustainable production and use of energy and resources. Research associated with this project shall be bundled and supported, particularly in Freiburg. For this purpose, total investments of over 80 million euro are designated. In November 2012, Dr Nils Schmid, State Minister of Economics and Finance, visited the five Fraunhofer institutes in Freiburg and confirmed support from the State.

The Fraunhofer institutes in Freiburg demonstrated their regional ties at the 60th anniversary celebration of Baden-Wuerttemberg. In June, the five institutes were open to the public. Tours of the institutes and laboratories as well as expert talks were offered. At Fraunhofer ISE, the visitors got an overview of the institute's activities and, in particular, could visit the new solar hydrogen filling station and view special exhibits to learn more about dye solar cells and new sorption materials.

In 2011 Fraunhofer ISE celebrated 30 years since its founding, and in 2012 an anniversary was again celebrated. Twenty-five years ago in 1987, the researchers at Fraunhofer ISE installed a hybrid photovoltaic system at the Rappenecker Hof, a remote hikers' inn in the Black Forest without grid connection. The system served not only as a practical solution for the owner and leaser of the hut but also as a research station for off-grid energy supply systems. Over the years, the system was successively expanded. In 1990 a wind generator was installed and in 2003 a fuel cell so that operation of the backup diesel generator could be progressively reduced. Therefore, in 2012 the Rappenecker Hof not only celebrated its 350th anniversary but also 25 successful years of photovoltaic history.

The renewable energy electricity supply for the hikers' inn is regarded as one of the milestones in the early history of Fraunhofer ISE. The successful project is a motivation to us for the coming years, in which our main concern is to consequently bring on the transformation of the energy system through our research activities.

I would like to especially express my gratitude for the support and encouragement we receive from our Board of Trustees and grant sponsoring organisations, our contact persons in the ministries on the federal and state levels as well as from our project partners – especially those in industry. Without this close co-operation we would not be able to do our best, consolidating all our expertise and resources, to promote the renewable energy transformation, one of the largest tasks today facing society as a whole.

TABLE OF CONTENTS

TABLE OF CONTENTS

1

2

ORGANISATIONAL STRUCTURE

The Fraunhofer Institute for Solar Energy Systems ISE is organised in two parallel structural forms that are mutually compatible: the business areas, subdivided into market areas, and the scientific divisions. The external presentation of our Institute, our marketing activities on R&D, and above all, our strategic planning are structured according to the eight business areas which reflect the main research topics addressed by the Institute. The scientific divisions of the Institute are responsible for the research and development (R&D) in the laboratories, project work and the concrete organisation of work.

Fraunhofer ISE is supported by long-standing mentors and experts in the solar energy branch: Prof Adolf Goetzberger (Founder of the Institute and Institute Director 1981–1993), Prof Joachim Luther (Institute Director 1993–2006) and Prof Volker Wittwer (Deputy Institute Director 1997–2009).

INSTITUTE DIRECTOR	Prof Eicke R. Weber	+49 761 4588-5121
DEPUTY DIRECTORS		
	Dr Andreas Bett	+49 761 4588-5257
	Dr Hans-Martin Henning	+49 761 4588-5134
CHIEF FINANCIAL OFFICER	Dr Holger Schroeter	+49 761 4588-5668
PRESS AND PUBLIC RELATIONS	Karin Schneider M.A.	+49 761 4588-5147
STRATEGIC PLANNING	Dr Thomas Schlegl	+49 761 4588-5473
ENERGY POLICY	Gerhard Stryi-Hipp	+49 761 4588-5686
COORDINATION PHOTOVOLTAICS	Prof Gerhard Willeke	+49 761 4588-5266
COORDINATION UNIVERSITIES	Prof Roland Schindler	+49 761 4588-5252

3

4

1 *The directors of Fraunhofer ISE (f. l. t. r.):*
Dr Holger Schroeter, Chief Financial Officer; Dr Hans-Martin Henning, Deputy Director and Division Director "Thermal Systems and Buildings"; Prof Eicke R. Weber, Institute Director; Dr Andreas Bett, Deputy Director and Division Director "Materials – Solar Cells and Technologies".

2 *Karin Schneider, Head of "Press and Public Relations".*

3 / 4 *Directors of the scientific divisions at Fraunhofer ISE (f. l. t. r.):*
Dr Werner Platzer "Solar Thermal and Optics", Dr Günther Ebert "Electrical Energy Systems", Dr Christopher Hebling "Energy Technology", Dr Hans-Martin Henning "Thermal Systems and Buildings", Dr Harry Wirth "Photovoltaic Modules, Systems and Reliability", Dr Andreas Bett "Materials – Solar Cells and Technologies", Dr Ralf Preu "PV Production Technology and Quality Assurance", Dr Stefan Glunz "Solar Cells – Development and Characterisation".

SCIENTIFIC DIVISIONS

Thermal Systems and Buildings	Dr Hans-Martin Henning	+49 761 4588-5134
Solar Thermal and Optics	Dr Werner Platzer	+49 761 4588-5983
Materials – Solar Cells and Technologies	Dr Andreas Bett	+49 761 4588-5257
Solar Cells – Development and Characterisation	Dr Stefan Glunz	+49 761 4588-5191
PV Production Technology and Quality Assurance	Dr Ralf Preu	+49 761 4588-5260
Photovoltaic Modules, Systems and Reliability	Dr Harry Wirth	+49 761 4588-5858
Electrical Energy Systems	Dr Günther Ebert	+49 761 4588-5229
Energy Technology	Dr Christopher Hebling	+49 761 4588-5195

THE INSTITUTE IN BRIEF

The Fraunhofer Institute for Solar Energy Systems ISE is committed to promoting energy supply systems which are sustainable, economic, safe and socially just. It creates technological foundations for supplying energy efficiently and on an environmentally sound basis in industrialised, threshold and developing countries. To this purpose, the Institute develops materials, components, systems and processes for the following business areas: energy-efficient buildings, applied optics and functional surfaces, solar thermal technology, silicon photovoltaics, photovoltaic modules and systems, alternative photovoltaic technology, renewable power generation and hydrogen technology. With activities extending well beyond fundamental scientific research, the Institute is engaged in the development of production technology and prototypes, the construction of demonstration systems and the operation of testing centres. The Institute plans, advises, tests and provides know-how and technical facilities as services. Fraunhofer ISE is certified according to DIN EN ISO 9001:2008.

Research and Services Spectrum

The Fraunhofer Institute for Solar Energy Systems ISE is a member of the Fraunhofer-Gesellschaft, a non-profit organisation, which occupies a mediating position between the fundamental research of universities and industrial practice. It conducts applications-oriented research to benefit the economy and society at large. Fraunhofer ISE finances itself to more than 90 percent with contracts for applied research, development and high-technology services. The working method is characterised by its clear relevance to practice and orientation toward the wishes of the client. The Institute is integrated into a network of national and international co-operation. Among others, it is a member of the Forschungs-Verbund Erneuerbare Energien (FVEE – German Research Association for Renewable Energy) and the European Renewable Energy Centres (EUREC) Agency. The Institute can draw on expertise from other Fraunhofer Institutes, so that complete interdisciplinary solutions can be offered.

Networking within the Fraunhofer-Gesellschaft

- member of the Fraunhofer Alliances: Batteries, Building Innovation, Energy, Nanotechnology, Optic Surfaces and Water Systems (SysWater)
- member of the Fraunhofer Electromobility Systems Research project
- member of the Fraunhofer Group Materials, Components
- member of the Fraunhofer Initiative "Morgenstadt – City of the Future"

External Branches and Co-operations

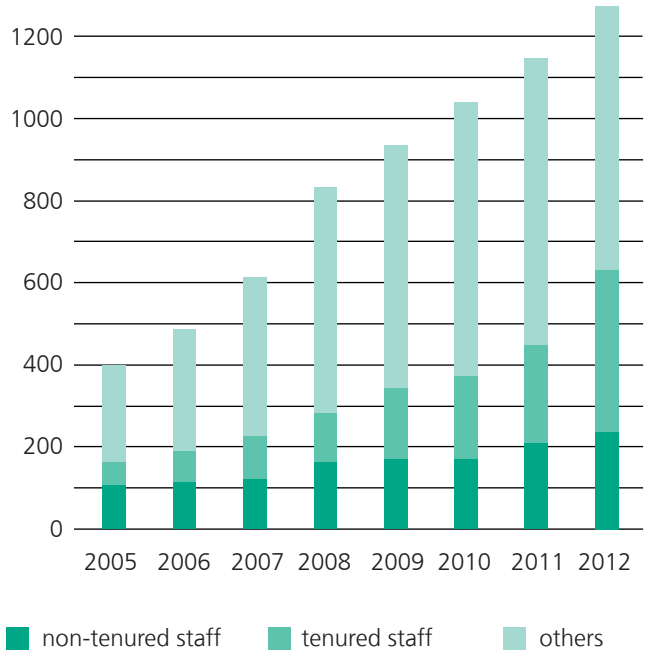
The Fraunhofer ISE Laboratory and Service Centre LSC in Gelsenkirchen, in the State of North Rhine-Westphalia (NRW), was founded in 2000. It serves as a partner for the photovoltaic industry also beyond the borders of NRW. Solar cell manufacturers draw on the services of LSC for quality control of their production and for rapid solutions to problems in their processing lines. The services offered by the Laboratory include the simulation and optimisation of in-line processes, the development of new processes and structures for solar cells as well as research on large-area hetero-junction solar cells of amorphous and crystalline silicon. LSC Gelsenkirchen also offers training sessions on characterisation procedures and solar cell technology (see page 82).

The Fraunhofer Centre for Silicon Photovoltaics CSP in Halle/Saale was jointly founded by the Fraunhofer Institute for Mechanics of Materials IWM, Freiburg and Halle, and the Fraunhofer ISE. Fraunhofer IWM contributes its expertise in the area of optimisation and evaluating silicon process technologies and module integration. Fraunhofer ISE's competence lies in the manufacture of materials, solar cell and module development as well as characterisation. The central facilities are presently Reliability and Technologies for Grid Parity (CSP-ZTN) and the Laboratory for Crystallisation Technology (CSP-LKT) (see page 65).

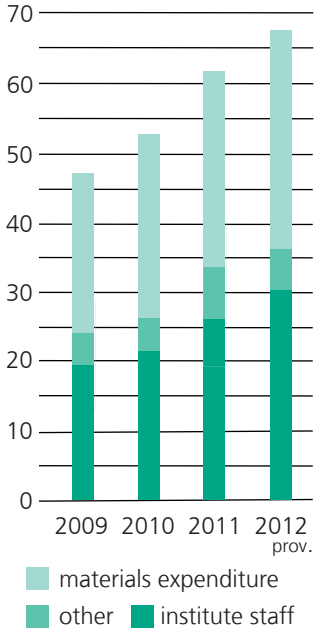
The Technology Centre for Semiconductor Materials THM in Freiberg, Saxony, is a co-operation between Fraunhofer ISE and the Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen. THM supports companies through research and development on materials preparation and processing of 300 mm silicon, solar silicon and III-V semiconductors. Beyond this, THM offers services in the fields of analytics, characterisation and testing to assist industry partners in their ongoing production.

The Fraunhofer Center for Sustainable Energy Systems CSE in Boston was founded in 2008. At Fraunhofer CSE, the expertise and technology in the field of renewable energy that is already established in Europe is to be further adapted and introduced to the United States market. Together with the Canadian Standards Association (CSA) and the VDE Institute for Testing and Certification, the Fraunhofer CSE set up a test facility for PV modules in 2010. The facility, called the CFV Solar Test Laboratory, is located in Albuquerque, New Mexico.

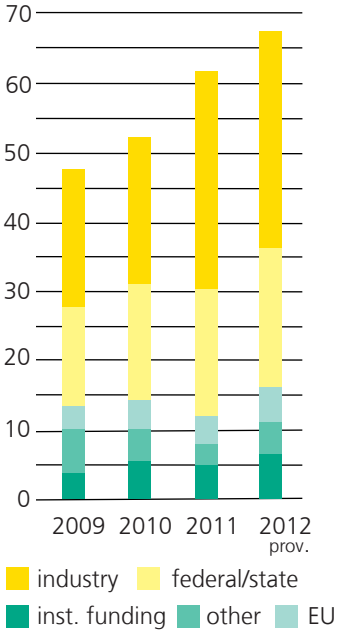
Personnel



Expenditure million euros



Income million euros



On 31 December 2012, a total of 1272 staff members were employed at Fraunhofer ISE. Included in this total are 170 doctoral candidates, 156 diploma/masters students, 38 trainees, 13 apprentices and 290 scientific assistants as well as 108 other staff members (e.g., guest scientists) who support the research projects with their work and thus contribute significantly to the scientific results obtained. In this way, Fraunhofer ISE makes an important contribution towards educating researchers in this significant field of work.

The financial structure of the Fraunhofer-Gesellschaft distinguishes between the operational and investment budgets. The operational budget includes all expenses for personnel and materials, as well as their financing with external income and institutional funding. In 2012 our operational totalled 66.3 million euro. In addition to the expenditure documented in the graph, the Institute made investments of 10.2 million euro in 2012 (not including investments for building construction and the economic stimulus programme).

1

MODELLING OF ENERGY SYSTEMS

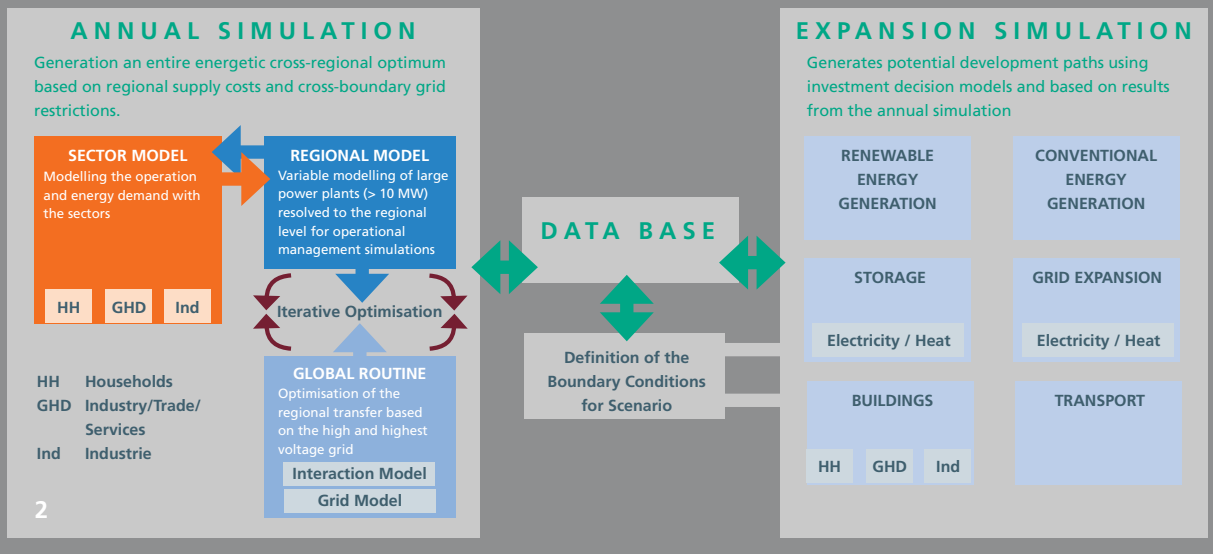
The increasing use of renewable energies at all levels, from solar systems in single buildings through to large wind farms in the sea, necessitates an increasing complexity in our energy system. New components, such as energy storage, assume a central role in order to balance out the shift between supply and demand over various time scales. New operating concepts are just as important as the development of new business models to guarantee the ambitious political goal of reducing energy-related CO_2 emissions as fast as possible and cost-effectively, while maintaining the security of supply. In the past year at Fraunhofer ISE, we have begun comprehensive work on modelling complex energy systems. Our aim is to offer these services to the different decision makers in the political and economic spheres.

Jörg Dengler, Jan-Bleicke Eggers, Mehmet Elci, Sebastian Herkel, Christoph Kost, Niklas Kreifels, Andreas Palzer, Thomas Schlegl, Charlotte Senkpiel, Gerhard Stryi-Hipp, Christof Wittwer, **Hans-Martin Henning**

To adequately address the different requirements for modelling complex energy systems, we decided upon three different simulation models. These three new models complement each other and as well as round off our extensive amount of long-standing simulation models for solar systems, buildings and municipal districts.

The simulation model REMOD-D (Renewable Energy Model – Germany) describes the target of the future electricity and heat sector in Germany, which is supplied largely or also completely by renewable energies. An optimisation program calculates the optimal mix of energy suppliers, converters and storage that leads to the least annual total costs for the operation and maintenance of the energy system. To accurately model the interaction between supply, storage and consumption, the entire system is simulated using hourly energy balances over an entire year. Compared to the other similar models existing, our model is unique in that the electricity and the heat sectors are considered in their entirety as well as in their interaction. Also the aspect of building energy renovation as a measure to reduce the heating demand is included in the optimisation. Figure 3 shows the installed capacities of the most important components of the three target systems. In particular, the scope of the building energy renovation and thus the total power of the renewable energy converters to be installed differ between the three systems.

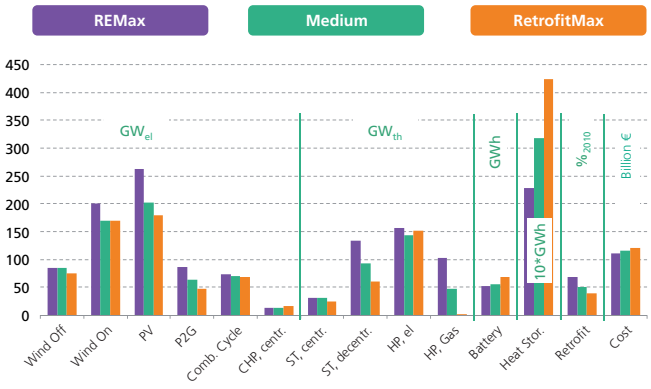
The simulation model E2S describes the German energy system as it is structured today, based on a strong, regionally disaggregated level of cities and districts. An annual simulation of this extensive system allows the detailed investigation of energy flows from suppliers and consumers on the basis of quarter-hour averages. In parallel, an expansion simulation runs, in which the development of the energy system is modelled with consideration to established boundary conditions. Here investment decision scenarios for important players such as the energy suppliers and municipal utilities but also building owners are simulated. The results show changes both in the supply and the demand structures because increasing the building energy renovation leads to



1 *Electricity from solar and wind is a fundamental element in the future energy supply (left). Building energy renovation contributes greatly to efficiency. In Freiburg, a 16-storey high-rise was renovated to passive house standards (middle). Solar process heat shows enormous potential for industrial applications (right).*

2 *Interaction of annual and expansion simulations in the E2S model is shown schematically.*

reduced heat consumption however increasing heat pump use leads to higher electricity consumption. The interaction between the annual and the expansion simulations allow conclusions to be drawn about the effects of the relevant political boundary conditions and how these conditions must be changed accordingly in order to reach a defined goal. Thus, the simulation program is of interest for policy makers as well as energy suppliers and power plant operators, who are seeking information about electricity and heat flows on the regional level, full load hours for different supply structures, appropriate market design and selected operating strategies. Manufacturers of individual components and technologies benefit from the energy system model, which provides specific simulation results on the use of different technologies and their operational behaviour in the system. Figure 2 schematically shows the interaction between the annual and the expansion simulations.



3 *Installed power, or magnitude, of key components in the three systems, in which the electricity and heat sectors in Germany are supplied completely from renewable energy.*

Many cities and regional districts in Germany have set ambitious goals to reduce their CO_2 emissions and implement renewable energy technologies in the communal energy supply. Now local governments face the challenge of developing an entire concept out of many single measures e.g. co-generation, local heating grid, photovoltaics, solar thermal energy, building energy renovation and heat pumps with the goal of achieving the largest utilization at the lowest cost. Only when the interaction between the single measures has been analysed and the possible energy system variants are available as quantitative results can a truly substantiated decision be made. The third energy system simulation model KomMod (Communal Energy System Model) does just this. It considers all three demand sectors: electricity, heat and, in future, the transport sector. The simulation results, calculated using a high temporal and spatial resolution and employing technical and economic detail, allow recommendations to be made on how to meet the energy demand down to the neighbourhood level. Beyond the pure analysis of a current or future state, the optimisation model in KomMod will, in future, determine optimised variants of future communal energy systems. Thus, it provides us with an important tool for advising local communities.

1

SMART ENERGY CITIES

Responsible for 75 per cent of the energy demand, cities and municipalities are key players in the transformation of the energy system. Many measures for the transformation will be realised primarily on the local level, e.g. building energy renovation, Smart Grids, local heating grids, electricity and heat storage and the development of multimodal transportation systems. Also taking place locally is the communication with the citizens, whose acceptance and support is essential to the energy transformation. Globally an increasing number of cities and municipalities are taking on this challenge. The demand on research to find suitable concepts and solutions is significantly rising. The high-tech strategy of the German federal government dedicates its efforts towards intensifying research in the future-oriented project "CO_2-freie, energieeffiziente und klimaangepasste Stadt" (CO_2-free, energy efficient and climate-adapted city).

Arnulf Dinkel, Sebastian Gölz, Sebastian Herkel, Dominik Noeren, **Gerhard Stryi-Hipp**, Christof Wittwer, Günter Ebert

Fraunhofer ISE researches and develops technologies for a sustainable energy supply. In addition to components, the development of complex energy systems is also gaining in importance due to the increasing market share of renewable energies. One example is the design of municipal energy systems which exclusively use renewable energies. To provide cities and municipalities with assistance in the transformation of their energy systems, Fraunhofer ISE set up the market area "Smart Energy Cities". This new area supports and coordinates the interdisciplinary collaboration between the individual research groups and the cooperation with external research institutes which, for example, specialise in economics related to urban research themes. Therefore, Fraunhofer ISE can not only rely on extensive technological research structures but also on research teams of social scientists, who deal with sustainable design concepts and acceptance of new technologies but also new business and participation models.

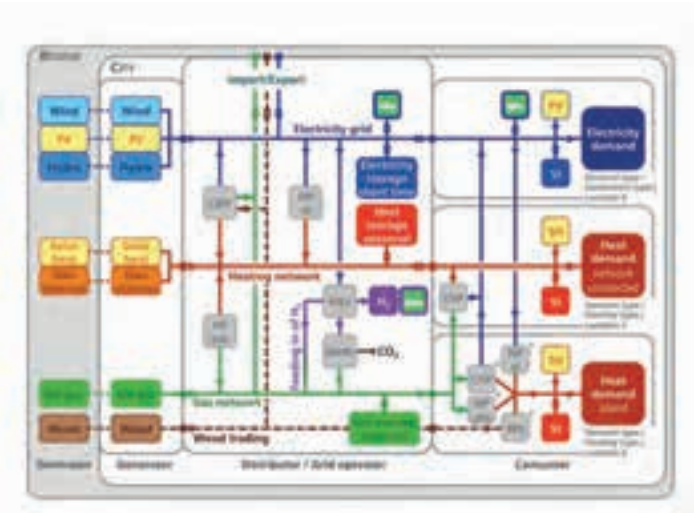
Technologies and concepts for sustainable cities and municipalities are also in the focus of the Fraunhofer-Gesellschaft. Under the title "Morgenstadt – City of the Future", twelve Fraunhofer institutes are cooperating on the topics of energy, buildings, mobility, safety, water, production and logistics, information and communications technology as well as business models and governance. In May 2012, the project "Morgenstadt: City Insights" (m:ci) was initiated together with industry. In 2013 as part of this project, multidisciplinary research teams will visit and analyse six cities throughout the world. In the cities of Tokyo, Singapore, New York, Copenhagen, Berlin and Freiburg, inspiring solutions for the City of the Future will be investigated and the transferability to other climate zones and countries will be investigated. Within the m:ci project, Fraunhofer ISE is in charge of the subproject "Energy". The Institute can build on its various activities to date on sustainable energy supply in cities and municipalities.

1 *Model of the Green City Freiburg.*

Projects were carried out in the areas of intelligent heating controls, efficient local heating supply, zero-energy buildings, passive house standards for high-rise buildings, Smart Grid technologies, electric and hydrogen-powered vehicles as well as electricity and heat storage systems.

Sustainable energy systems based to a large per cent, or exclusively, on renewable energy sources must be customised to fit each community. The potential of local and regional renewable sources must be considered and the supply must be balanced with the projected demand profile. In order to guarantee a high security of supply at the lowest possible costs, an optimal energy mix with suitable grid structures and operating equipment must be determined using a time-resolved dynamic, annual simulation. In order to offer cities and municipalities the appropriate services, several simulation tools were developed and implemented at Fraunhofer ISE. With these tools, various options for transforming the energy system can be evaluated. Beyond this, methods are developed to work out ways to implement the strategies and achieve the target scenarios.

Further development of the existing municipal energy system is supported by tools and concepts which optimise the operation with respect to the liberalised energy market and the regulatory boundary conditions. To monitor the project success, long-term monitoring and further scientific consulting services are offered.



2 *Municipal energy concept based on renewable energies.*
(HPel/gas = electrically or gas powered heat pump,
CHP = co-generation, WS = wood stove, St = storage
SH = solar heat, Elys = electrolyser, Meth = methanisation
** one heat supply per building)*

1

DEVELOPMENT PLANNING FOR RENEWABLE ENERGIES IN EGYPT

The Middle East and North Africa (MENA) offer enormous solar and wind resources, which have been little used up to now. At the same time, the available fossil fuel resources such as natural gas and oil are dramatically decreasing in these regions. For this reason, many MENA countries have announced plans for the expansion of renewable energies. The country's own consumption becomes more sustainable and the surplus fossil fuels can be exported. The working group Renewable Energy Innovation Policy (RENIP) was founded jointly by the Fraunhofer Institute for Solar Energy Systems ISE and the Fraunhofer Institute for Systems and Innovation Research ISI. The group supports customers from business and the public sector in developing strategies for the expansion of renewable energies. It provides consultancy services on financial support for renewable energy implementation. Among other projects, we are presently working on a development plan for renewable energy in Egypt.

Verena Jülch, Christoph Kost, Noha Saad, Jessica Thomsen, Thomas Schlegl

In the project "Combined Renewable Energy Master Plan for Egypt" (CREMP), RENIP is working with colleagues from the division "Solar Thermal Technology" at Fraunhofer ISE and with Lahmeyer International, Engineering and Consulting Services. Together we are creating a development plan for renewable energy in Egypt and are carrying out a feasibility study for CSP power plants. The development plan is made up of the following building blocks:

- analysis of the techno-economic potential of wind and solar energy
- possibilities for integrating renewable energies into the local electricity supply
- investigating and evaluating the political incentive plan for the installation of power plants and using the local value chain potential
- analysis of the financing possibilities in order to create the required boundary conditions

To analyse the value chain potential of the Egyptian local industry for the technologies of photovoltaics (PV), concentrated solar power (CSP) and wind, RENIP carried out 39 interviews with representatives from different companies. With the results of these interviews, the local value chain potentials for PV, CSP and wind were determined (Figure 3 and 4). For existing projects, the local value reached to date was analysed. With this basis, we then determined local value chain potentials that can be realised in the future. A further focus of our work was to investigate measures which support national research and development work on renewable energy. Here the existing measures were evaluated and compared to developments in selected sample countries. From this analysis, weak areas could be identified and recommendations for improvement were proposed. These results flow into the development of a comprehensive strategy for supporting renewable energy in Egypt.

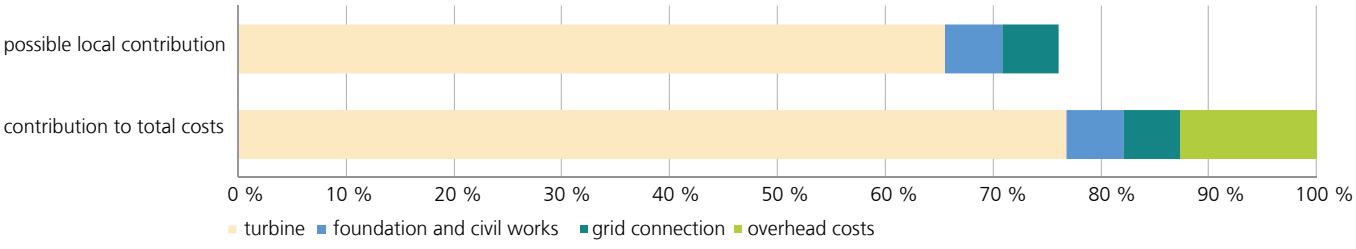
1 *CSP power plant in Kruaymat, 90 km south of Cairo, Egypt: 140 MW overall capacity (additional heating with gas), 20 MW_{el} solar field capacity.*

2 *Wind farm in Zafarna on the Golf of Suez, Egypt: 517 MW overall capacity with 700 wind generators.*

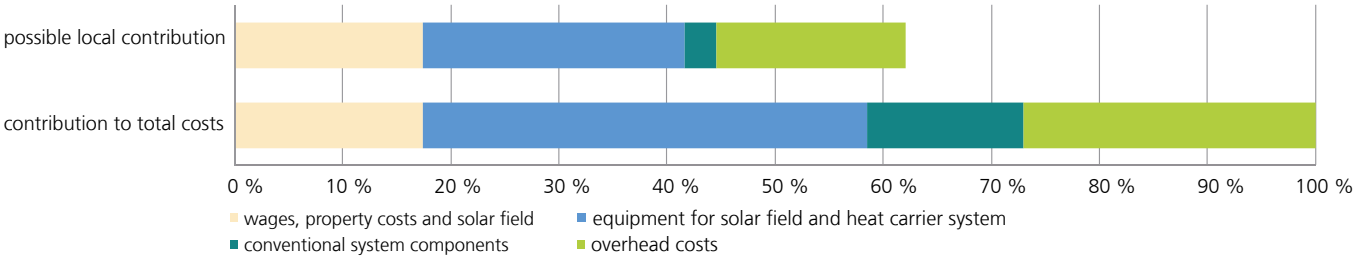
The cooperation "Renewable Energy Innovation Policy" (RENIP) was founded in 2009 and joins the expertise of both the Fraunhofer ISE and the Fraunhofer ISI. The areas of technology development and applied research at Fraunhofer ISE and the economic system analysis and innovation research at Fraunhofer ISI complement each other, offering together a package of comprehensive and interdisciplinary competence. In the cooperation led by Dr Mario Ragwitz (Fraunhofer ISI) and Dr Thomas Schlegl (Fraunhofer ISE), services are offered in which technologies are investigated from their initial development and implementation through to their innovation potential on the energy market. Throughout all phases, the technology development can be optimally directed.

The study "MENA Assessment of Local Manufacturing Potential for Concentrated Solar Power (CSP) Projects" commissioned by the World Bank is one of the projects we have worked on to date. In the meanwhile, this study is considered a standard work in value chain potential for renewable energies with regard to action plans and their implementation in the MENA regions. Building on this work, RENIP now assists some MENA countries in strategy development, providing advisory services on financing strategies with consideration to the national boundary conditions in the energy sector.

www.renip.fraunhofer.de



3 *Local value chain potential of wind farm in Egypt.*



4 *Local value chain potential of solar thermal power plant in Egypt.*

R&D HIGHLIGHTS

ENERGY-EFFICIENT BUILDINGS

- newly developed, comprehensive energy model for Germany: 100 % renewable energy supply for electricity and heating sector; considers building energy renovation measures
- ab initio model for building integrated photovoltaics (BIPV) developed and applied
- development and demonstration of façade-integrated ventilation systems for new and renovated buildings
- material-independent coating of sorptive materials on heat exchangers

APPLIED OPTICS AND FUNCTIONAL SURFACES

- world's largest hexagonal diffraction grating with area of 1.2 x 1.2 m², produced seamlessly with interference lithography
- production of ordered plasmonic metal nanoparticle array on large areas using interference lithography, nanoimprint and lift-off processes

SOLAR THERMAL TECHNOLOGY

- expansion of simulation environment ColSim to include the development of controllers and operative management for components in high temperature applications (e.g. salt melt, direct evaporation, storage models)
- proof of salt melt recrystallization in a screw heat exchanger (10 kW laboratory version)
- construction of a test stand to investigate mechanical loads, induced by wind and snow, on solar collectors
- development of test procedure for measurements on air collectors in conformity with standards

SILICON PHOTOVOLTAICS

- successful silicon epitaxy in high throughput ProConCVD
- TCO-free silicon heterojunction solar cell with diffused front-side and collecting back-side amorphous silicon emitter with an efficiency of 22.8 %
- back-side contacted solar cell featuring decoupled emitter and diffusion geometry with an efficiency of 23.0 %
- production of an n-type solar cell with aluminium point emitters with an efficiency of 19.7 % by applying an adapted process sequence for p-type PERC solar cells
- manufacture of seed layer ink for contacting weakly doped boron emitters with a surface concentration of 1×10^{19} cm^{-3}
- expanding the Klaasen mobility model to include charge carriers in compensated silicon
- using the TOPAS (Thermal Oxide Passivated All Sides) process, 20 % solar cell efficiency on large industry substrates (mCz, 156 mm edge length) and 19.7 % on quasi-mono silicon
- large area HIP-MWT solar cells (p-type, Cz-silicon) with stencil printed front-side and 20.2 % efficiency
- cost-efficient, ozone-based one-step cleaning process used in place of elaborate RCA cleaning in the manufacturing process, tested using industrial system technology
- high density plasma deposition system developed successfully with industry partners for the industrial production of antireflection and passivation layers
- development of procedure to tomographically reconstruct defects in multi-crystalline silicon columns based on photo-luminescence images on as-cut wafers
- production of module-integrated large area p-type mc-Si Al-BSF solar cells from 100 % UMG silicon feedstock with over 17.0 % efficiency

PHOTOVOLTAIC MODULES AND SYSTEMS

- accuracy of precision measurements for solar modules improved, present measurement uncertainty one of worldwide best at 1.8 % (CalLab PV Modules)
- demonstration module developed with sixteen MWT cells from PV-TEC at Fraunhofer ISE. Through optimised connecting and encapsulation technology, cell to module power losses of less than 1 % with respect to the aperture surface area achieved (Module Technology Center MTC)

ALTERNATIVE PHOTOVOLTAIC TECHNOLOGIES

- record module with 32.1 % efficiency (outdoor measurements)
- first GaInP/GaAs tandem cell grown directly on silicon with 16 % efficiency
- first silicon quantum dot solar cell with 370 mV realised
- ITO-free organic solar cell with 6 % efficiency
- roll-to-roll coating system for organic solar cells put into operation

RENEWABLE POWER SUPPLY

- field test phase for the intelligent charging infrastructure of the electromobility fleet test (BMU) ended successfully
- development of methods for reliable quality control of batteries and PV luminaires
- highly precise determination of the state-of-charge and aging status of lithium iron phosphate batteries
- compact direct-current converter with GaN transistors and 1 MHz switching frequency
- for 25 years, off-grid PV system operating successfully at Rappenecker Hof

HYDROGEN TECHNOLOGY

- 50 kW biomass gasifier produced a tar-free (< 50 mg / Nm^3) synthesis gas for more than 600 hours, thereby demonstrating the technical maturity of the new Fraunhofer ISE gasification procedure
- successful upscaling of the cell area of a redox flow battery from 700 cm^2 to over 2000 cm^2 for stacks with a power of 5 kW
- four outdoor test stands, developed in-house for the parallel characterisation of 30 test fuel cells, successfully operated for over 6000 hours in the field
- inauguration of a publically accessible solar hydrogen filling station for 700 bar fast-fill according to SAE J2601

© Foto: Peter Himsel; Quelle: Archiv DBU

AWARDS AND PRIZES

At the 27th Symposium Photovoltaische Solarenergie (29.2.–2.3.2012) at Kloster Banz in Bad Staffelstein, **Sönke Rogalla** and **Sebastian Blume** with co-authors **Bruno Burger**, **Stefan Reichert** and **Christoph Siedle** won the first prize for their poster, which features an improved approach for determining harmonic current emissions from inverters.

Harry Kummer was awarded 2nd place in the Hugo Geiger Prize for the development of a coating system for heat exchangers in his diploma thesis. With this award, the Bavarian State Ministry of Economy, Infrastructure, Transport and Technology honours excellent and application-oriented diploma or master theses. This year the award ceremony took place on 8th May 2012 during the Fraunhofer Annual Meeting in Stuttgart.

The 22nd Symposium Thermische Solarenergie took place from 9.–11.5.2012 also in Kloster Banz, Bad Staffelstein. Together with the co-authors Frank Steinbach, Jörg Witulski and A. Erman Tekkaya from the Institute of Forming Technology and Lightweight Construction (IUL) at the Technical University Dortmund, **Lotta Koch** and **Dr Michael Hermann** received second place for their poster on the experiences and results from their work on steel absorber development.

At the Metallography Congress in Rostock (19.–21.9.2012), the jurors from the scientific advisory committee of the specialist periodical "Praktische Metallographie" selected the three best essays of the past year for the Buehler Best Paper Award. This year together with Patrik Voos (ITW Test & Measurement GmbH, Düsseldorf), **Dirk Eberlein** and **Peter Schmitt** received first place for their joint publication "Metallographische Probenpräparation von verlöteten Solarzellen" (Metallographic sample preparation of soldered solar cells).

1 *Award-winning concentrator photovoltaics: Dr Andreas Bett (left) and Hansjörg Lerchenmüller (right) of Soitec Solar were awarded the German Environmental Award 2012.*

This year's sensation was the German Environmental Award, received by **Dr Andreas Bett** and **Hansjörg Lerchenmüller** of Soitec Solar for their achievements in the development, market introduction and commercialization of the concentrator photovoltaic technology (Fig. 1). "In bringing a new solar technology onto the market, Bett and Lerchenmüller have done an extraordinary job for the benefit of solar energy," says Dr Fritz Brickwedde, Secretary General of the Deutsche Bundesstiftung Umwelt (DBU). Installed as large power stations in sun-rich regions, the concentrator technology converts solar energy into electricity. What began on a small scale in the laboratory contributes to the energy transformation today on an industrial scale. In large power stations, thousands of industrial manufactured concentrator PV modules track the sun. In each module, lenses concentrate the sunlight 500 fold. Miniature multi-junction solar cells made of semiconductor materials convert the concentrated sunlight efficiently into electricity. Another awardee in 2012 is Günther Cramer, co-founder and supervisory board member of SMA Solar Technology AG. The German Environmental Award was presented by the German President Joachim Gauck on 28th October 2012 in Leipzig.

BOARD OF TRUSTEES

CHAIRMAN

Dr Carsten Voigtländer
Vaillant GmbH, Remscheid

DEPUTY CHAIRMAN

Dr Hubert Aulich
PV Crystalox Solar GmbH, Erfurt

TRUSTEES

Dr Nikolaus Benz
Schott Solar CSP GmbH, Mainz

Dr Klaus Bonhoff
Now GmbH, Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie GmbH, Berlin

Kerstin Deller
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Berlin

Hans-Josef Fell
Member of the German Federal Parliament, Berlin

Stefan Gloger
State Ministry for the Environment, Climate and Energy Economy, Baden-Wuerttemberg, Stuttgart

Dr Winfried Hoffmann
Advisor Applied Solar Expertise, President EPIA, Brussels

Helmut Jäger
Solvis GmbH & Co. KG, Braunschweig

Wilfried Jäger
VDE Prüf- und Zertifizierungsinstitut GmbH, Offenbach

Dr Knut Kübler
Federal Ministry of Economics and Technology (BMWi), Bonn

Günther Leßnerkraus
State Ministry for Finance and Economy Baden-Wuerttemberg, Stuttgart

Prof Ralf Lüdemann
SCHMID Group, Freudenstadt

Klaus-Peter Pischke
Kreditanstalt für Wiederaufbau, Frankfurt

Dr Klaus-Dieter Rasch
AZUR SPACE Solar Power GmbH, Heilbronn

Dr Dietmar Roth
Classic Centrum Zwickau AG, Zwickau

Prof Frithjof Staiß
Zentrum für Sonnenenergie und Wasserstoff-Forschung (ZSW), Stuttgart

Prof Andreas Wagner
Karlsruher Institut für Technologie (KIT), Karlsruhe

The Board of Trustees assesses the research projects and advises the Institute Directorate and the Executive of the Fraunhofer-Gesellschaft with regard to the work programme of Fraunhofer ISE (Status: 28. November 2012).

BUILDING EFFICIENTLY WITH THE SUN

ENERGY-EFFICIENT BUILDINGS

Buildings today are energy consumers, being responsible for around 40 % of the end energy consumption in Germany. Creating indoor comfort, providing lighting and using the building all lead to a demand – which varies in magnitude according to the building standard – for electricity and other forms of energy, most commonly fossil fuels. In future, buildings could become net energy suppliers, if renewable sources of energy are used locally and excess energy is fed into the electricity grid. In buildings with a very high energy standard and correspondingly low consumption, a positive balance can be achieved for the annual average. Buildings of this type are already operating today, but to date, they still have the status of pilot projects.

However, the European Parliament has drafted a law which requires that new public buildings after 2018 and all new buildings after 2020 will be required to meet a nearly zero-energy standard – in other words, they must demonstrate a nearly zero or even positive energy balance on average over the year. Regardless of how the standard is achieved for specific cases, the use of solar energy will play a central role. Solar thermal systems help to reduce the remaining energy demand significantly for domestic hot water and space heating, and also for cooling if required, and photovoltaic systems can not only contribute to meeting the electricity demand but also feed excess solar energy in the form of electricity into the grid. One major challenge for the future is to enable much greater integration of the solar systems into the building and the building envelope, without affecting structural requirements and the lifetime of building systems negatively. It is also important to develop concepts which minimise the negative impact on electricity grids. This topic is highly relevant, as the share of fluctuating energy from renewable sources such as the sun and wind in the electricity supply has already increased rapidly and will continue to grow. Work on developing appropriate concepts for operation management and control thus has a high priority, as does the development of new storage technology, which makes a larger proportion of local load management feasible. With our SmartEnergyLab, we can provide support by developing high-performance concepts and operation management strategies.

Energy retrofit of the existing building stock will play a central role in transforming the energy system. One way to reduce costs for energy-related renovation is to integrate building technology functions into the insulating layer. In addition to allowing pre-fabrication and the associated potential for cost saving, the amount of construction work needed inside the building is reduced. Here, we developed initial concepts to integrate both windows and ventilation systems with heat recovery into pre-fabricated insulation modules for existing buildings and successfully demonstrated their application.

At Fraunhofer ISE, buildings and their technical equipment represent a central field of work. Our comprehensive knowledge of solar energy conversion technology, on the one hand, and our long years of experience in R&D activities for energy-efficient buildings, on the other, allow us to develop optimal solutions for new buildings and energy retrofit. In the same way as we assist manufacturers in the development of new components and energy supply technology, we also support planners and architects in designing high-quality buildings. We address the topics on a broad scope, ranging from fundamental development, e.g. of materials or coating technology, to market introduction of components and systems. For implementation in building projects, we offer planning, consultancy and concept development on all issues concerning energy and user comfort. In doing so, we apply the most advanced simulation modules, which we continually develop further so that innovative new solutions can also be introduced in the design phase. Practical implementation of quality control plays an important role, which we achieve by accompanying and analysing demonstration buildings and urban districts, and also by carrying out comprehensive field tests and monitoring campaigns.

ENERGY-EFFICIENT BUILDINGS

Classic topics of our work on the building envelope are the use of daylight and solar shading. In addition, the integration of active components into the building envelope, including solar energy converters such as photovoltaic modules or solar thermal collectors, is demanded more and more frequently. The thermal storage capacity of building systems plays an important role in implementing energy-saving cooling concepts. Processes and systems based on phase-change materials for lightweight buildings continue to be significant here, as do thermally activated building systems.

Efficient conversion technology plays a central role in heating buildings. Both electric and gas-fuelled heat pumps form a basis for promising concepts, particularly for energy-efficient buildings which can be heated with low-temperature systems. Thermal solar energy can be used not only for heating of domestic hot water and solar-assisted space heating but also for air-conditioning in summer, an application which is particularly attractive for sunny regions with a high cooling demand. Architecturally appealing integration of photovoltaics into the building envelope is a central task to encourage widespread adoption and high acceptance.

Operation management is essential for optimal functioning of complete systems, consisting of the building envelope, HVAC technology and the users. New, model-based concepts for operation management are used to constantly monitor and evaluate, and if necessary modify, the performance of individual building components. Such measures, which are implemented at relatively low investment cost, can achieve significant savings in energy consumption and operating costs. Both the development and also the implementation of corresponding procedures for energy-efficient operation management and control thus represent important fields of our work.

The "Energy Dream Center" has been constructed by the City Council of Seoul as a centre for renewable energy. The zero-energy building with a floor area of 3500 m² is dedicated to publicising this topic with exhibitions and a broad range of information services. An interdisciplinary team led by Fraunhofer ISE designed the Energy Dream Center and accompanied its construction. The landmark project was officially opened in December 2012 (see page 26).

In collaboration with architects, professional planners and industrial companies, we develop concepts for the buildings of tomorrow. We follow an integrated planning approach, optimising concepts with respect to economic viability, energy efficiency and user comfort. Particularly in built-up areas, energy concepts which address not just individual buildings but whole urban districts are playing a growing role, specifically when grid-connected approaches are involved. We have extended the scope of our activities accordingly and have completed initial projects together with energy utilities and housing bodies. Our efforts to define the international boundary conditions for this work include our participation in programmes of the International Energy Agency IEA.

CONTACTS

Façades and windows	Tilmann Kuhn	Phone +49 761 4588-5297 tilmann.kuhn@ise.fraunhofer.de
Building concepts, analysis and operation	Sebastian Herkel	Phone +49 761 4588-5117 sebastian.herkel@ise.fraunhofer.de
Heat storage for heating and cooling	Dr Peter Schossig	Phone +49 761 4588-5130 peter.schossig@ise.fraunhofer.de
Energy-efficient and solar cooling	Dr Doreen Kalz	Phone +49 761 4588-5403 doreen.kalz@ise.fraunhofer.de
Energy supply systems for buildings	Sebastian Herkel	Phone +49 761 4588-5117 sebastian.herkel@ise.fraunhofer.de
Lighting technology	Dr Jan Wienold	Phone +49 761 4588-5133 jan.wienold@ise.fraunhofer.de
Building-integrated Photovoltaics	Tilmann Kuhn	Phone +49 761 4588-5297 tilmann.kuhn@ise.fraunhofer.de

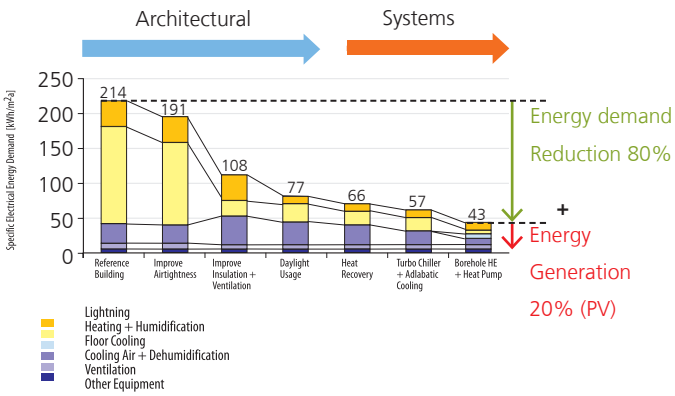
ENERGY DREAM CENTER – A ZERO-ENERGY BUILDING IN SEOUL

Increasing numbers of countries are defining ambitious goals for buildings concerning energy efficiency. Korea has also formulated targets that should be attained within the near future. The Energy Dream Center in Seoul is a showcase project for the implementation of modern technology and the application of regenerative energy. A zero-energy standard was targeted, which features a balanced budget of zero primary energy when averaged over a complete year. Renewable energy is used either directly in the building or in its immediate surroundings. A holistic planning and implementation approach and the most modern technological systems were applied in preparing this building.

Arnulf Dinkel, Sebastian Herkel, Jan Wienold, Hans-Martin Henning

1 *The Energy Dream Center in Seoul.*

2 *Detail of the building façade.*



3 *Contribution of individual measures toward meeting the zero-energy balance.*

The following conditions have to be fulfilled to achieve a zero energy balance for a building:

- minimisation of energy consumption with a high-quality building envelope
- optimisation and control of technical systems
- meeting the remaining energy demand by locally available, renewable energy sources

The city of Seoul commissioned Fraunhofer ISE to design the Energy Dream Center and to construct it with an interdisciplinary German and Korean team. We prepared the energy and technological system concepts and supervised all energy-relevant decisions and their implementation.
In order to achieve a zero-energy balance, different technical and architectural approaches were investigated. The favoured design allows optimal use of daylight and simultaneously provides good solar control. The energy consumption was calculated and optimised with detailed simulation models (thermal building performance, daylighting, thermal bridges). This was the basis for defining an optimal building envelope and dimensioning a ventilation system with two-stage heat recovery and adiabatic condensation cooling. The energy demand for heating and cooling was reduced by 70 % with respect to the Korean standard. The remaining demand for heating energy is met by heat pumps using the ground as a thermal reservoir. The borehole probes are used in summer for surface cooling. The remaining energy demand for cooling and dehumidification is met by pre-cooling the inlet air in combination with a highly efficient turbo-compression cooling system. All of the required primary energy is supplied by a PV system. Long-term monitoring is planned to check the energy concept and the building performance.

The project was financed by the Seoul Metropolitan Government.

1

NEW COMPONENTS FOR HEAT PUMPS AND COOLING SYSTEMS

Fraunhofer ISE has worked intensively on vapour compression processes for heating and cooling applications for more than ten years. In addition to extensive quality assurance of systems in practical operation, we have long-term and wide-ranging experience in developing new designs and components for the cooling circuit. In the development of new system approaches, we co-operate closely with national and international partners.

Simon Braungardt, Marek Miara, **Thore Oltersdorf**, Lena Schnabel, Peter Schossig, Christian Sonner, Hans-Martin Henning

Over the past years, we have intensively investigated the market situation, the research landscape, the state of the art and the patent situation concerning vapour compression systems in Germany, Europe and internationally. On this basis, we were able to identify topics which have become the focus of our R&D work. The overriding goal of our work is to minimise the consumption of resources by optimising system and materials efficiency. The latter aspect is closely related to reduction of volume and charge of refrigerant in components and piping, as well as the application of natural refrigerants. However, the reduction of refrigerant charge is a design approach which applies to all refrigerants and is not restricted to natural ones.

In the EU-funded "GreenHP" project, we are designing concepts for brazed, air-cooled evaporators. Up to now, the use of these heat exchangers was accompanied by considerable losses of exergy. These losses are caused by suboptimal distribution on both the air and the refrigerant sides. Our approach is based on transferring knowledge on fluid distribution processes from other application fields, e.g. single-phase flow in solar thermal systems, as has already been applied at Fraunhofer ISE for more than a decade with the boinic based FracTherm® concept. Together with several companies and research partners, we are now applying a slightly modified approach for two-phase fluid distribution before the evaporator in the "GreenHP" project.

1 *Container from the Mærsk company at the testing facility of Fraunhofer ISE.*

Co-operation with the A. P. Moeller Mærsk company and several Fraunhofer Institutes began in 2012 with the aim of improving refrigerated transport containers. The global leaders in container construction and container transport are united in this project, and Fraunhofer ISE co-ordinates the research on suitable cooling circuits. The main aim of the project is to achieve a significant reduction in life-cycle costs. Two aspects predominate: the relatively high system efficiency of refrigerated containers in comparison to competitors is to be retained, and long-term product conformity with anticipated demands for a reduction in greenhouse gas emissions from refrigerants should be ensured.

Innovative safety concepts round out our portfolio. In principle, these are suitable for all refrigerants, but apply particularly to refrigerants belonging to the A2/A2L/A3 safety categories according to ISO 5149. This generic approach has already been implemented together with partners for mobile refrigeration systems.

The "GreenHP" project is financially supported by the European Union.

HEAT PUMPS IN THE ELECTRICITY GRID OF THE FUTURE

The depletion of fossil-fuel resources, the targeted reduction of greenhouse gas emission, the increasing proportion of renewable energy in the electricity mix and the departure from nuclear energy are fundamentally changing the established energy supply structure in Germany. For electricity generation, the Federal government is primarily relying on the sun, the wind and biomass as the energy sources. As a result, a major challenge is posed by the increasing temporal discrepancy between supply and demand for electricity. The fluctuating suppliers (wind generators and photovoltaics) are governed only by the availability of wind and sun, so that the demand for energy storage is increasing continually. One solution is presented by converting electricity and storing it as heat in heating systems based on heat pumps.

Danny Günther, Sebastian Helmling, Thomas Kramer, Robert Langner, **Marek Miara**, Jeannette Wapler, Hans-Martin Henning

The conventional application of heat pump technology in suitable sectors already brings significant advantages. When the systems are correctly designed and installed, the efficiency values achieved for heat pumps offer ecological and primary-energy advantages compared to fossil-fuelled, condensing boiler systems. These are only the most significant conclusions drawn from four field tests which have been conducted to date by Fraunhofer ISE on around 300 systems. The preliminary results from the current project "WP Monitor" additionally indicate continuous improvement in the efficiency of heat pump systems over the past few years.

1 *Heating systems based on heat pumps as instruments to shift loads in the electricity grid.*

Heating systems based on heat pumps are well suited to load shifting due to the options for storing the heat generated from electricity and ambient heat either in hot-water tanks or in the building mass. This means that the time-dependent profiles for supply and demand are decoupled – at least partially. Finally, optimised operation times contribute to a load profile in the electricity grid which is better synchronised to electricity generation. Today, already the installed heat pumps could accept approximately the same amount of electricity as the total number of pumped-storage power plants. The contribution which heat pumps can make to load shifting is closely related to their dimensioning, their controls and parametrisation, as well as the storage capacity in the heating system and the building. In recent studies, Fraunhofer ISE has already proven that real, installed systems are usually generously dimensioned, so that the operating times can be shifted sufficiently also during the core heating period. Further-reaching studies are dedicated to the analysis and optimisation of these potentials as well as investigation of the effects of electricity-led operating modes on the efficiency of heat pump systems.

www.wp-monitor.ise.fraunhofer.de

CASCADE – ENERGY MANAGEMENT FOR AIRPORTS ACCORDING TO ISO 50001

Airports are important hubs in transport networks and represent publicly accessible areas with high energy intensity. In the "CASCADE" project, the technical part of an energy management system based on ISO 50001, with integrated methods for fault detection and operation optimisation of building technology systems, is demonstrated practically in Rome and Milan airports.

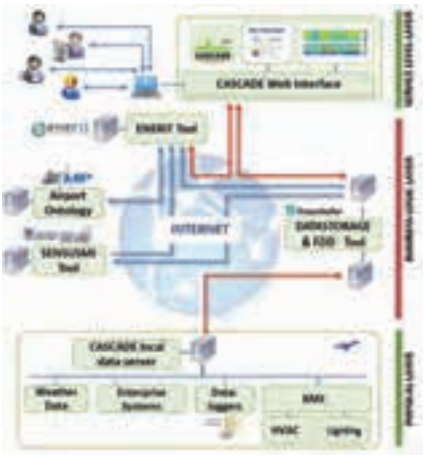
Sebastian Burhenne, Sebastian Herkel, Thorsten Müller, Felix Ohr, **Nicolas Réhault**, Tim Rist, Sebastian Zehnle, Hans-Martin Henning

The selected demonstration airports, Rome-Fiumicino and Milan-Malpensa, are among the largest European airports, with annual passenger turnovers of 36.3 million and 18.7 million, respectively. The annual electricity consumption is around 175 GWh in Fiumicino and around 140 GWh in Malpensa. More than 70 % of the electricity is consumed for lighting, air-conditioning and heating.

The IT solution (Fig. 3) which was developed as part of the "CASCADE" project is intended to support the airport operators in identifying faulty system operating conditions which cause higher energy consumption. Algorithms for automated fault identification and diagnosis are to be applied here, which search for operating and system faults in building technology plants. For initial test implementation, certain specific subsystems have been selected to develop the innovative energy management tools and carry out tests. Extension of the knowledge gained and successfully tested methods to further building technology systems can then follow. The goal

1 *Check-in area of Terminal 1 of the Fiumicino Airport in Rome. Comfortable indoor conditions are maintained by operating large air-conditioning units. The energy efficiency of their operation can be optimised.*

2 *Eastern aspect of the Malpensa Airport in Milan.*

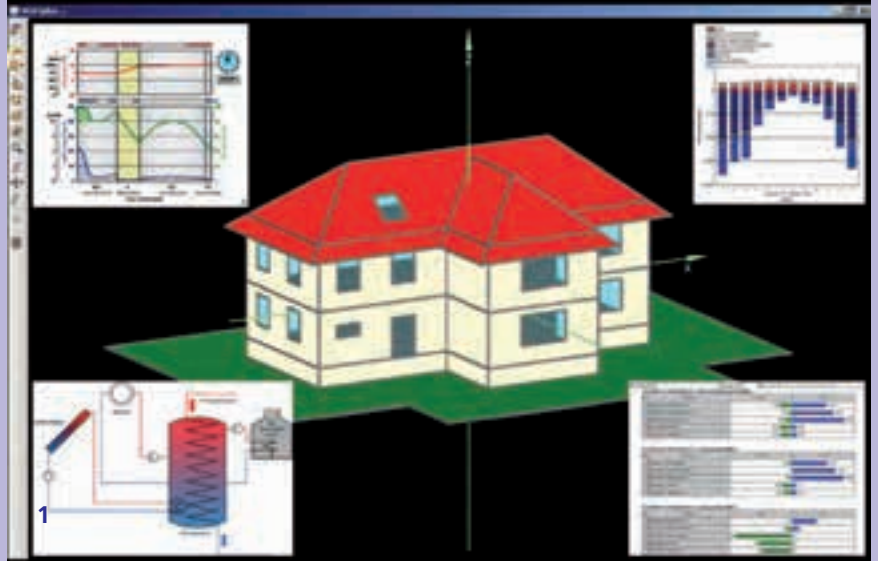


3 *IT structure of the CASCADE solution.*

is to save 20 % primary energy and 20 % CO_2 emissions within the selected subsystems. The investments made by the operators should be amortised in three years at most. The results of the project are transferable to other airports and large building complexes with similar consumption profiles.

The project is funded by the European Commission within the Seventh Framework Programme (FP7).

www.cascade-eu.org



WUFI PLUS THERM – BUILDING AND SYSTEM SIMULATION FOR PRACTICAL APPLICATION

Planning buildings with a low energy demand increasingly requires the application of thermal building simulation programs. These allow the dynamic interaction between the building, building technology and users to be investigated holistically under realistic conditions. This is particularly necessary for planning zero-energy and plus-energy buildings. The "WUFI Plus Therm" simulation program was developed on the basis of the "WUFI" program core. In the project presented here, "WUFI Plus Therm" is being further developed and extended with models to simulate building technology systems. This is being done in co-operation with the Fraunhofer Institute for Building Physics IBP, with Fraunhofer ISE being responsible for the system technology models.

Sebastian Burhenne, Sebastian Herkel, Tobias Klimmt, Felix Ohr, Hans-Martin Henning

"WUFI Plus Therm" is a program to calculate thermal building performance, taking account of meteorological data, internal thermal loads, temperature setpoints, ventilation strategies and systems technology. The building and system models can be defined with the aid of graphical user interfaces. Simulation results, e.g. temperature profiles or energy demand, are presented as graphs and the user is supported in interpreting the results.

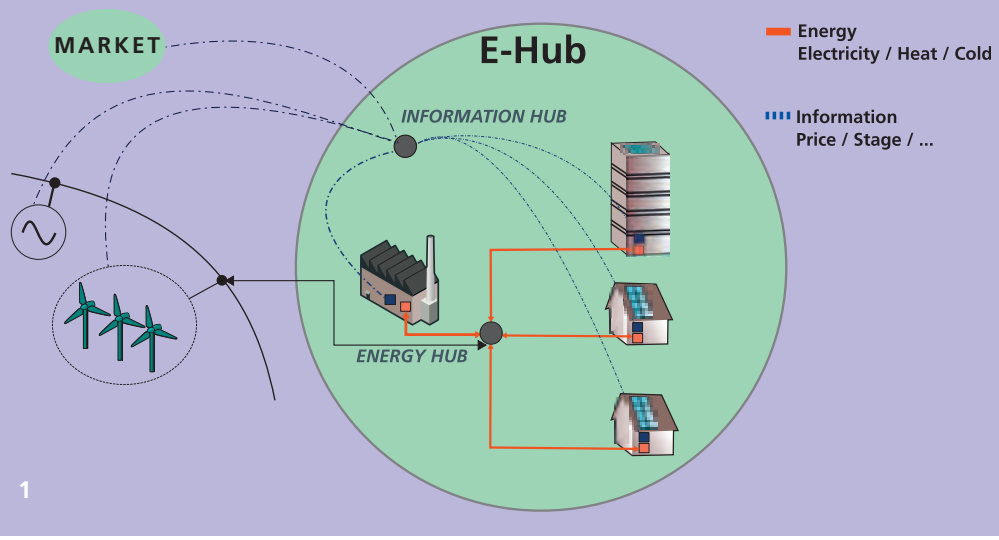
Models are developed and implemented for those variants of system technology which are generally commercially available.

1 *Example of a simulation with "WUFI Plus Therm" and options for presenting results. The system configuration shown lower left consists of a thermal solar collector, a stratified storage tank, a heating circuit and a gas-fuelled, condensing boiler.*

These include gas-fuelled, condensing boilers, solar thermal collectors, heat pumps, stratified storage tanks, radiators, thermally activated building component systems, ventilation and photovoltaic systems. All models of systems technology can be parametrised with the usual manufacturer's specifications, which is important for practical application. As commercially available building technology is continually being further developed, particular care was taken to ensure that the models for systems technology can be extended. This was achieved by applying models which were prepared using the "Modelica" modelling language. These models are constantly being developed further in diverse projects at Fraunhofer ISE. This ensures that recent research results can be introduced quickly into the "WUFI Plus Therm" building simulation program.

The project is supported by the German Federal Ministry of Economics and Technology (BMWi). Further information and the thermal version of the program can be downloaded free of charge from the Internet. A fee is charged for the hygrothermal version.

www.enob.info/de/software-und-tools



1

ENERGY MANAGEMENT OF BUILDINGS AND URBAN DISTRICTS

Interaction between the energy management systems of individual buildings within an urban district and higher-level grids supports the integration of distributed sources of renewable energy. Compensation of surpluses and shortfalls in the supply of renewable energy contributes to increased system stability. Within a European research project, connections and relations between the electricity and heat market will be identified at the district level. Control strategies for energy management within a district will be developed, taking different criteria for thermal and electric components into account.

Sebastian Herkel, Florian Kagerer, **Sattaya Narmsara**, Hans-Martin Henning

The fluctuating energy supply from regenerative sources does not always coincide with the energy demand. In addition to the storage of renewable energy, intelligent control and distribution of the available energy to different consumer groups present a promising option to achieve greater simultaneity. The generation, distribution and consumption of energy can be managed efficiently by taking the interaction between the components of individual buildings and the buildings within a district into account. Energy management at the district level has received increasing attention, particularly when aspects of the energy economy need to be considered. The "Weingarten 2020" project provided comprehensive results regarding structural optimisation, which serve as a basis for preparing strategies to optimise operation.

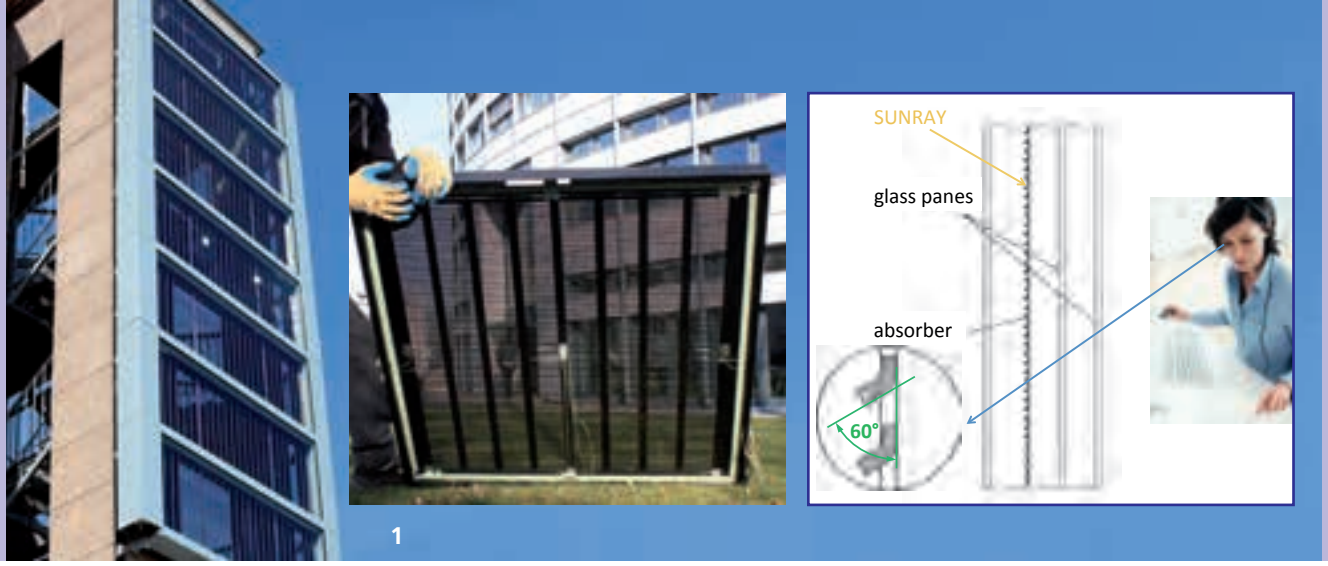
1 *Simplified schematic diagram of the concept for the "E-Hub" project. The central element of the project is the development of algorithms for load and generation management of heat and electricity for distributed systems, taking control parameters from the energy economy into account.*

Within the EU-funded "E-Hub" project, we are co-operating with European partners to prepare efficient algorithms for the interaction between the components of energy systems at the building and district levels, which meet economic and ecological demands. To evaluate operation conditions and operation commands derived from them, we apply multi-criteria analysis, drawing on results from the "Weingarten 2020" project. In the developed concept, energy flows within a district are identified and connected to form hubs. The exchange of energy and information at these hubs allows the energy demand and the availability of different loads and generators to be managed efficiently.

Control algorithms based on multi-agents help in making the right decision. The thermodynamic states of individual components and boundary conditions from the energy economy are included with the goal of enabling maximal integration and usage of renewable energy.

The aim of our work is to develop methods and algorithms which can be used in future by energy utilities or grid operators for energy management at the district level.

The project is supported by the European Commission.



1

"COST-EFFECTIVE" – NEW SOLAR-THERMAL AND BIPV FAÇADE COMPONENTS

The goal of the EU-funded "Cost-Effective" project was to gain access to the façades of existing high-rise buildings for thermal or photovoltaic conversion of solar energy. Within this project, which was co-ordinated by Fraunhofer ISE, four new solar façade components and a ventilation system with distributed heat recovery were developed.

Sebastian Herkel, Michael Hermann, Korbinian Kramer, **Tilmann E. Kuhn**, Paolo Di Lauro, Christoph Maurer, Jörn Ruschenburg, Christoph Thoma, Helen Rose Wilson, Hans-Martin Henning

1 *Partly transparent thermal façade collector, pilot installation in Slovenia, integration into a closed cavity façade (left). Integration into a hermetically sealed insulating glass unit (centre). The collector blocks rays from the high summer sun, reducing the cooling demand, and yet still allows a view to the outside (operating principle, right).*

2 *Evacuated tubular air-heating collectors in the pilot building in Slovenia.*

Partly transparent, solar thermal façade collectors

Within this project, two different concepts were developed for façade integration of partly transparent, flat solar absorbers. In one, the absorbers were integrated into hermetically sealed, triple-glazed insulating glass units (Fig. 1); in the other, they were incorporated into the "closed cavity façade" (CCF) of a project partner. The CCF is not completely airtight, but is maintained at overpressure by a constant flow of clean, dry air, so that dirt and moisture from outside cannot enter.

The collectors are suitable for use in solar heating and solar (sorptive) dehumidification. These applications each require collector operating temperatures exceeding 55 °C, which can well be achieved in the façade. In some cases, the collectors can also be used for solar cooling (demanding operating temperatures greater than 70 °C). In addition, the multi-functional collectors offer solar control and glare protection, and allow visual contact from inside to outside. They are designed for application in the spandrel region, where the primary outward viewing direction of the building occupants is downward. A further advantage of the spandrel region is that it is hardly relevant for the room daylighting, so that the lower light transmittance for high solar altitude has little to no effect. It is important to note that the new, active façade systems have a g value which can vary by a factor of two, depending on the temperature of the solar collector (Fig. 3). To take account of this feature and allow inclusion of these components during the building planning phase, not only real components but also models for the TRNSYS building simulation program were developed and validated with calorimetric measurements.

2

Evacuated tubular air-heating collectors

The principle of this air-heating collector is that air as the heat transfer fluid flows through an inner absorber tube, which has a highly absorptive and low-emissive coating. The absorber tube is located inside an insulating outer tube. The space between the inner and outer tubes is either evacuated or filled with a rare gas for thermal insulation. Two tube designs were investigated in the project, both the conventional "Sydney" tubes, in which the air enters and leaves at the same end through a split ring, and also tubes in which the air flows in at one end and flows out at the other. These tubes can be connected to form long, continuous air-heating collectors. The second type was installed in a pilot plant in Slovenia (Fig. 2).

Plaster-integrated, unglazed collector connected to a multi-source heat pump

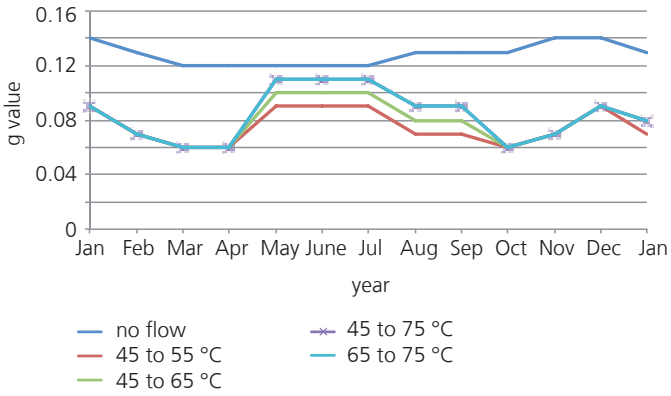
In this case, mats of capillary tubes integrated into plaster rendering form an unglazed collector which is not evident from outside, and which is connected to a heat pump. To allow the heat pump to be operated at times when the façade could freeze, the heat pump was additionally connected to an air inlet as an ambient heat source. The aim is to operate the heat pump whenever the sun shines on the façade. For this reason, and because the direct heating demand is low due to the passive gains, a thermal storage unit was also added to the design.

Angle-selective, transparent BIPV glazing unit

In addition to the three thermal façade collectors, an angle-selective transparent BIPV glazing unit was developed. This glazing unit is also designed for installation in the spandrel region and offers solar control and view in addition to electricity generation.

The work was supported by the European Union within the "Cost-Effective" project. We thank the Slovenian National Building and Civil Engineering Institute in Ljubljana, Slovenia, for the possibility to install the new systems in their building.

www.cost-effective-renewables.eu



3 *Average monthly g values for a transparent façade collector based on a triple-glazed unit. The red line shows the effective monthly values for the stagnation case (maximum g value). The other lines show the g value for different operating modes with different absorber temperatures.*

1

SOLAR COOLING – NEW DEVELOPMENTS AND SYSTEMS ANALYSIS

Solar thermal energy is being used increasingly to air-condition buildings, particularly in sunny countries with a high cooling load. In recent years, more and more processes and systems have been developed to make solar-thermally driven cooling feasible for commercial and industrial processes. The topic of solar cooling has a long tradition at Fraunhofer ISE. In many research projects of the last year, we were able to advance the development of new processes in co-operation with industrial partners, carry out cross-sectional analyses of installed systems and comprehensively analyse the perspectives for solar cooling in a fundamental project.

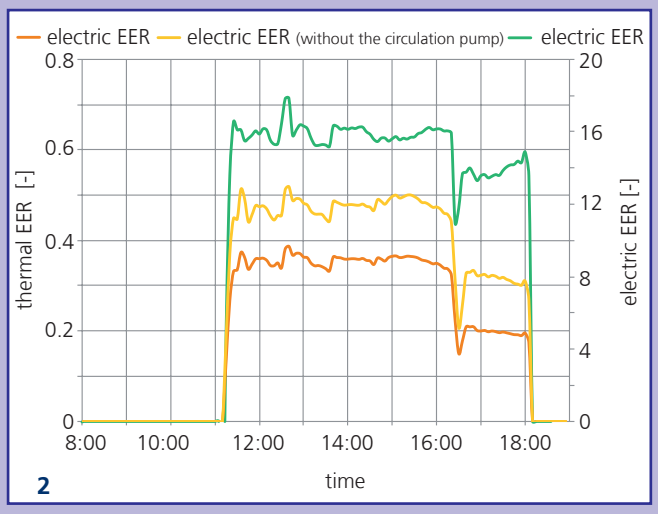
Constanze Bongs, Jochen Döll, Gerrit Füldner, Florian Mehling, Alexander Morgenstern, Björn Nienborg, Lena Schnabel, Peter Schossig, Christine Weber, Edo Wiemken,
Hans-Martin Henning

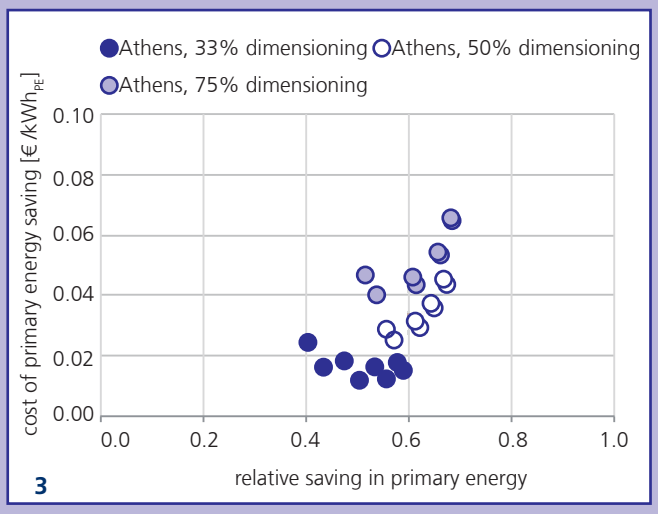
The goal of the "AgroKühl" project is to develop a solar-thermally operated, refrigerated warehouse as an integrated complete concept, including the storage and supply of cooling power based on renewable energy. A pilot plant was constructed near Freiburg on the grounds of the Kramer company, one of four project partners of Fraunhofer ISE, in order to gain experience on the interaction between the refrigerated rooms and the solar system and its dependence on the operation mode for the refrigerated rooms. The installed system consists of a Fresnel collector with an area of 88 m^2, which generates process heat at a temperature of 180 °C, and a single-effect water-ammonia absorption chiller with an integrated dry cooler. With this configuration, temperatures well below 0 °C can be reached, allowing intermediate storage in two conventional ice storage units. The newly constructed refrigerated warehouse has a volume of app. 100 m^3 as well as an entrance room. The pilot plant has been operating since July 2012. The experience gained with the pilot plant will be applied to develop a complete system with a minimal energy demand due to energy-conserving and energy-efficient measures coupled with a large proportion of renewably generated cooling power. At the same time, the quality of the perishable goods which require cooling is to be maintained at all times, despite the fluctuating production of cooling power.

A similar plant was also constructed in Freiburg and measured as part of the EU-funded "SOLERA" project. The current measurement results document its great reliability and stable operation.

Together with the Vaillant company, we are developing a novel system for solar cooling, in which the sorption modules are integrated into the solar collector. This approach allows higher desorption temperatures and temporal decoupling between the supply of solar energy and provision of cooling power due to its batch operation. This means that the cooler night temperatures can be used for heat rejection. Hygroscopic salts and water are being studied as the working pair, which allow high storage density to be achieved. A cooling power range from 3 to 10 kW is planned. Within this project, Fraunhofer ISE is responsible for experimental characterisation of the dynamic performance of the sorption modules and sorption collectors, as well as simulation-based modelling and optimisation of components and the complete system using TRNSYS. The "KollSorp" project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

Around the world, many hundreds of solar-driven cooling systems are operating, representing a wide range of cooling power from a few kW to the MW range. Nevertheless, the





1 *In the "AgroKühl" project, solar thermal collectors are used for the first time in the world to cool food or medicaments in refrigerated warehouses.*

components of many systems – solar system, chiller, heat rejection unit, controls – are still not optimally adapted to each other and there is a lack of experience concerning system planning and construction. Therefore, in the "SolCoolSys" project, we have co-operated with the Solvis and Sortech companies to develop system concepts for the low power range and have subjected these to a field test. Five systems have now been installed in four countries and equipped with detailed measurement technology. Next year they are to be used to optimise the control strategies and in particular to test heat rejection concepts.

A key to the success of solar cooling systems is their practicability in everyday application. Within the framework of the "Solarthermie2000plus" programme of the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU), we have supported the Ministry in selecting the demonstration projects to be funded, and have carried out a cross-sectional analysis of solar cooling systems. In this project, we analysed five systems in detail and extracted important information to improve the system efficiency and operation.

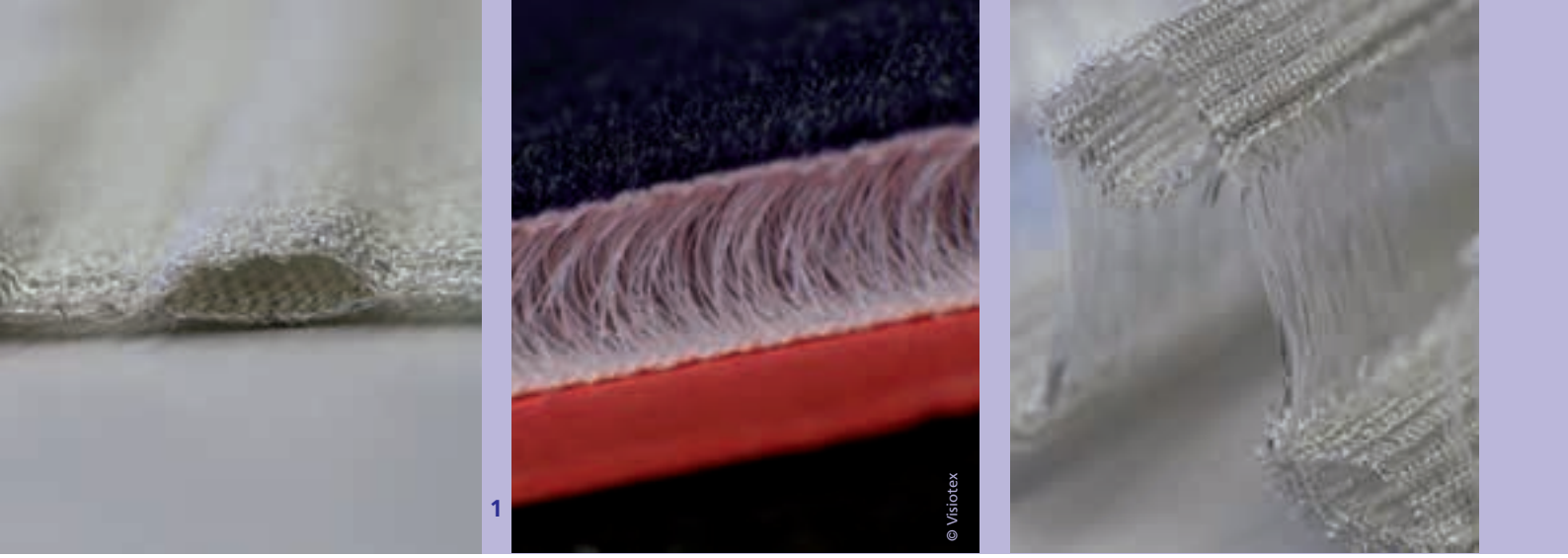
In the past ten to fifteen years, considerable progress has been made in solar cooling systems. Due to the steep price drop for photovoltaic modules, today not only solar-thermally driven processes but also photovoltaically powered processes present an economically interesting option. Together with ZAE Bayern and ILK Dresden, we are conducting an extensive study (EvaSolK) on the medium to long-term perspectives for solar cooling which is financed by the German Federal Ministry for the Environment, Nature Conservation and Reactor

2 *Measurement results from the solar cooling system in the "SOLERA" project. The energy efficiency ratio (EER) is the ratio of useful energy to consumed energy. The left abscissa shows the thermal EER and the right abscissa the electric EER. Average daily profile for the 23rd July 2012 as an example.*

3 *Example for the effect of dimensioning on the solar-thermally driven cooling supply for a hotel in Athens. An electric-powered compression chiller is available for back-up cooling. If the rated power of the solar-thermal cooling system is reduced from 75 % to 33 % of the maximum building cooling load, the cost of primary energy saving already closely approaches that for a comparable conventional system (cost of primary energy saving > 0: additional costs compared to reference). Additional cost reduction of the total investment for the solar-thermal and cooling systems by 10 % already results in economic comparability.*

Safety (BMU). Both solar-thermal and photovoltaic variants are being investigated with regard to their energy-related performance and economic viability by a large number of simulations and parameter studies based on them. The study is focussing on different application areas from hotels through office buildings to residential buildings, and different climatic conditions ranging from continental through Mediterranean to hot and sunny.

With today's cost structure, solar cooling systems usually cost more than a comparable conventional system. However, in applications with single-effect, thermally driven cooling technology, it has become evident that sites with long operating times for the cooling system and an additional high heat demand (e.g. for domestic hot water in hotels) are favourable for solar cooling applications. If, in addition, the thermally driven part of the cooling supply is not dimensioned for peak loads, economic viability can already be achieved in specific cases. When a package of measures is applied, consisting of increased efficiency, moderate cost reduction, careful system design and a high utilisation factor of the collector array also for other heating applications, solar cooling is economically competitive at hot locations.



EFFICIENT HEAT TRANSFER WITH METALLIC TEXTILE STRUCTURES

In many applications, efficient heat transfer plays a key role for increasing energy efficiency. This is equally true for industrial applications and heating and cooling technology. The usual approaches to improve heat-transfer properties are optimised configurations, the use of innovative materials or the design of optimised flow patterns. Another approach is to transfer processes and methods from other disciplines such as textile technology, as presented here.

1 *The photos show structural manufacturing options to create flow pattern structures by the combination of felting and knitting processes. The centre photo shows an enlargement of a textile spacer structure, which can serve as a turbulence structure or provide a larger surface area for a coating. To the right and the left are sample channel structures, which have already been made of fine metal wire and which were investigated and evaluated within the project.*

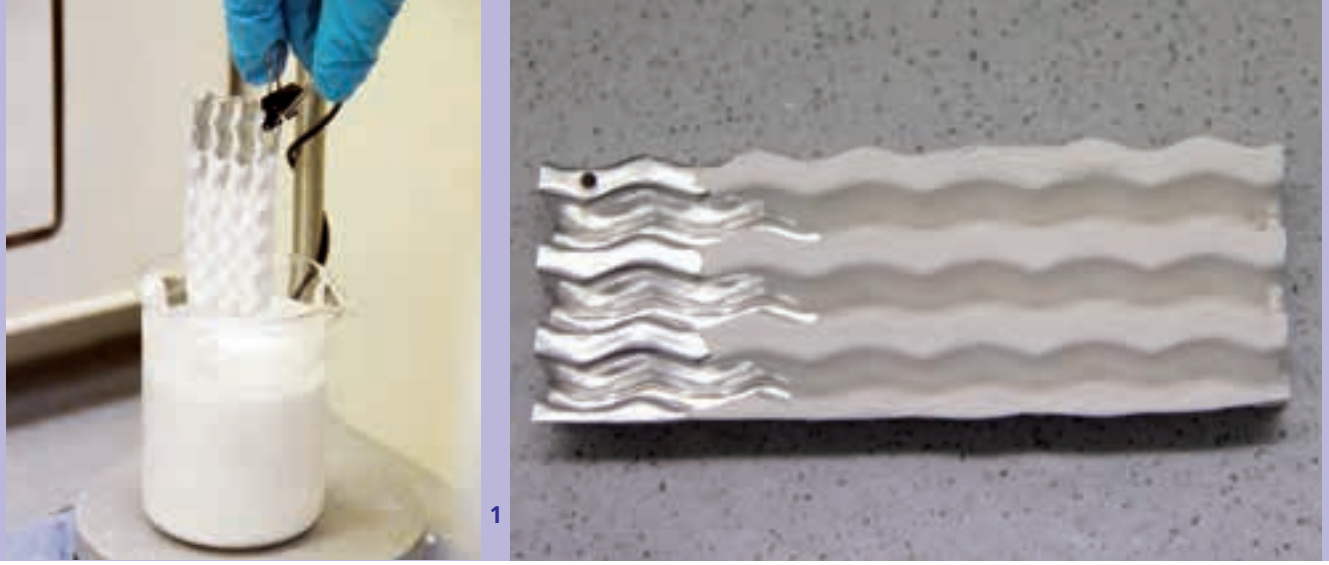
Eric Laurenz, **Lena Schnabel**, Ursula Wittstadt,
Hans-Martin Henning

The "EffiMet" project focuses on the application of innovative textile manufacturing processes to create highly efficient heat-transfer structures. The research work aims to further develop textile manufacturing technology for metallic structures. It draws on innovations made in recent years, which have created textile-based products in great geometric diversity.

Textile manufacturing processes, with their high degree of flexibility concerning procedures and materials, allow the structure design to be optimised with regard to the volume-specific surface area, thermal conductivity and pressure loss. Suitable structures are identified on the basis of simulations; the achieved properties are measured and tested on samples. The project specifically addresses heat-transfer applications which require a large specific or structured surface and morphology that can be flexibly dimensioned. These include air/water heat exchangers, evaporators and condensers. We have already succeeded in adapting the textile manufacturing technology such that structures suitable for heat transfer can be produced from fine metal wires. Galvanic, chemical and suspension-based coating processes are being studied and further developed to modify and stabilise the structures, as well as to seal the channel walls.

The joint project, which was initiated and is co-ordinated by Fraunhofer ISE, involves the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Dresden, as well as Visiotex GmbH as a textile manufacturer and Hattler & Sohn as a galvanic coater.

The project is funded by the German Federal Ministry of Education and Research (BMBF) in its "KMU-innovativ" programme to support small and medium-sized enterprises.



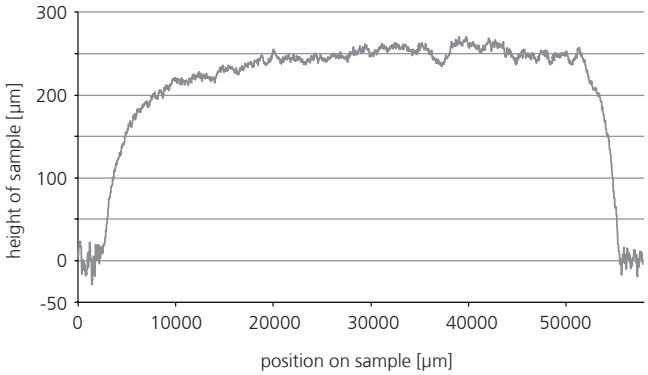
1

INDIRECT SORPTIVE COATINGS FOR HEAT EXCHANGER STRUCTURES

There is great potential for applying heat exchangers with sorptive coatings in heating and cooling technology. In all situations where heat is used as the driving energy in heat pumps or cooling processes, optimisation of the heat and mass transport offers great potential for increasing the efficiency significantly. Particularly for sorption applications, e.g. the adsorption of water vapour on the inner surfaces of porous materials, good access to these surfaces must be guaranteed for the water vapour on the one hand, and the resulting heat must be quickly transported away, on the other. At Fraunhofer ISE, we have developed promising coating processes to deposit various sorption materials onto heat exchanger structures.

Stefan Henninger, Harry Kummer, Peter Schossig, Hans-Martin Henning

1 *Indirect coating of a three-dimensional substrate structure.*



2 *Coating thickness characterisation on a flat, sheet-metal sample, with a maximum coating thickness of 250 µm.*

The demands on mass and heat transport have been raised by the successful synthesis of new sorption materials with greatly increased adsorption capacity, e.g. compounds from the class of metal-organic frameworks (MOF). With a view to the achievable power density for the complete process, it is essential to combine good thermal coupling of the sorption materials to the substrate structure with very good access to the adsorption centres.

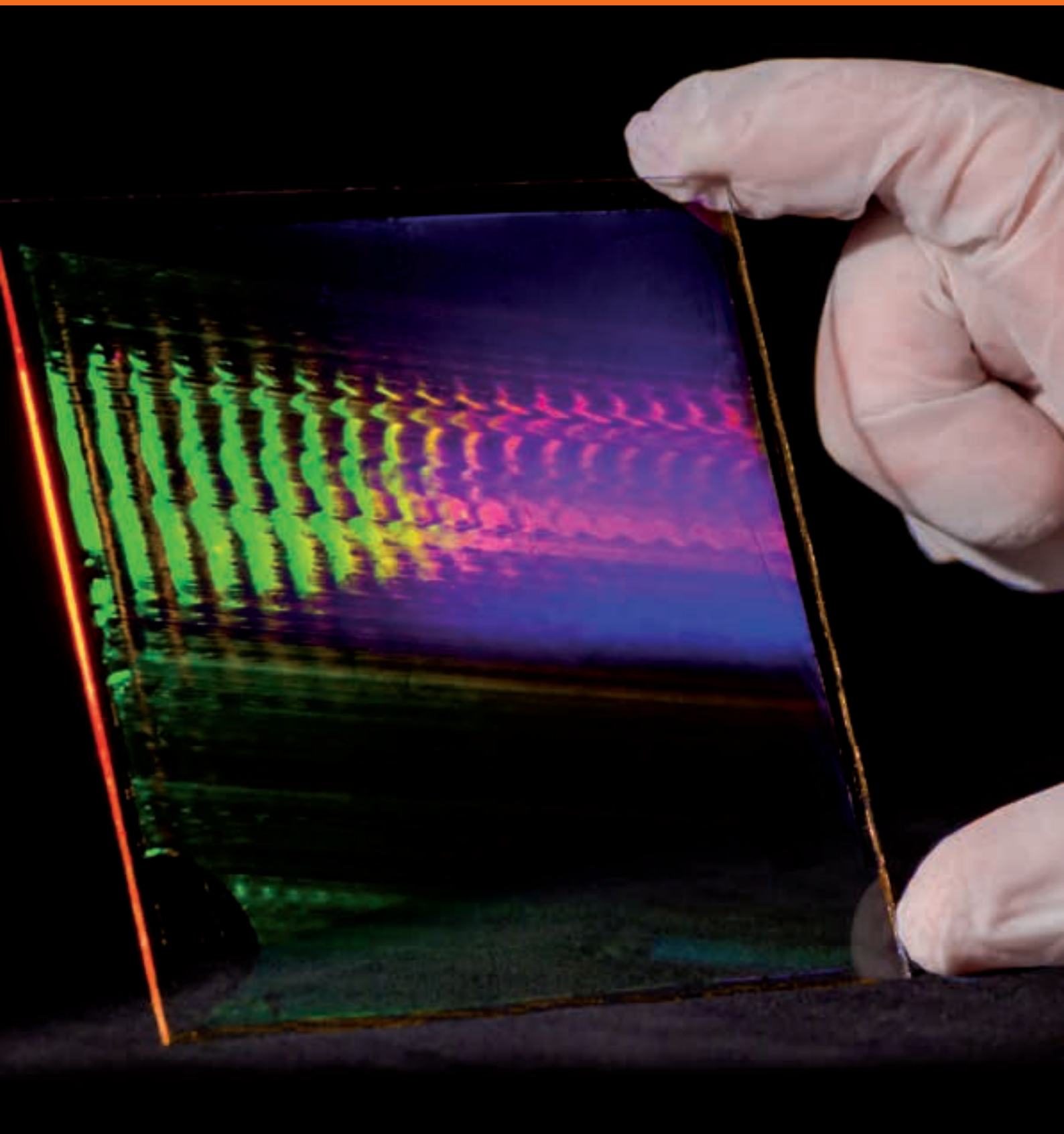
Thus, we have intensively investigated the coating of diverse substrate structures made of various materials such as metals and ceramics. We succeeded in developing new coating procedures and applying for patents.

Coating the entire surface of structures with high thermal conductivity (e.g. metals) presents an attractive option for optimisation, combined with good adaptation to industrial manufacturing processes (e.g. dip-coating in baths). Typical applications include thermally driven heat pumps or chillers, but also dehumidification, exhaust gas treatment or catalytic processes.

In indirect coating processes, the sorption material is deposited onto the substrate structure with the help of a binder. In addition to varying the proportion of binder, the rheological properties can be adapted for the dip-coating process by the use of additives. Three-dimensional substrate structures with dimensions up to 10 cm x 10 cm have already been coated successfully.

The work on coating development was recognised in 2012 with the award of the 2nd Hugo Geiger Prize of the Fraunhofer-Gesellschaft. The project is supported by the German Federal Ministry of Economics and Technology (BMWi).

BETTER WITH GOOD OPTICS



APPLIED OPTICS AND FUNCTIONAL SURFACES

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

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

The interdisciplinary topic "Applied Optics and Functional Surfaces" is the basis for several market sectors of solar technology: windows and façades, solar thermal collectors, concentrator systems for photovoltaics and solar-thermal collectors. Our expertise is also appreciated by clients who do not come from the solar sector. For example, we provide support for lighting and display technology.

Effective control of the light and solar energy fluxes through the façade is very important for energy-efficient buildings with large glazed areas. Switchable coatings on window panes allow the window transmittance to be changed over a wide range. As non-mechanical solar-shading systems, they offer advantages with regard to viewing quality and vulnerability to wind damage, for example. Coatings to reduce reflection or soiling increase the transmittance.

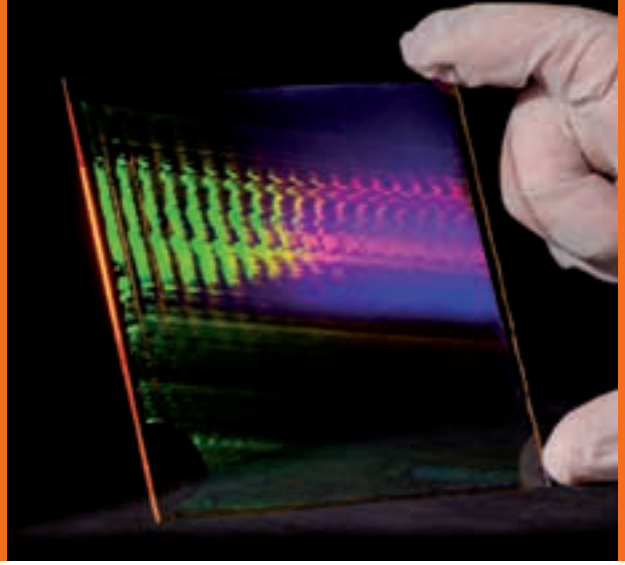
Glazing units with very good thermally insulating properties can be achieved with highly transparent low-emissivity coatings and inert gas fillings, but also with vacuum or transparent insulating materials. Stable functional coatings can also be applied to the outer surface of glazing units, e.g. to prevent condensation or reduce dust accumulation or soiling. Transparent, electrically conductive coatings are required as electric contacts for thin-film photovoltaics and organic solar cells.

Microstructured surfaces form the basis for solar-control systems which reflect undesired direct solar radiation but still transmit diffuse daylight. Photonic gratings and light-trapping structures increase the efficiency of organic and silicon solar cells. Plasmonic structures also allow novel concepts such as up-conversion of photons to be implemented. In photovoltaic concentrator modules, solar radiation is concentrated onto tiny high-performance solar cells. We optimise concentrator optics with regard to its efficiency and costs.

The combination of micro-optical know how and interference lithography over large areas has made a sector interesting to Fraunhofer ISE outside of solar technology, namely display technology. Here, we are working on micro-structured polymer films which improve the brightness and contrast of displays. Light redirection and light scattering based on both imaging and non-imaging optics are central topics in lighting technology. Drawing on our work on light scattering and light redirection, we offer our expertise in optical materials and surface properties also for optical design in artificial lighting technology.

Over the past years, we have continually extended our modelling capacity. It encompasses fundamental physical models such as effective-medium theory, rigorous and scalar diffraction theory, scattering theory, thin-film methods,

APPLIED OPTICS AND FUNCTIONAL SURFACES



geometric and non-imaging optics, as well as planning tools, e.g. for lamp design. This means that we can respond quickly and efficiently to clients' enquiries by determining the feasibility of a desired optical component. Vacuum coating and micro-structuring processes are available to us as production methods. Our characterisation methods not only include standard procedures but also use special equipment, e.g. to determine the accuracy of reflector forms with scanning fringe reflectometry or quantify the degree of reflector soiling. Whenever needed, we extend the palette of services by close co-operation with recognised research institutions within and outside the Fraunhofer-Gesellschaft.

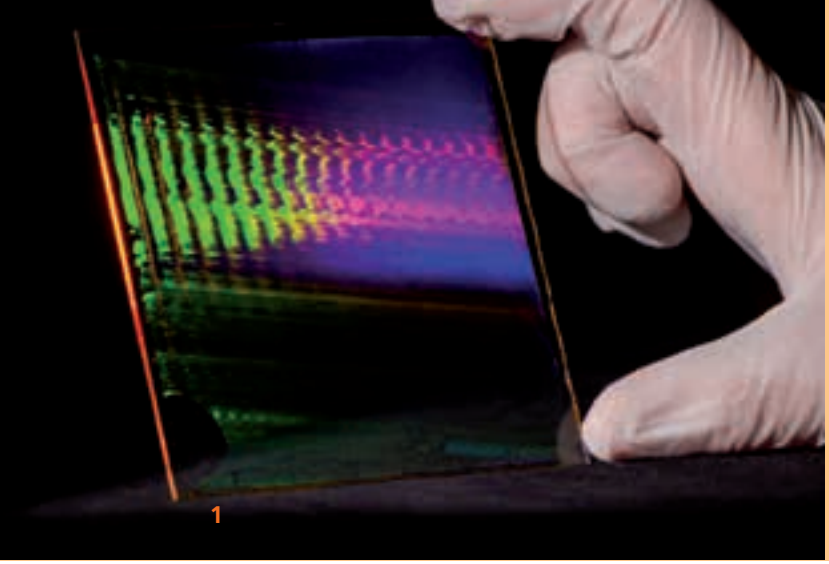
Special facilities:

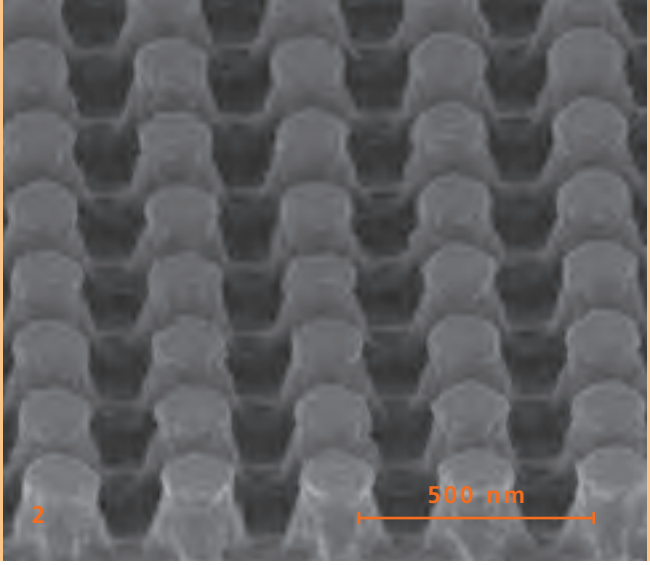
- vacuum deposition system for quasi-industrial production of complex coating systems over large areas (150 x 400 cm^2)
- interference-lithography equipment for homogeneous production of microstructures and nanostructures over areas of up to 120 x 120 cm^2
- optical measurement technology: spectrometry, goniometry, light-scattering measurements, refractometry, luminance measurements with imaging methods, fringe reflectometry, special measurement facilities for concentrating optics, quality control for production
- surface characterisation: optical profilometry, scanning electron microscopy, atomic force microscopy, Auger electron spectroscopy

Glass substrate with a photoresist coating structured by nano-imprint lithography (NIL). In this NIL process, a structure is embossed with a silicone stamp in a photoresist, which is then cured by UV radiation. The photoresist subsequently serves as the basis for producing metallic nanostructures by a lift-off process (see page 42). Metallic nanostructures, with their spectrally selective properties, are being investigated with regard to enhanced light absorption in solar cells.

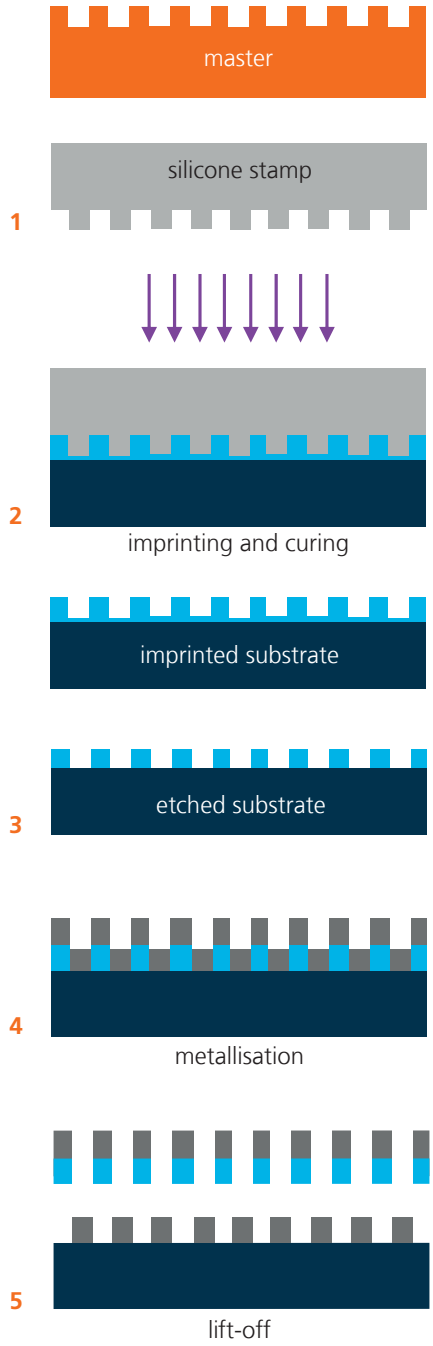
CONTACTS

Coating – technology and systems	Wolfgang Graf	Phone +49 761 4588-5946 wolfgang.graf@ise.fraunhofer.de
Microstructured surfaces	Dr Benedikt Bläsi	Phone +49 761 4588-5995 benedikt.blaesi@ise.fraunhofer.de
Façades and windows	Tilmann Kuhn	Phone +49 761 4588-5297 tilmann.kuhn@ise.fraunhofer.de
Lighting technology	Dr Jan Wienold	Phone +49 761 4588-5133 jan.wienold@ise.fraunhofer.de
Concentrator optics	Dr Peter Nitz	Phone +49 761 4588-5410 peter.nitz@ise.fraunhofer.de





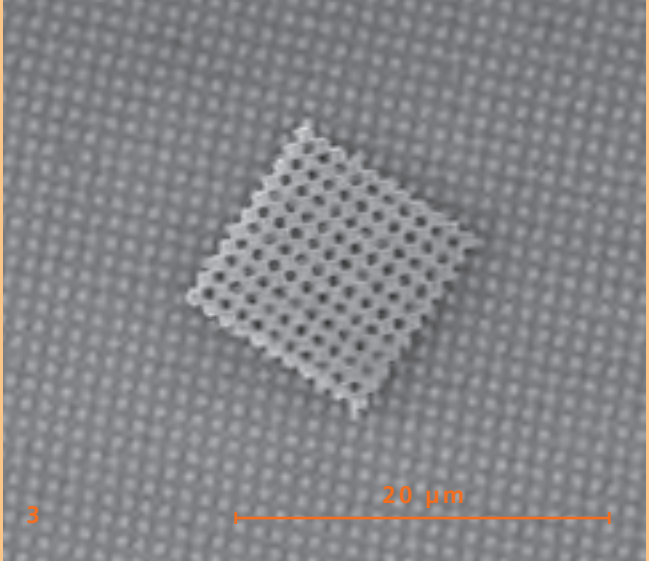
ORDERED METALLIC NANOPARTICLES FOR PLASMONIC EFFECTS

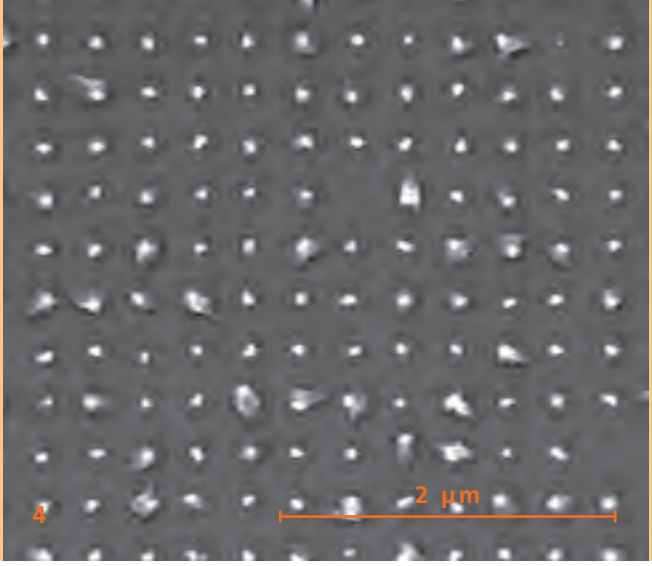


Metallic nanoparticles have attracted great scientific attention for a number of years. The spectrally selective, light-scattering and diffracting properties of these particles are based on resonance phenomena. Due to this selectivity, they can be used e.g. for photon management in solar cells. In weakly absorbing spectral regions, scattering can be applied deliberately to lengthen the light path within the cell and thus increase its absorption. Local field amplification due to plasmonic light-electron interactions can be used to support non-linear effects (e.g. upconversion). One challenge is the production of ordered structures over large areas. We have established a processing chain based on interference lithography, nano-imprint lithography and lift-off, and achieved promising results with it.

Benedikt Bläsi, Hubert Hauser, **Sabrina Jüchter**, Volker Kübler, Sarah-Katharina Meisenheimer, Christine Wellens, Werner Platzer

5 *Schematic representation of the process chain to produce ordered metallic nanoparticles with NIL and lift-off processes. (1) Production of the silicone stamp – we use a two-layer stamp with a softer silicone block as the base and a harder silicone layer, (2) structuring (imprint) and curing with UV radiation, (3) substrate after reactive ion etching (RIE), (4) metallisation, (5) lift-off.*





Lithographic techniques are usually applied to produce ordered plasmonic structures. Many of these methods are limited to small areas, e.g. electron beam lithography. By contrast, we are able to produce structures over an area of up to one square meter with interference lithography (IL). If IL is combined with a replication method such as nano-imprint lithography (NIL), the process chain becomes very flexible and the structures can be reproduced quickly and easily.

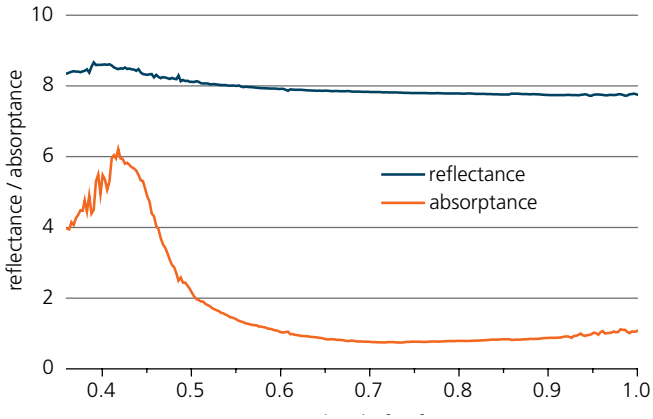
To produce ordered nanostructures (Fig. 5), we use a master structure which is produced by interference lithography. A silicon stamp is formed from this master structure. This is embossed in a previously applied photoresist, which is then cured with UV radiation. After removal from the form, the substrate is etched, opening the structured photoresist layer down to the substrate. Then the structure is metallised with silver. In the final step, the photoresist is lifted off. Only those particles with direct contact to the substrate remain attached.

With our NIL processing chain, the nanoparticles shown in Figures 3 and 4 were produced over areas of 75 x 75 mm² and 100 x 100 mm². The silver particles show plasmonic effects in the form of enhanced reflection and absorption between 360 nm and 500 nm (Fig. 6).

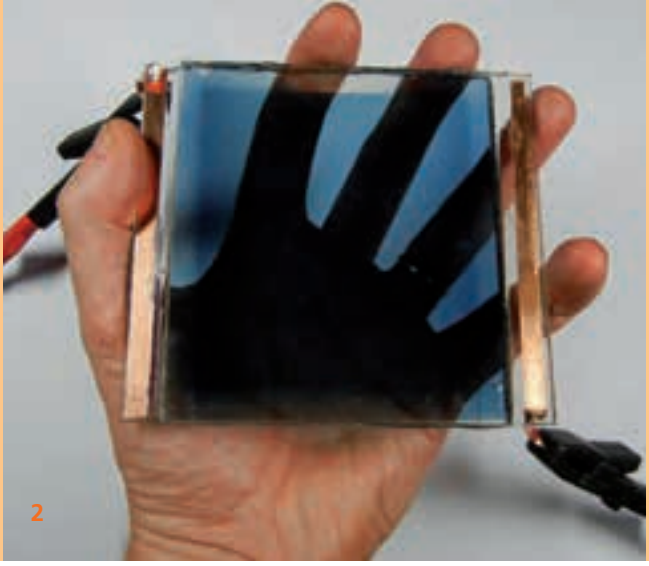
The illustrated process chain is suitable for producing ordered metallic nanostructures. In future, the production process is to be extended to an area of 156 x 156 mm² by replacing the simple imprinting step by a roller NIL process.

The work was supported by the Deutsche Forschungsgemeinschaft (DFG) within the "Nanosun II" project.

1 *Glass substrate with a structured photoresist coating (Fig. 5, step 2) over an area of 100 x 100 mm².*
2–4 *Scanning electron microscope (SEM) images of the master structure in photoresist (Fig. 2), a successful lift-off of platinum particles (period 1 µm, ∅ 600 nm, area 75 x 75 mm²), with a rotated piece of photoresist in the centre (Fig. 3), and silver nanoparticles with a period of 300 nm and a diameter of app. 150 nm over a total area of 100 x 100 mm² (Fig. 4).*



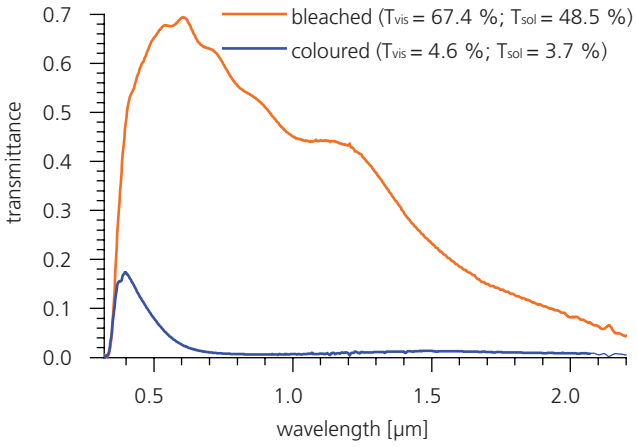
6 *Optical characterisation of the silver nanoparticles on a glass substrate. The graph shows the reflectance as measured with an integrating sphere and the calculated absorptance (A=1-R-T) as a function of wavelength.*



DEVELOPMENT OF ROBUST MATERIALS FOR PHOTOCHROMIC WINDOWS

The photochromic window systems which we have developed become coloured when exposed to intensive solar radiation and bleach again when the solar radiance level is low. This can prevent overheating in buildings with large glazed areas. The production costs are low due to the simple layer configuration. The materials which have been used so far have limited stability when exposed to water or oxygen, so that sealing is imperative. In order to reduce the production costs, we aim to develop materials which can tolerate water and oxygen within the system. This would also allow polymer films to be used as substrates.

Shankar Bogati, **Andreas Georg**, Wolfgang Graf, Carmen Jerg, Helena Orvalho, Rishabh Raj, Werner Platzer



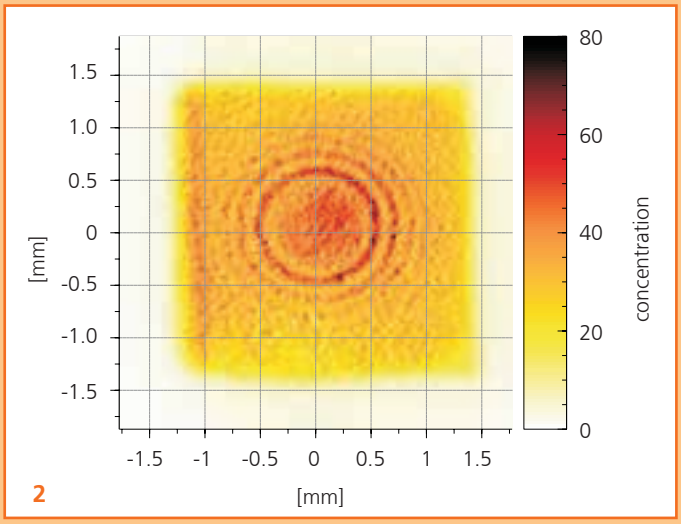
3 *Transmittance of an electrochromic system with the newly developed redox electrolyte in the bleached (orange) and coloured (blue) states.*

1 *Electrochromic system with the newly developed redox electrolyte in the bleached state.*
2 *Electrochromic system with the newly developed redox electrolyte in the coloured state.*

The photochromic window system developed at Fraunhofer ISE is based on the combination of a dye solar cell with electrochromic tungsten oxide. A dye is excited by illumination and donates an electron via a titanium oxide layer to tungsten oxide, which changes colour from transparent to blue. Charge compensation is achieved with a redox electrolyte, which contains lithium ions and a redox couple. The redox couple donates electrons to the dye, and lithium ions transfer simultaneously from the electrolyte to the tungsten oxide. Up to now, iodide/tri-iodide was used as the redox couple and a ruthenium complex as the dye. Both materials tolerate only extremely small quantities of water and oxygen in the electrolyte.

The acceptance of electrons leads to bleaching. This reverse reaction would correspond to a loss in photovoltaics but it is necessary in photochromic systems. Thus, materials can be used in photochromic systems which would be unsuitable for photovoltaic applications. This applies to both the dye and the redox couple.

For further development of this concept, we need materials which demonstrate greater stability, even though they would lead to lower efficiency values in a solar cell. Particularly suitable materials were selected in a material screening process and tested in electrochromic subsystems. The development into a complete electrochromic system will be continued within an EU-funded project.



CHARACTERISATION OF SECONDARY OPTICS FOR CONCENTRATING PHOTOVOLTAICS

In conventional flat photovoltaic modules, large-area semiconductors absorb sunlight and convert it directly to electricity. Concentrating photovoltaics (CPV) reduces costs by using tiny solar cells and covering the large area with optical components which focus the light. A further small optical component located directly on the solar cell can increase the optical concentration further and result in more homogeneous irradiation of the solar cell. With this secondary optics, the solar cell area can be reduced and the efficiency value can simultaneously be increased. We can optically characterise secondary optics with our measurement set-up. This enables us to optimise the geometrical design, the manufacturing process and quality control.

Thorsten Hornung, Peter Nitz, Tobias Schmid, Werner Platzer

1 *Measurement set-up to characterise secondary optics. The light source (at the top of the photo) illuminates a specially produced Fresnel lens (not shown in photo), which serves as the primary optics in this set-up. The secondary optics to be measured is positioned in the focus of the Fresnel lens with the help of alignment devices. A screen is used to make the light distribution at the exit aperture of the secondary optics visible and is photographed with a CCD camera.*

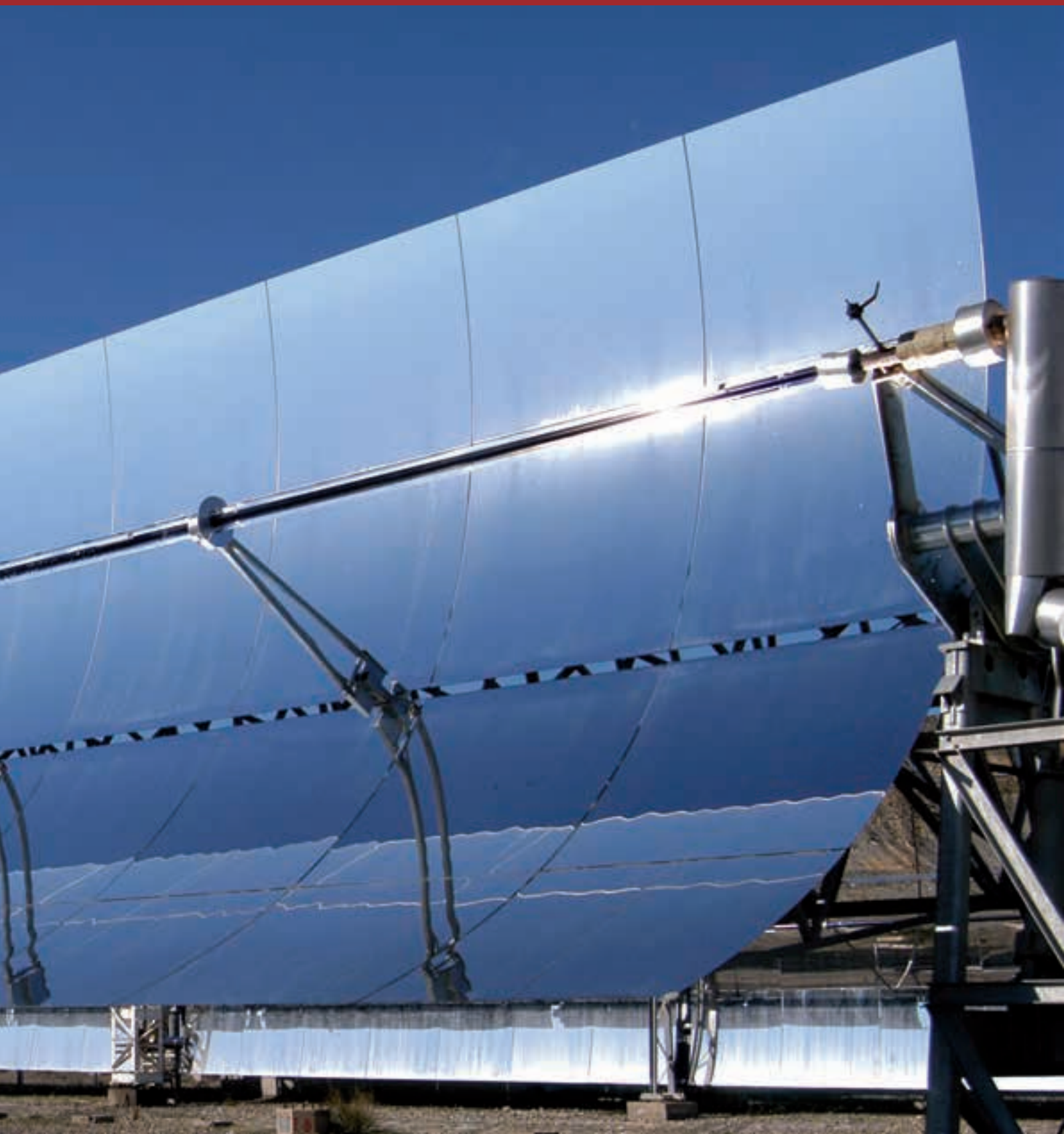
2 *Measured concentration distribution at the exit aperture of tested secondary optics. The ring pattern results from the draft facets of the Fresnel lens structure which was used as the primary concentrator for this measurement. The measured concentration is determined by the measurement configuration and must be scaled up by a factor of 20 to 25, depending on the primary optics used, for a full-scale concentration system.*

CPV systems concentrate direct sunlight with large-area optics, so-called primary optics, onto tiny solar cells. A second optical concentrator, so-called secondary optics, is often mounted directly onto the solar cell. Its optical properties can be characterised in our newly developed measurement set-up (Fig. 1). The measurement system determines the spatial distribution of the concentration factor at the exit aperture of the secondary optics (Fig. 2). In a concentrating photovoltaic system, the solar cell would be located at this position, so that the measurement provides direct information on the spatial distribution of the cell irradiation in real systems.

Because optical concentrators are non-imaging optical components, defects can have a significantly different effect on the system function to those occurring in imaging systems. In concentrating photovoltaics, electricity generation is the decisive measure. It depends on both the radiative power incident on the solar cell and its spatial distribution – exactly those quantities which are determined in our measurement system. Thus, the optical characterisation of secondary optics with our measurement facility provides a good basis to determine the influence of the secondary optics on the electricity yield. Comparative measurements demonstrate the effect of variations in the production of secondary optics. The information obtained provides a basis for further improvement of an optical concentrator system.

The project is supported by the German Federal Ministry of Education and Research (BMBF).

HEATING, COOLING AND ELECTRICITY FROM THE SUN



SOLAR THERMAL TECHNOLOGY

Solar thermal systems with different operating temperatures find their application in HVAC technology in residential and commercial buildings, in industry or as large-area, ground-based solar arrays. The heat generated from solar energy can either be used directly or converted via thermal power plants into electricity or by thermal chillers into cooling power. In general, the two decisive factors for system performance are the optical efficiency and the reduction of thermal losses.

The market for "Solar Thermal Technology" ranges from low-temperature to high-temperature applications: solar-thermal collectors and collector systems based on different types of flat-plate and evacuated tubular collectors have multi-facetted applications ranging from domestic hot water and solar-assisted space heating systems, through cooling and refrigeration, to desalination units suitable for use with seawater. New developments concerning façade-integrated collectors or collectors combined with photovoltaic electricity generation extend the range of options. Operating temperatures ranging from 150 °C to 550 °C can be reached with linearly concentrating collectors. Both parabolic trough and Fresnel collectors are used not only in large power stations for solar-thermal electricity generation, but also in often simpler and less expensive variants to generate process heat, process steam and driving heat for absorption chillers.

Solar-thermal energy systems convert solar energy into heat. Depending on the design of the solar-thermal collectors, the temperature increase above ambient temperature can vary from only a few degrees to several hundred degrees. The lower the thermal losses of a receiver, the better the optical efficiency values and the higher the concentration factor for the radiation, the higher are the possible operating temperatures. Durable, optical surfaces and materials are important for implementing efficient systems. This is the link to the business unit addressing "Applied Optics and Functional Surfaces".

We have developed selective absorber coatings for solar-thermal collectors (temperatures of up to 230 °C) and transferred them to industrial production for many years now. However, coatings for absorber pipes in solar-thermal power plants may permanently have to withstand much higher temperatures (up to 650 °C for tower receivers). This is achieved by integrating additional layers into the coating stack to act as diffusion barriers, selected according to the type of absorber pipe.

The efficiency of a collector, however, does not only depend on its surface properties, because the fluid dynamic properties and heat transport within the collector are also decisive parameters. A homogeneous flow distribution combined with a low pressure loss in flat-plate collectors is achieved with our FracTherm® concept, which is based on bionic principles. Completely new design and manufacturing options for solar-thermal collectors have been opened up by applying this approach. We are investigating alternative collector materials to aluminium and copper, e.g. steel, but also non-metallic materials such as ultra-high performance concrete and polymers.

Open, sorption-assisted air-conditioning processes can be operated efficiently with simple flat-plate collectors. They allow the temperature and relative humidity of inlet air to be conditioned as required. Some other thermal cooling processes demand higher operating temperatures. For this reason, concentrator collectors are also being developed and applied to optimise the complete system.

Process heat for industrial processes is needed in enormous quantities at very different temperature levels. Thus, different types of solar arrays are used to provide hot water, steam or heated air, depending on the location and industrial application.

In countries with a high proportion of direct solar radiation, solar-thermal power stations offer enormous potential to generate electricity inexpensively, both for the daily peak load and for longer periods with higher loads. Steam is generated at high temperatures and drives the turbine as in a conventional power station. In contrast to fluctuating photovoltaic generators or wind energy converters, this technology allows operation to be scheduled around the clock. This can be achieved either by hybridisation (combination with fuel-fed heating generators) or heat storage. Biomass offers a

regenerative option for non-solar heating. In general, the concept of solar power plants is associated with large projects in the 20–400 MW_{el} range. However, we are also investigating the opportunities for medium-sized solar-thermal systems on an industrial scale. Their economic feasibility can be clearly improved by heat and power (and cooling power) cogeneration and simpler operating conditions.

Fraunhofer ISE is competent in all fields relevant to thermal applications of solar energy, ranging from materials science, component design, testing and measurement procedures, theoretical modelling and simulation up to systems controls and systems technology for the different applications.

Special facilities:

- vacuum deposition system for quasi-industrial production of complex absorber and reflector prototypes on flat and curved surfaces and tubes (140 x 180 cm^2)
- measurement technology (REM, Auger, EDX) applying materials science to investigate changes in the coatings due to thermal or other loads
- optical measurement technology: spectrometry, goniometry, luminance measurements with imaging methods, fringe reflectometry, special measurement facilities for concentrating optics
- thermal technological laboratory to measure the performance and transient behaviour of thermal power generators (up to 50 kW_{el}) and high-temperature storage units
- testing laboratory to test the performance of membrane distillation systems and the stability of components to seawater exposure
- TestLab Solar Thermal Systems: certified solar-thermal testing laboratory for collectors and systems according to the Solar Keymark (performance and authorisation tests, outdoor and indoor testing, temperature measurement of heat-transfer media up to 200 °C), also suitable for measuring solar air collectors

In countries with a high proportion of direct radiation, solar thermal power plants offer great potential to generate solar electricity flexibly and cost-effectively, to meet daily consumption peaks and cover periods with increased loads. Fraunhofer ISE is occupied both with optimising optical surfaces and materials and also with Fresnel concepts and corresponding adaptation of reflectors for collector arrays. Another focus is on the development of novel, latent-storage concepts with phase change materials, so that electricity can be generated independently of the daily irradiation profile.

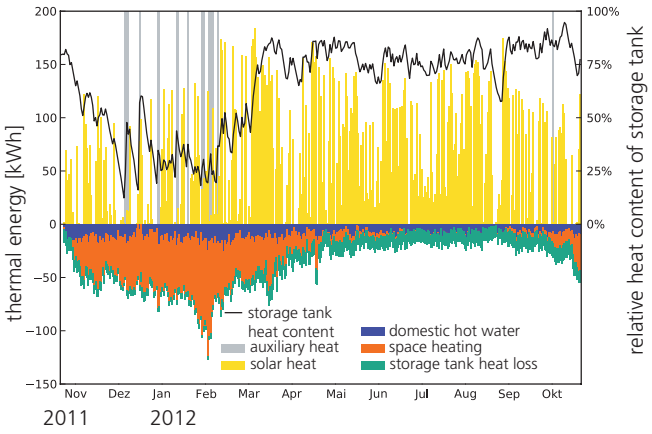
CONTACT

Thermal solar systems	Dr Wolfgang Kramer	Phone +49 761 4588-5096 wolfgang.kramer@ise.fraunhofer.de
Energy-efficient and solar cooling	Dr Doreen Kalz	Phone +49 761 4588-5403 doreen.kalz@ise.fraunhofer.de
Solar process heat	Dr Werner Platzer	Phone +49 761 4588-5983 werner.platzer@ise.fraunhofer.de
Solar-thermal power plants	Dr Thomas Fluri	Phone +49 761 4588-5994 thomas.fluri@ise.fraunhofer.de
Heat storage for heating and cooling	Dr Peter Schossig	Phone +49 761 4588-5130 peter.schossig@ise.fraunhofer.de

MONITORING AND OPTIMISATION OF SOLAR ACTIVE BUILDINGS

The European Union demands nearly zero-energy buildings as the standard for new buildings from 2020 onward in its current Building Directive. To achieve this, primarily the building energy demand for conventional fuels, which have an unfavourable primary energy balance, must be reduced significantly. "Solar active buildings" is the name given to highly efficient buildings, in which more than 50 % of the heat needed for space heating and domestic hot water is supplied by solar thermal systems directly on the building. In our current monitoring programme, nine typical, commercially available solar active buildings are being comprehensively measured and simulation is being applied to identify potential for optimisation.

Andreas Mayer, **Axel Oliva**, Gerhard Stryi-Hipp, Werner Platzer



2 *Energy balance for the thermal storage unit in a monitored building during the course of a year. The solar yield gained in winter is particularly important in significantly reducing the amount of heat supplied by the auxiliary heating system by about 75 %.*

1 *A house in Munich which is being monitored in the "HeizSolar" project.*

The generation of solar heat specifically during the heating season is decisive for the concept of solar active buildings. For this reason, the installed thermal collectors are mounted with a steep tilt and oriented toward the south wherever possible. The goal is to make optimal use of the solar radiation incident on the building, primarily by active measures. It is essential that the energy generated during the period defined for the energy balance is stored and used in this same period. This allows the amount of energy which is drawn from beyond the building system boundary to be reduced significantly.

Of the approximately thousand solar active buildings that now exist, nine were selected for the monitoring programme which represent the bandwidth of the current market with regard to their construction and building systems technology. The hot water storage tanks installed in the monitored buildings are able to store heat for periods ranging from a day to a week or even a season. Commercially available technology, such as sequentially switchable, internal heat exchangers or stratified storage devices, is used to introduce the heat into the storage units. Heat is usually withdrawn from the water tanks at several different heights, so that the appropriate temperature can be selected for the supplied hot water. Model-based analysis of the measurement data is applied to determine the potential for optimising operation management, to recommend dimensioning combinations and to identify promising development routes for the presented concept.

The "HeizSolar" project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

www.DieSolarHeizung.info

INVESTIGATION OF WIND AND SNOW LOADS ON COLLECTORS

The European standard, Eurocode 1 (EN 1991), defines product specifications concerning mechanical stability and safety related to wind and snow loads. Manufacturers of solar thermal collectors must ensure conformity of their products with Eurocode 1. The products also continue to be subjected to a certification process (e.g. Solar Keymark), to provide an independent evaluation of their performance and quality. This includes a mechanical test, but this is far from sufficient to meet the demands of Eurocode 1. Within the "MechTest" project, a novel test stand for mechanical loads was developed as a basis for designing extended testing procedures.

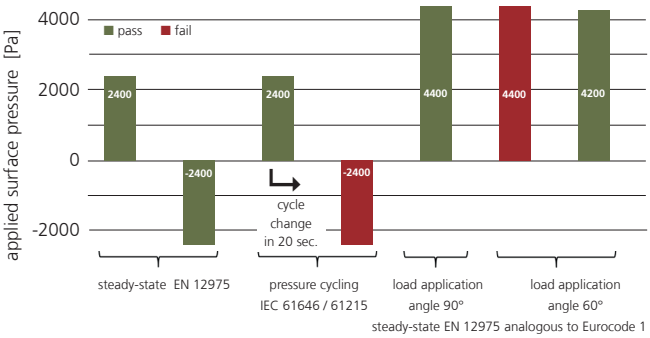
Konstantin Geimer, Korbinian Kramer, Werner Platzer

To date, only stationary, perpendicular loads in compression and tension were applied to the collector cover, in accordance with the relevant mechanical tests specified by the collector testing standard, EN 12975. In addition, evacuated tubular collectors and their back reflectors are exempted from tension loads due to the lack of testing facilities. In contrast to the load conditions specified in Eurocode 1, cyclic or asymmetrical loads, which could be caused by gusts of wind or inhomogeneous heaps of snow, are not taken into account. A large selection of these realistic load cases, and the influence of temperature on mechanical stability, can now be investigated with the novel load test stand (Fig. 1). The first extended tests on reference collectors show results which are significantly different in some cases to those of simple steady-state testing with a perpendicular load direction.

Figure 2 shows results from the first tests of a reference collector model, depending on the testing procedure. Whereas the collector passed the steady-state test according to EN 12975, it failed already during the first cycle when the photovoltaic testing standard, IEC 61646 / IEC 61215, was applied. The failure occurred after pressure had been applied constantly for one hour and was then changed from +2400 to -2400 Pa within 20 seconds. In other work, the new mechanical load test stand is currently being used to investigate the influence of different temperatures and the effect on different types of collectors.

The "MechTest" project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

1 *New mechanical load test stand installed in a climatic chamber. The test stand is equipped with four crossbeams, each with six pneumatic cylinders.*

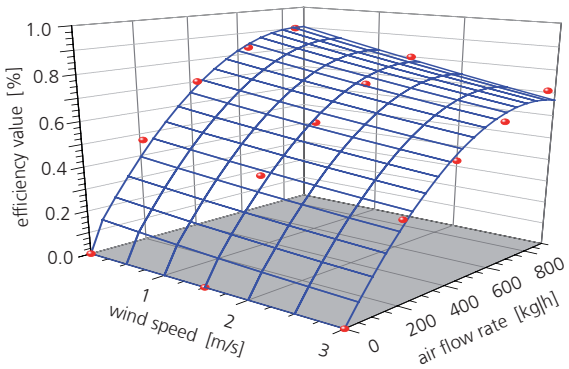


2 *Collectors of the same type (reference collector) were tested with different load procedures and load types. Failure occurred during a standard pressure cycling test (photovoltaic test standard), whereas this did not happen for a steady-state test (solar thermal test standard) with the same values. The load limit is reduced by 5 % when the load application angle is changed from 90° to 60° (shearing load).*

MEASUREMENT OF AIR-HEATING COLLECTORS WITHOUT TRANSPARENT COVERS

In the "Luko-E" project, we co-operated with partners to define test procedures for air-heating collectors, which will be the basis for a future international standard. No European standards exist yet for this type of product. Air-heating collectors could thus only be subsidised on the basis of a special agreement with the funding agencies. As is the case for water-heating collectors, a distinction is also made for air-heating collectors between those with and without a transparent cover. As only collectors with transparent covers were treated in the first phase of the project, the second project phase is concentrating on testing air-heating collectors without transparent covers.

Korbinian Kramer, **Christoph Thoma**, Gerhard Stryi-Hipp, Werner Platzer



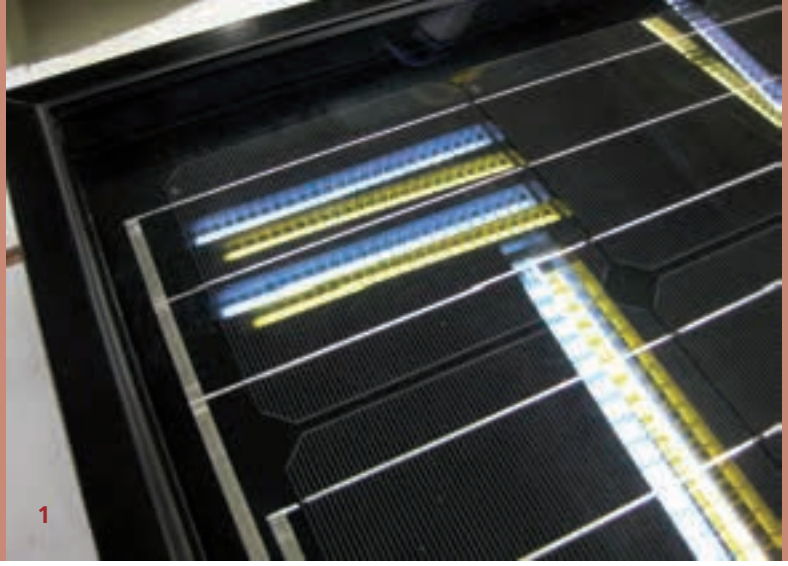
2 *Results of measuring an air-heating collector without a transparent cover under the solar simulator with stable wind speeds. The red points indicate the efficiency values as a function of the wind speed and the air flow rate. The irradiance value was 882.5 W/m²; the inlet air temperature is always equal to the ambient air temperature. The blue grid was created with a non-linear surface fit.*

1 *Collector covered with a clamped polymer film. Ventilators are located below the collector, which are used to set the air flow rate over the absorber. To describe the collectors behaviour completely, measurements with and without a polymer film are needed.*

Air-heating collectors use air as the heat transfer medium. One of the characteristics of air-heating collectors is the strong dependence of the collector efficiency on the air mass which flows through the collector. The higher the flow rate, the better is the heat transfer from the absorber to the heat transfer medium and the higher the efficiency, for constant density. If an air-heating collector is to be completely characterised, the efficiency values must be determined as a function of the operating temperature and different flow rates.

In addition, if the collector does not have a transparent cover over the absorber, the efficiency value depends strongly on the wind speed. The wind speed has a major effect on the convective heat losses from the collector. When such a collector is measured, it is important to ensure that the influencing quantities can be set reproducibly and remain constant during the test.

To allow air-heating collectors without covers to be tested outdoors, as is necessary e.g. if the collector is too large to be tested indoors with a solar simulator, a test stand was constructed specifically for this purpose. In addition to a defined substructure to support the collector, the test stand is also equipped with a clamping system to span a highly transparent cover over the collector, forming a wind channel with controlled flow conditions over the absorber surface. This minimises disturbance due to fluctuating wind speed caused by gusts, for example.



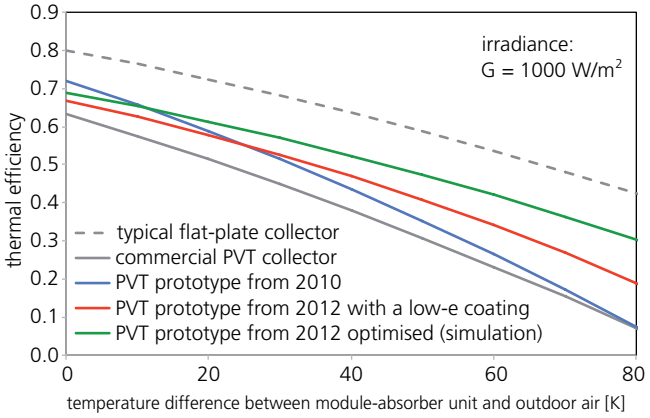
OPTIMISATION OF A PV-THERMAL (PVT) HYBRID COLLECTOR

A high proportion of solar energy in the electricity and heat supply for Germany demands that rooftop areas be used efficiently. "Covered" PV-thermal (PVT) collectors, in which the solar cell/absorber combination is located in a collector housing beneath a glass pane, are promising, as they can supply up to 50 % more solar heat and electricity per unit area than separate PV modules and solar-thermal collectors. However, the PVT collectors available to date do not feature satisfactory efficiency values. Fraunhofer ISE is thus now developing optimised covered PVT collectors and was able to achieve a significant increase in efficiency by the integration of a newly developed low-emissivity coating.

Stefan Fortuin, Wolfgang Graf, Ingrid Hädrich, Thomas Kroyer, **Gerhard Stryi-Hipp**, Martin Wiese, Werner Platzer

The efficiency of PVT collectors for generating electricity and heat is fundamentally somewhat lower than for separate PV modules and solar-thermal collectors. It is thus sensible to use them only when the available area is limited and they can achieve a significantly higher total energy yield from this area. Covered PVT collectors are intended to replace solar-thermal collectors and heat domestic hot water up to 60 °C. Up to now, this has only been possible in summer, because their efficiency is too low when the temperature difference between the module-absorber combination and the outdoor air is greater, as the absorber coating is not spectrally selective. Free-standing houses require a collector area of only about 5 m^2 for heating domestic hot water, so that PVT collectors do not present any significant advantages there. Their advantage with respect to the total efficiency becomes relevant for larger collector areas, such as those needed for solar-assisted space heating (about 12 m^2) or Solar-Active-Houses (more than 30 m^2).

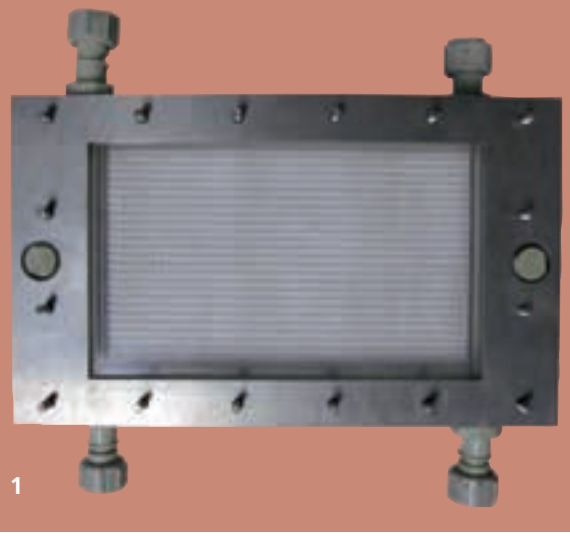
1 *Detail of the PVT prototype collector with visible reflections from the anti-reflectively coated glass cover (blue) and the low-e coated cover (yellow) of the module-absorber combination.*

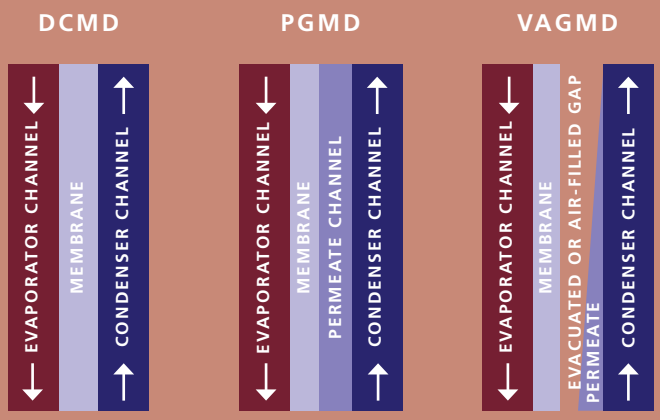


2 *Thermal efficiency curves for a commercial PVT collector and three prototypes, measured in the MPP mode, compared to a typical flat-plate collector. The difference between the green and the dotted lines is mainly caused by the additional electricity generation.*

Solar-assisted space heating demands a higher PVT collector efficiency for greater temperature differences. Thus, at Fraunhofer ISE, a low-e coating was deposited onto the glass cover of the solar cells to reduce the transmission of infrared radiation. As the low-e coatings used in thermally insulating glazing are not suitable due to their reduced transmittance for the complete solar spectrum, a special low-e coating based on silver was developed and samples were produced. With it, the efficiency of a prototype PVT collector for a temperature difference of 60 K was increased by 25 %.

The work was supported by the Deutschen Bundesstiftung Umwelt (DBU).



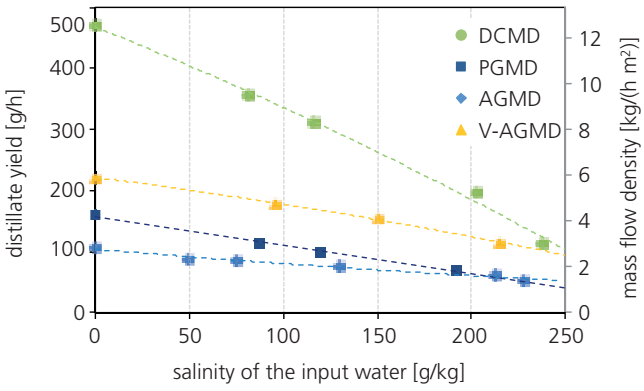


1 2

OPERATION OF MEMBRANE DISTILLATION WITH LOW-TEMPERATURE HEAT SOURCES

The desalination of seawater and brackish water is an essential component in supplying drinking water in many countries. In addition to well-established, large-scale technology, the application of decentralised plants is becoming increasingly important. More attention is also being paid to energy-efficient and sustainable treatment of industrial waste water. Rising energy costs, increasingly strict environmental regulations and other legal requirements mean that new technology must be developed. To this purpose, research was conducted at Fraunhofer ISE on membrane distillation, a process which can be applied to separate a great variety of material combinations. It is particularly well suited to operation with low-temperature waste heat or solar-thermal energy.

Julia Braun, David Düver, Florian Groß, Joachim Koschikowski, Marco Pergher, Christiane Pohlisch, Martin Rolletschek, Rebecca Schwantes, **Daniel Winter**, Werner Platzer



3 *Comparative experimental investigations on different membrane distillation procedures. The investigations serve to determine the sensitivity of the processes to the salinity of the sols.*

1 *Membrane test cell for fundamental investigations of membrane distillation.*

2 *Membrane distillation variants which can be configured in the membrane test cell: "Direct Contact (DCMD)" configuration, in which the evaporator channel is separated directly by the membrane from the condenser channel, as well as the "Permeate Gap (PGMD)", "Air Gap (AGMD)" and "Vacuum Air Gap (VAGMD)" configurations, in which an additional film separates the distillate space from the condenser channel.*

Membrane distillation (MD) is a thermal separation procedure in which evaporation takes place through a membrane. The liquid sol is held back by the semipermeable membrane, while water vapour can pass through it. The driving force is a temperature difference between the two outer surfaces of the membrane. At Fraunhofer ISE, MD modules and systems are developed for desalination and for separation of other material combinations. Experimental investigations using test cells on a laboratory scale are made to optimise the materials involved, the channel configuration and to identify efficient operating points. The main approach taken is comparative analysis of different procedural variants. Many membrane samples were characterised in the test cell in co-operation with industrial partners. The separation performance of MD for different media was investigated. The development and validation of a very comprehensive simulation tool, which is based on a physical multi-node model, has enabled us to design membrane distillation modules for a great variety of capacities and applications. The model is also used in dimensioning complete complex systems, e.g. solar-driven desalination plants. We have set up systems to produce and characterise membrane distillation modules in the laboratory, allowing us to construct membrane distillation field systems. More than 150 modules have already been produced and experimentally investigated.

MEASUREMENT OF CONCENTRATING TRACKING COLLECTORS

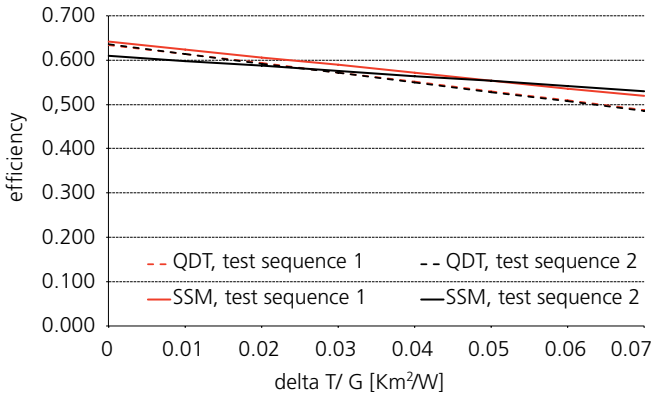
Increasing numbers of manufacturers of thermal solar collectors consider industrial process heat to be a future market and are including corresponding products in their portfolio. The German Federal Government has also recognised the importance of this sector and significantly increased funding to support such systems in the most recent revision of the market stimulation programme. When higher process temperatures are needed, concentrating collectors are particularly suitable. The growing and diversifying market for such collectors is accompanied by an increasing demand for testing. This year, TestLab Solar Thermal Systems characterised a concentrating collector for the first time according to the steady-state and quasi-dynamic methods of the European standard.

Sven Fahr, Stefan Hess, Korbinian Kramer, Stefan Mehnert, Werner Platzer

The concentrating collector sector encompasses a much wider range of technology than that for flat-plate and evacuated tubular collectors. The collectors differ significantly in the receiver construction, the concentrator design and the concept for tracking the sun. Thus, reliable determination of the influence of the diffuse radiation fraction and the incidence angle (incidence angle modifier IAM) on the thermal performance is essential for generally valid characterisation and thus for accurate yield predictions.

The characterisation of concentrating collectors raises specific questions and demands re-evaluation of established testing procedures. Experiments demonstrated that the steady-state method (SSM) in its current form is not suited to characterise concentrating collectors adequately, as the acceptance of diffuse radiation is not taken into account. The quasi-dynamic test method (QDT) defines this parameter and also offers a

1 *Concentrating tracking collectors from the isomorph company, which were characterised at Fraunhofer ISE.*



2 *The graph shows the efficiency characteristic curve at 1000 W/m² based on two analyses of different test sequences under different weather conditions. The steady-state method (SSM) delivers strongly deviating results for different diffuse radiation fractions whereas the result of the quasi-dynamic test method (QDT) is reproducible.*

method to determine unknown biaxial IAM profiles on the basis of extended multi-linear regression. With this measurement procedure, very good and reproducible experimental results have already been obtained for individual cases (Fig. 2).

We have also demonstrated the operating reliability of a collector by functional tests based on procedures to be included in a future revision of the standard. After successful completion of the tests, the concentrating tracking collector (Fig. 1) developed by the isomorph s.r.l. were recommended for certification, the first time that Fraunhofer ISE had done this for a concentrating collector.

ACCELERATED AGING TESTS FOR SOLAR THERMAL COLLECTORS

Solar collectors are the components of a thermal solar energy system which must withstand the greatest loads, as they are exposed not only to high temperatures but also to UV radiation, wind, salt, dust and moisture. To quantify the aging behaviour of solar thermal collectors and their components, the "Service Life Analysis" group at Fraunhofer ISE conducts field tests for solar collectors at locations with extreme climates, in order to develop and validate appropriate tests.

Markus Heck, Thomas Kaltenbach, Matthis Reinke Kurth, Sandrin Saile, **Karl-Anders Weiß**, Harry Wirth

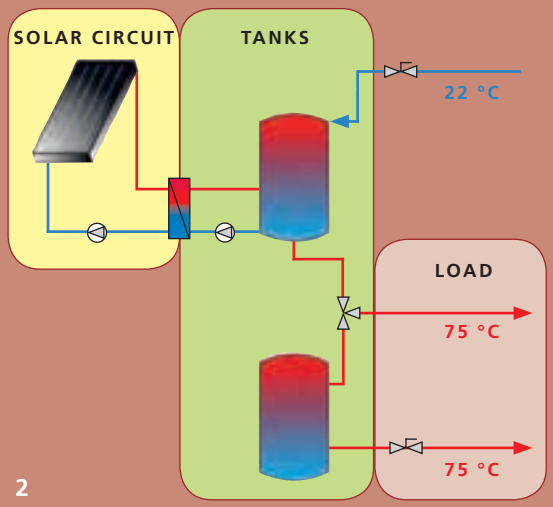
1 *Collectors exposed on the maritime outdoor test site of Fraunhofer ISE on the grounds of the Instituto Tecnológico de Canarias, Pozo Izquierdo, Gran Canaria.*

The outdoor exposure sites are characterised by typical combinations of different load factors, e.g. high UV irradiance with mechanical wind and snow loads at the Zugspitze or high irradiance with high temperatures and strong day/night differences at the desert site in Israel. At the maritime location on Gran Canaria, the high air humidity with a large content of salt aerosols is usually accompanied by strong wind (Fig. 1). The combination of these factors results in a "sticky film" on the test samples after only a few days, which causes wind-blown sand to stick to the samples as a layer of dirt. The infrequent rain can no longer wash these incrustations away, so that they must be removed mechanically. Thus, manufacturers and operators are very interested to test the functionality of anti-soiling or self-cleaning surfaces.

The effect and durability of anti-soiling coatings for glass covers when exposed to weathering were thus investigated. To this purpose, a procedure was developed to reproducibly soil the test samples with standardised dust. The stability of the coatings was tested by subjecting selected samples to different accelerated aging tests (85 °C with and without UV radiation). The degradation of the anti-soiling functionality was characterised by measurements of transmittance and contact angle, as well as by a specially developed soiling test. Major differences in performance and durability were determined. The testing procedure is currently being further developed. Further glass types and coatings are also being investigated.

Our work is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) and industrial partners within the "SpeedColl" project.

www.speedcoll.de



MARKET AND SYSTEMS TECHNOLOGY FOR SOLAR PROCESS HEAT IN INDIA

With its high solar irradiance and rapidly growing economy, India is a promising market for solar process heat. Despite legal requirements and financial support for thermal solar systems, however, the market for this application area is growing only slowly. In co-operation with GIZ India, we have evaluated the opportunities and boundary conditions for transferring German solar thermal technology to India to supply solar process heat, based on our experience with the European development of solar thermal technology and markets. We have compared European systems technology with the solutions from Indian suppliers on the basis of individual systems, and have conducted a survey of market players in India.

Annabell Helmke, Stefan Heß, Deepthaa Sampath Kumar, Gerhard Stryi-Hipp, Werner Platzer

At present, thermal use of solar energy has a somewhat negative image in India, because faulty dimensioning, operation management and maintenance in the past have resulted in the functionality and lifetime of systems falling well below expectations. To prepare measures for improved market development, we have analysed and evaluated not only economic and legal boundary conditions for funding but also common planning practices and the available systems technology in India. There are essential differences between Germany and India which must be taken into account for technology and knowledge transfer. The European state of the art can be transferred only to a limited extent to India, because other demands are made here on components, systems technology, system design, controls and operation management.

Factor	Germany	India
Annual solar radiation kWh/m²/a	*app. 1140 Freiburg app. 970 Bremen*	*app. 2370 Jaipur app. 1640 New Delhi*
Pressurised systems	*usual*	*not usual*
Medium in solar circuit	*water-glycol mixture*	*water*
Controls	*complex*	*simple*
Electronic yield monitoring	*frequent*	*seldom*

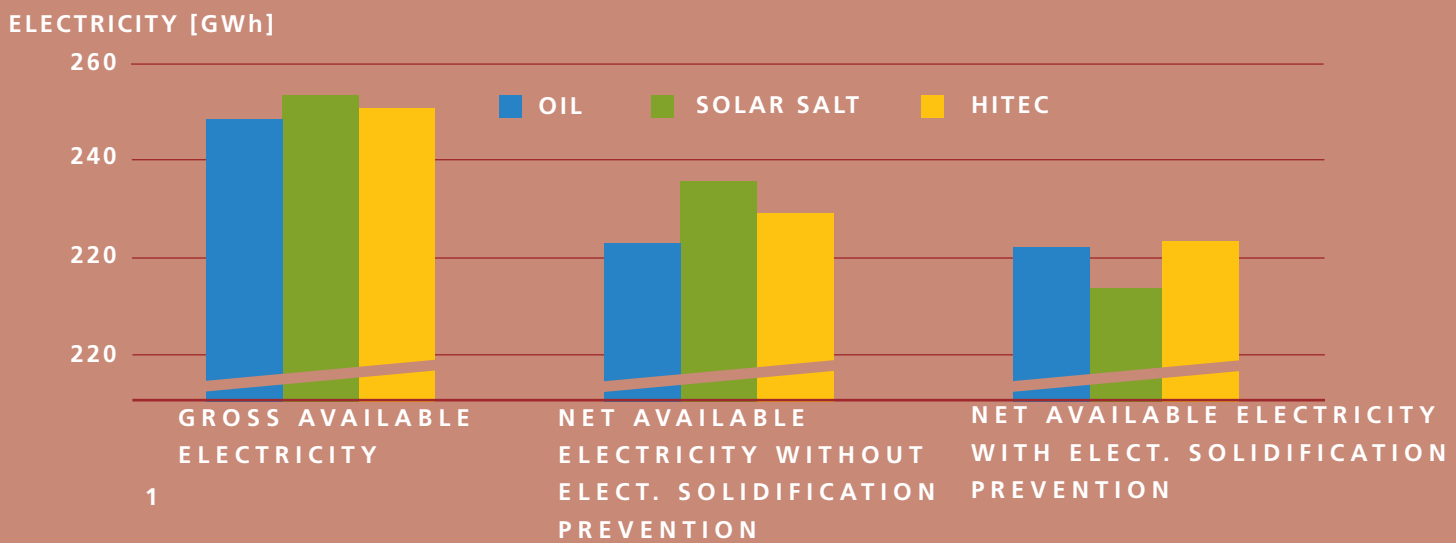
3 *Factors affecting the technology transfer of solar process heat.*

1 *Process heat system with a flat-plate collector area of 150 m² and a storage tank volume of 6.5 m³ in New Delhi. The buffer tank is filled during day 1 and emptied manually in the evening into an electrically heated tank, which is discharged at 75 °C in four sessions during day 2.*

2 *Schematic diagram of the non-pressurised system example with the solar circuit, buffer tank and electrically heated storage tank (including its heating element). There is a height difference of app. 10 m between the two tanks.*

A solar process heat system for a pharmaceutical concern in New Delhi is characteristic for a local installation (Fig. 1). At the wish of the system operator, the suppliers deliberately applied a simple control strategy. The choice was made for an inexpensive, non-pressurised system (Fig. 2) with a solar pre-heated tank, the content of which was manually emptied each evening into an already existing, electrically heated tank. We evaluated the submitted quotes from the call for tenders, suggested improvements to the controls and systems technology and prepared a monitoring concept.

The intermediate results of this work demonstrate that a significantly improved market development for solar process heat in India will only be possible if the specific demands on systems technology and operation management are known, so that appropriate optimisation can occur which takes nationally specific circumstances into account.



EVALUATION OF PARABOLIC TROUGH POWER PLANTS WITH MOLTEN-SALT CIRCUITS

Eutectic mixtures of molten salts are proposed as new heat-transfer fluids in solar-thermal power plants. They would allow the operating temperatures of the solar arrays to be significantly raised compared to the thermal oil which is currently used. Higher steam temperatures in the evaporator and superheater could then lead to higher thermodynamic efficiency values in the power plant itself. This is a positive factor, which can result in better economic viability of parabolic trough or Fresnel power plants. By contrast, negative factors are the higher possible costs to prevent the molten salts from solidifying during operation and corrosion.

Florian Boess, Raymond Branke, Thomas Fluri, **Werner Platzer**

Molten salt is already being experimentally used with success in parabolic troughs in Sicily. In order to prevent the fluid from solidifying below the melting temperature, auxiliary electric heating is switched on if temperatures fall. This is necessary at a temperature which varies with the melting temperature of the fluid. As a result, the parasitic energy consumption differs, and it also depends on the hydraulic pressure losses, which determine the pump energy consumption. The range of operating temperatures is 20–390 °C for thermal oil, 260–560 °C for "Solar Salt" (mixture of 40 % KNO_3/60 % $NaNO_3$) and 150–540 °C for commercial HITEC® salt.

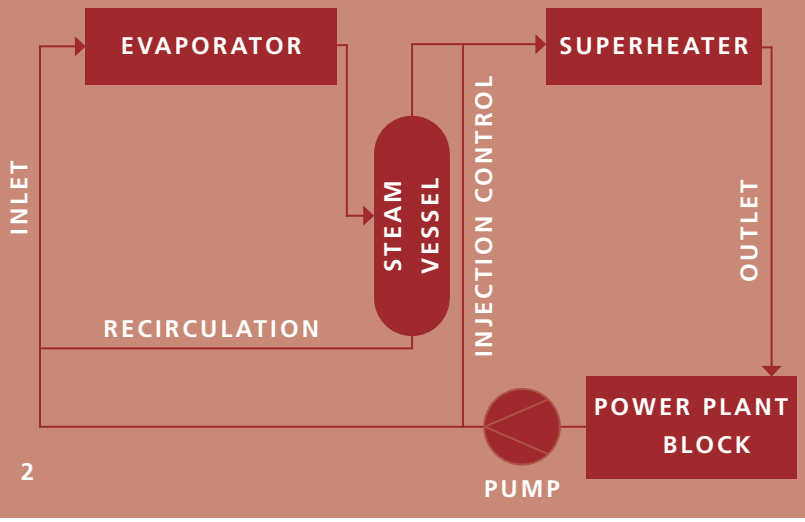
In order to estimate the parasitic energy demand, a model power plant corresponding to the ANDASOL 3 type was simulated. A parabolic trough power plant with an aperture area of 500 000 m² and a 50 MW turbine with storage was assumed. The nominal thermodynamic efficiency value for the steam circuit increases due to the higher steam temperature from 34.5 % in the case of thermal oil to 39.7 % with Solar Salt. In the simulation of cooling behaviour during stagnation at night or very low irradiance conditions, it is absolutely essential not to simulate on a quasi-stationary basis with hourly values but to dynamically observe the cooling behaviour at short time intervals and include heat capacity effects. To this purpose, we extended our "ColSim" simulation model so that molten-salt circuits can be simulated dynamically.

1 *Comparison of the generated gross and net electricity, with and without solidification prevention by auxiliary heat with three standard heat-transfer media, Therminol VP1 (thermal oil), Solar Salt KNO_3/$NaNO_3$ and Hitec®.*

At sites with little direct normal irradiance (DNI), we identified high parasitic energy consumption due to the necessary auxiliary heating (Fig. 1). For this reason, the net energy gains for the investigated cases, taking the auxiliary heating into account, are clearly higher for thermal oil or the commercially available HITEC® salt than with the Solar Salt mixture. The net energy yield for Solar Salt is then 4.3 % lower than with thermal oil, whereas the value of 16.8 % for HITEC® salt is 0.4 % higher than for Solar Salt. Lowering the melting point of the molten salt thus appears to be necessary for optimal application. However, other factors such as costs must be considered in a comprehensive evaluation. The costs for salt as a heat-transfer medium are lower than for thermal oil. Other mechanisms to prevent solidification are also being investigated.

The project is supported by the European Union within the 7th Framework Programme.

1



2

OPTIMISATION OF LIVE STEAM PARAMETERS IN A LINEAR FRESNEL POWER PLANT

A trend toward higher solar array temperatures can be observed in the development of solar-thermal power technology. The goal is lower levellised costs of electricity. On the one hand, the thermodynamic efficiency of the power plant block can be raised. On the other, the component costs are higher and the thermal losses in the solar array increase. To optimise the live steam parameters with respect to minimal levellised costs of electricity, we have implemented a model of a direct-steam generation linear Fresnel power plant in the ColSim software developed by Fraunhofer ISE, and connected it with a cost model. This enabled us to conduct optimisation studies for different locations and power plant concepts.

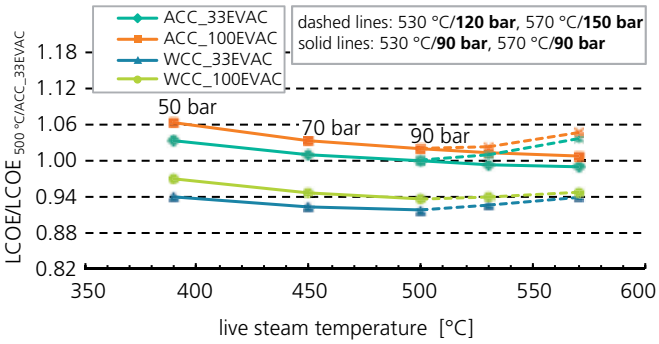
Thomas Fluri, Simon Lude, Werner Platzer

The ColSim simulation environment allows hydraulic circuits to be represented as dynamic models. This means that we can simulate different operating strategies, new technology and power plant designs, and evaluate their effect on yield or operating stability, also concerning short-term behaviour. The model developed for this study is based on technology of the Novatec Solar GmbH company. The solar array is divided into an evaporator section and a superheater section. A steam vessel is positioned between them to separate the liquid from the gas phase. The power plant block can be either air-cooled or water-cooled. An absorber which is stable in air and an evacuated absorber are available for the solar array. The influence of the different absorber types in the two solar array sections was investigated for four locations.

It was demonstrated that a higher live steam temperature had a positive effect on the levellised cost of electricity over the entire investigated temperature range, but only when the live steam pressure was maintained at 90 bar for temperatures above 500 °C. The positive effect on the levellised cost of electricity is much more pronounced, at 3.0 % / 100 °C, for temperatures below 500 °C, than for temperatures above 500 °C, where it is 1.7 % / 100 °C. If the live steam pressure is increased further, additional material costs have a negative effect. The advantages of water cooling compared to air cooling and the advantage of applying absorbers that are stable to air rather than evacuated absorbers in the evaporator section are evident.

1 *Collector array of the PE2 Fresnel power plant owned by Novatec Solar GmbH in Spain.*

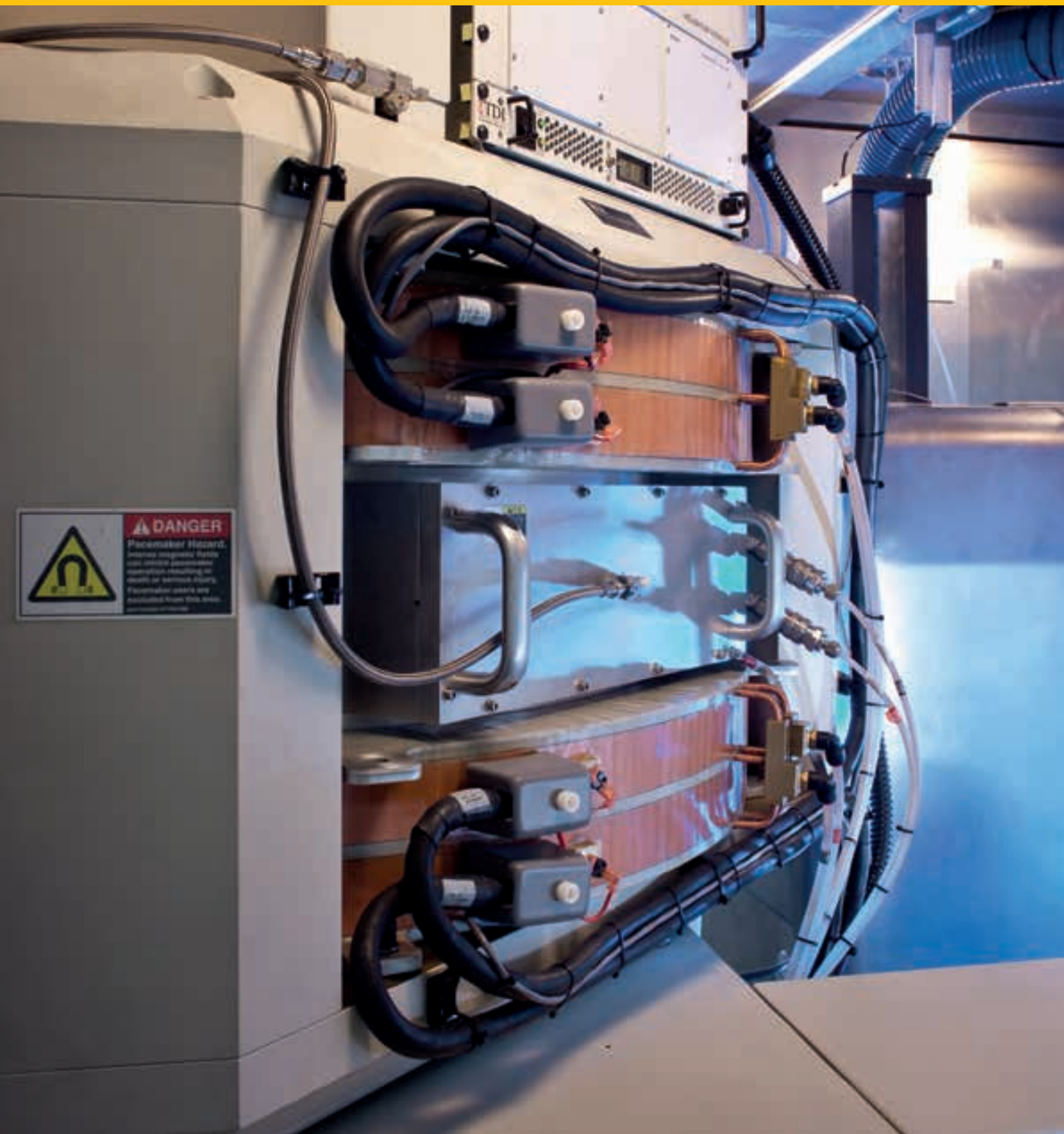
2 *Block circuit diagram of the implemented ColSim model for a linear Fresnel power plant.*



3 *Calculated relative levellised costs of electricity (LCOE) for the Daggett site: Optional air-cooled condenser (ACC) or water-cooled condenser (WCC) and evacuated absorbers only in the superheater section (33EVAC) or in the complete array (100EVAC).*

The work was supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

ELECTRICITY FROM SUNLIGHT



SILICON PHOTOVOLTAICS

After years of successful growth, the global production capacity for silicon photovoltaics has now reached a level of about 60 GWp. By contrast, the market volume for Si-based modules was only around 30 GWp in 2012. As a result, the module prices have fallen below the manufacturing costs in some cases. The associated economic difficulties caused a number of companies in Germany and elsewhere to become insolvent. 2012 was thus marked by an industrial crisis in this sector. Our R&D spectrum now has the goal of co-operating with the industry to introduce new, innovative products to the market, so that the manufacturing costs can be reduced and the PV industry in Germany and Europe can manufacture competitively.

Around 90 % of the rated power capacity is based on solar cells manufactured of crystalline silicon. The price-to-performance ratio, long-term stability and reliable predictions for further cost reduction indicate that this peak performer in terrestrial photovoltaics will continue to dominate the market in the future. Our R&D activities mirror the complete value chain for crystalline silicon photovoltaics.

The PV materials platform of Fraunhofer ISE covers all research topics concerning silicon materials and consists of the following centres: the Silicon Material Technology and Evaluation Centre SIMTEC in Freiburg, the Technology Centre for Semiconductor Materials THM in Freiberg, Saxony, which is operated jointly with Fraunhofer IISB, and the Centre for Silicon Photovoltaics CSP in Halle, which is operated jointly with Fraunhofer IWM. In the crystallisation segment, we investigate process technology for the float-zone and Czochralski methods to produce monocrystalline silicon. In addition, we work on block-crystallised silicon. Our equipment includes a crystallisation facility, where multicrystalline blocks weighing 15 kg to 250 kg can be produced. Sawing and polishing technology is available to produce columns and wafers from the crystallised blocks. Our scientific work here focuses on improving the crystallisation process to produce silicon crystals as the starting point for highly efficient solar cells, and adapting the crystallisation processes to each particular type of solar silicon, e.g. upgraded metallurgical grade (UMG) silicon. Concerning sawing technology, we work to manufacture thinner wafers and to improve processes based on diamond-studded wire saws.

The concept of the crystalline silicon thin-film solar cell combines very high-quality crystalline films with methods from thin-film solar cell production, such that it can potentially achieve very low costs for PV modules. We are developing specific facilities and processes for this concept. Our work is focussed mainly on equipment for high-throughput silicon deposition and zone-melting recrystallisation, as well as appropriate processes to produce substrates, films and solar cells.

A central activity of our ETAlab® is the development and analysis of high-efficiency solar cell concepts and processes. The goal is to achieve higher efficiency values with cost-effective processes and thus provide the pre-requisite for substantial cost reduction in silicon photovoltaics. ETA in the laboratory name stands for Efficiency, Technology and Analysis. Among the various solar cell concepts that currently exist, we focuse particularly on back-contacted cells and structures for n-type silicon. ETAlab® is equipped with excellent processing infrastructure in a clean-room laboratory with a floor area of 500 m^2, which has allowed us to set several international records for efficiency. In addition, further laboratory area of 900 m^2 is available for us to develop effective surface passivation methods, novel metallisation and doping procedures, innovative nano-structuring technology and new characterisation methods. This year, we further extended our technological portfolio by setting up an ion implanter to produce structured profiles of boron and phosphorus doping.

SILICON PHOTOVOLTAICS

The ion implanter, which was recently installed in the clean room of Fraunhofer ISE, allows silicon to be doped with boron and phosphorus at very exactly defined positions. In combination with an annealing step that was developed at Fraunhofer ISE, we were able to produce emitters with very low recombination currents. This technology offers great advantages, particularly for solar cell configurations with structured doping profiles, such as back-contact solar cells.

In our Photovoltaic Technology Evaluation Centre PV-TEC with an area of more than 1200 m^2, we can produce both solar cells with screen-printed contacts, as are common in industry, and also solar cells with high-quality surface passivation on a pilot scale, i.e. with a throughput of more than 100 wafers per hour. For the various types of processing technology, both flexible, semi-automatic equipment and high-rate, fully automatic systems for process development are available. Our development of production-relevant technology for crystalline silicon photovoltaics is concentrating on high-temperature and printing technology, wet chemical and plasma chemical processes, as well as laser and physical vapour deposition. These technological facilities are complemented by in-line and off-line measurement instrumentation. All material and processing data are stored in a central data base, guaranteeing that our high quality specifications are met, which makes them particularly suitable for analysing new materials. Our activities range from development of new concepts at the pilot stage, through evaluation of new technology, to transfer to the production lines of our co-operation partners. In 2012, we considerably expanded our technological platform for producing solar cells based on n-doped silicon.

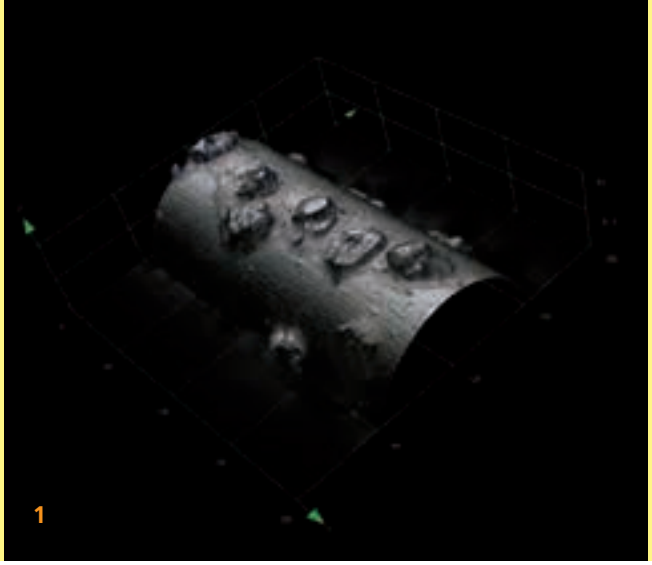
For all of the technological foci mentioned above, our excellent characterisation and simulation pool provides the foundation for effective and scientifically based development. We are playing a leading role in the development of new characterisation procedures such as the imaging photoluminescence method to analyse silicon material and cells.

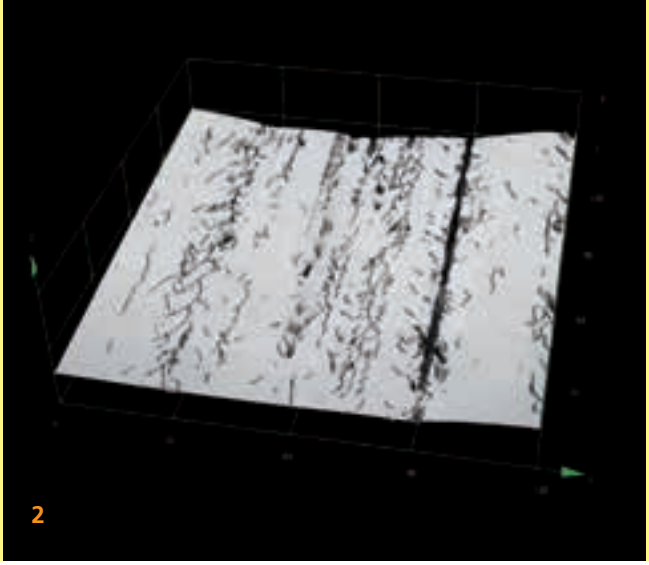
Finally, the Photovoltaic Module Technology Centre MTC at Fraunhofer ISE allows new cells and materials to be processed in industrially relevant quantities and formats. Processing steps and systems technology for module production are developed up to the preliminary stage of mass production. The core equipment includes an industrial stringer and a laminator, accompanied by a selection of measurement and analytical platforms. Further details of these activities can be found in the chapter on photovoltaic modules and systems (see p. 88).

Our activities on silicon material and solar cells in Freiburg are complemented by the Fraunhofer ISE Laboratory and Service Centre in Gelsenkirchen (see page 82).

CONTACTS

Feedstock, crystallisation and processing	Dr Stephan Riepe SIMTEC	Phone +49 761 4588-5636 stephan.riepe@ise.fraunhofer.de
	Dr Peter Dold CSP-LKT	Phone + 49 345 5589-428 peter.dold@csp.fraunhofer.de
	Prof Hans Joachim Möller THM	Phone +49 3731 2033-160 hans.joachim.moeller@ise.fraunhofer.de
Crystalline silicon thin-film solar cells	Dr Stefan Reber	Phone +49 761 4588-5248 stefan.reber@ise.fraunhofer.de
Industrial and novel solar cell structures	Dr Stefan Glunz	Phone +49 761 4588-5191 stefan.glunz@ise.fraunhofer.de
	Dr Ralf Preu	Phone +49 761 4588-5260 ralf.preu@ise.fraunhofer.de
Modules	Dr Harry Wirth	Phone +49 761 4588-5858 harry.wirth@ise.fraunhofer.de
Production systems and process development	Dr Ralf Preu	Phone +49 761 4588-5260 ralf.preu@ise.fraunhofer.de
	Dr Stefan Glunz	Phone +49 761 4588-5191 stefan.glunz@ise.fraunhofer.de
Characterisation, quality control and development of measurement technology: materials, cells and modules	Dr Wilhelm Warta	Phone +49 761 4588-5192 wilhelm.warta@ise.fraunhofer.de



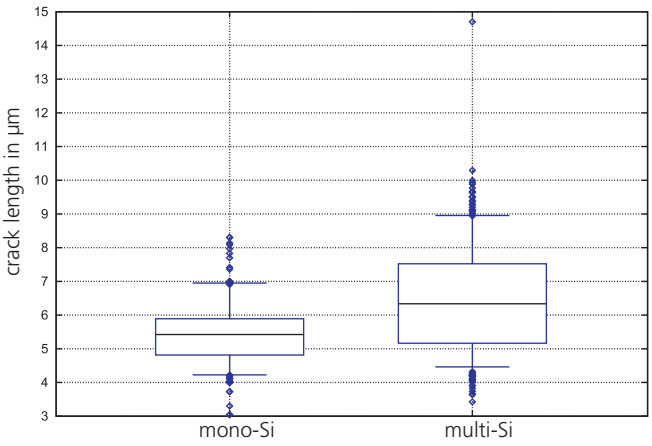


SILICON WAFER PRODUCTION WITH DIAMOND-COATED SAWING WIRE

Wafer production with diamond-coated sawing wire is a new technological alternative to the sawing process with loose abrasives. The main technological difference is the coating of the sawing wire with fixed, abrasive diamond particles. This results in a microscopically different ablation process. Research and further development of this slicing technology is a major field of work at the Fraunhofer Technological Centre for Semiconductor Materials THM. Our results show that surface damage and resistance to fracture of monocrystalline and multicrystalline silicon material differ greatly.

Rajko Buchwald, Marcel Fuchs, Hans Joachim Möller, Stefan Retsch, Sindy Würzner, Andreas Bett

The application of diamond-coated wires to sawing silicon wafers is a relatively new process. For industrial application of this technology, investigations, including some fundamental research, and innovative process optimisation are needed. The technical and analytical equipment of Fraunhofer THM was oriented toward this research goal. For the sawing experiments, we used a technically optimised, industrial multi-wire saw and equipped it with additional measurement technology. We used this to produce wafers of monocrystalline and multicrystalline silicon and characterised their surface, micro-crack and fracture properties. The surfaces are characterised with laser confocal and chromatic confocal measurement systems. We prepare bevelled-polish cross-sections to determine the depth of cracks in the wafers. The micro-cracks are subsequently made visible by structural etching and evaluated optically to determine the maximum crack depth. Analysis of these parameters allows not only the sawing process to be improved, but also the resistance to fracture of wafers to be determined and optimised on an industrial scale. We demonstrated that the maximal crack depths for monocrystalline wafers are about 15 % less and the fluctuation in the crack depth on a single wafer is about 40 % less than for multicrystalline silicon wafers (Fig. 3). This indicates a higher critical fracture stress for monocrystalline wafers, which was confirmed by fracture tests.



3 *Comparison of the maximal crack depths for polished, oblique cross-sections of several monocrystalline and multicrystalline silicon samples.*

1 *Highly resolved, confocal laser 3D image [256 x 256 x 80 µm³] of a commercial diamond-coated sawing wire.*

2 *3D image (128 x 128 µm²) of a bevelled-polish cross-section. The black areas are micro-cracks that were made visible by structural etching.*

The work was supported by the European Regional Development Fund (ERDF), the German Federal Ministries for the Environment, Nature Conservation and Reactor Safety (BMU) and of Education and Research (BMBF), the Saxon State Ministry for Sciences and Arts (SMWK) and the Sächsische AufbauBank (SAB).

1

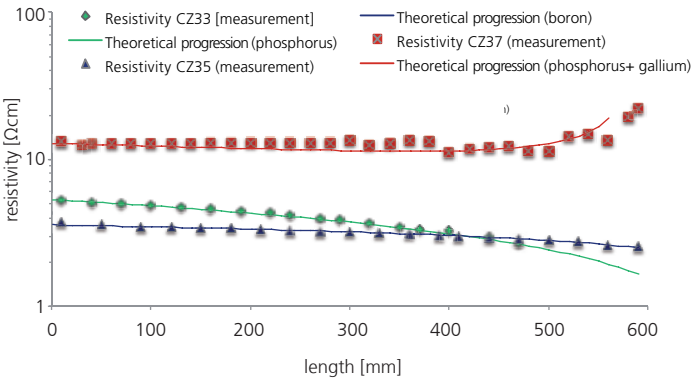
PRODUCTION OF MONOCRYSTALLINE P- AND N-TYPE INGOTS BY THE CZOCHRALSKI PROCESS

The Czochralski technique is currently the standard process for producing monocrystalline ingots. With our Czochralski puller, we are able to produce crystals in industrial dimensions, with typical diameters of 8" (210 mm). A current challenge is to prepare n-type material with the lowest possible variation in resistivity, as a basis for high-efficiency cell concepts. In the Crystallisation Technology Laboratory at Fraunhofer CSP (CSP-LKT) in Halle, we are investigating the interaction behaviour of various dopants and are testing different options to influence the axial resistivity profile. One approach which we are currently following is additional doping with gallium. Another possibility is to feed additional silicon into the process.

Rainer Barth, **Peter Dold**, Thorsten Eckardt, Malte Ernst, André Henkel, Roland Kunert, Stefan Wieczorek, Frank Zobel, Andreas Bett

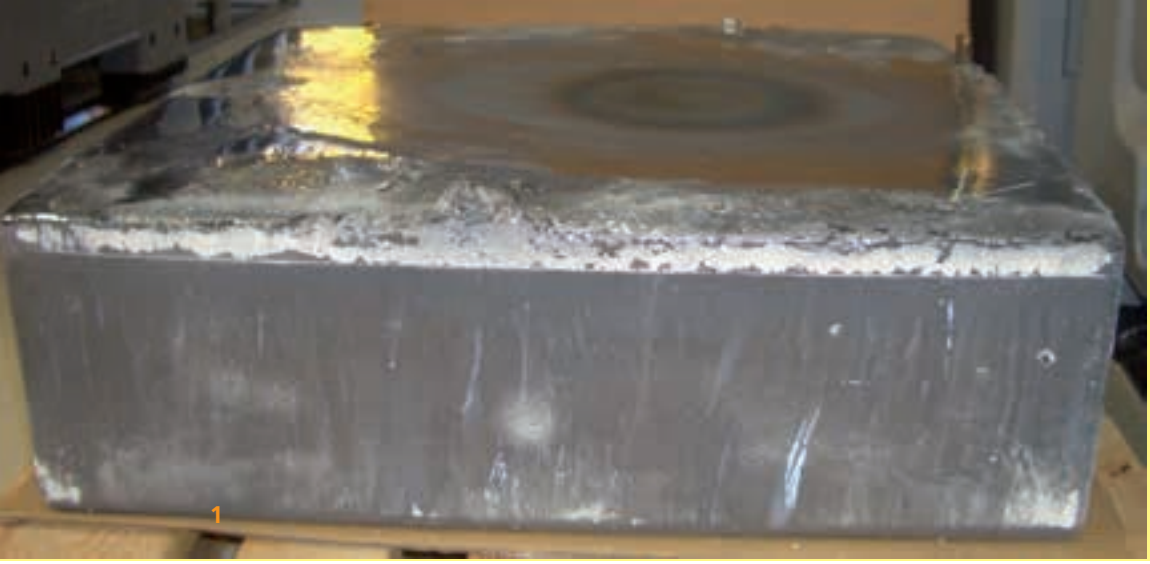
The production of monocrystalline ingots as the starting material for cell manufacturing is a central topic for CSP-LKT. With our Czochralski puller, model EZ-2700, we are able to process an initial charge of up to 60 kg, which corresponds to an ingot length of about 600 mm for a diameter of 210 mm (or the equivalent of about 2000 wafers per batch). Key questions which we address include the evaluation of feedstock materials, the interaction between the silicon melt and the quartz glass crucible and its effect on crucible corrosion, the crystallisation behaviour of different types of material, such as granulate compared to silicon chunks, additional feeding of silicon during the process and finally the production of ingots with specific dopants and doping profiles.

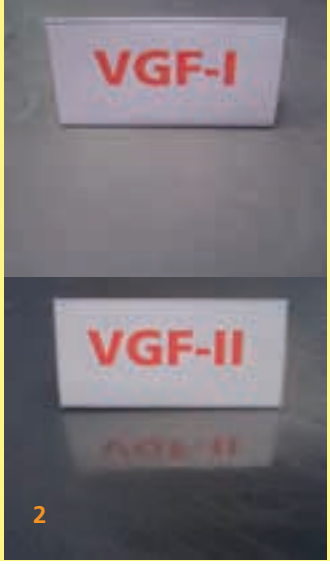
1 *Czochralski single crystal, diameter: 210 mm, mass 55 kg.*



2 *Resistivity profiles of different 8" crystals: calculated values and values determined experimentally with a four-pin probe.*

The increasing demand for n-type material – as the basis for future high-efficiency cell concepts – creates more challenges for the crystallisation process: Whereas boron (for the production of p-type material) distributes itself relatively homogeneously throughout the crystal, the phosphorus used to create n-type crystals is present in a significantly higher concentration toward the end of the ingot than at the beginning, which causes the resistivity to drop markedly. It is desirable to attain an even, homogeneous resistivity profile in order to minimise variations during cell production. This can be controlled e.g. by feeding in additional silicon or co-doping the phosphorus with gallium.





CRYSTALLISATION OF 250 KG SILICON BLOCKS – OPTIMISATION OF THE GAS FLOW

Multicrystalline ingots feature a relatively low oxygen concentration and thus reduced formation of B-O complexes, but they are also subject to possible supersaturation with carbon and thus formation of SiC precipitates. Optimisation of the gas flow in our G4 crystalliser is an important focus of our work. The goal is to minimise the interaction between the CO contained in the processing gas atmosphere and the surface of the molten silicon, in order to obtain the highest possible yield of blocks and usable wafer material.

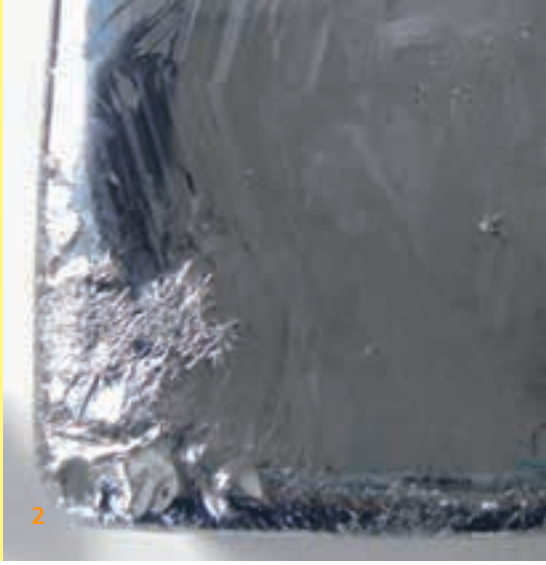
Rainer Barth, **Peter Dold**, Thorsten Eckardt, Malte Ernst, André Henkel, Roland Kunert, Stefan Wieczorek, Frank Zobel, Andreas Bett

1 *Multicrystalline G4 block, mass 250 kg.*

2 *Crystallisation in an open crucible system leads to green-grey discoloration of the block surface (above: VGF-I). Optimisation of the argon flow results in glossy surfaces (below: VGF-II).*

At CSP-LKT in Halle, we are equipped with a VGF-732 Multicrystalliser system for crystallisation of G4 blocks with a mass of 250 kg. Typical processing times are in the range of 40 to 50 hours, with solidification rates of about 1 cm/h. Crystallisation takes places in a continuous flow of argon. On the one hand, the argon enhances convection in the melt, which improves melt mixing. On the other hand, the argon facilitates the removal of CO from the interior of the furnace. The so-called "hot box", i.e. the region of the furnace where the crucible with the silicon melt is located, consists of a graphite support crucible, graphite heating elements and graphite insulation material. At the high temperatures of up to 1500 °C, traces of oxygen or residual moisture lead to the formation of CO. If CO comes into contact with liquid silicon, it is absorbed, dissolves in the melt and then, above a limiting concentration, forms SiC precipitates, which are then incorporated into the growing crystal. These SiC precipitates cause problems when the blocks are sawn into wafers and can lead to short circuits (shunts) in the cells. The interaction between CO and the silicon melt can be controlled and minimised by varying the design of the hot box and optimising the argon flow and the geometrical configuration of the inlet pipe. To better understand the chemical processes in the gas chamber, we have installed a residual gas analyser – this allows us to investigate the concentration of residual moisture, oxygen, carbon monoxide or other gas-phase impurities as a function of the processing conditions and the process parameters.

The transition from an open to a partially open and finally to an almost closed crucible configuration led to a continous reduction in SiC formation. Whereas initially there was green-grey discoloration of the block surface, we are now able to crystallise blocks with almost mirror-like surfaces. There is further potential for optimising the flow rate of the incoming argon and the geometrical configuration of the gas inlet pipe. By improving the pipe configuration and combining this with an almost closed crucible system, we were able to reduce the argon flow rate (and thus the argon consumption) appreciably, without causing any noticeable formation of SiC in the surface zone.



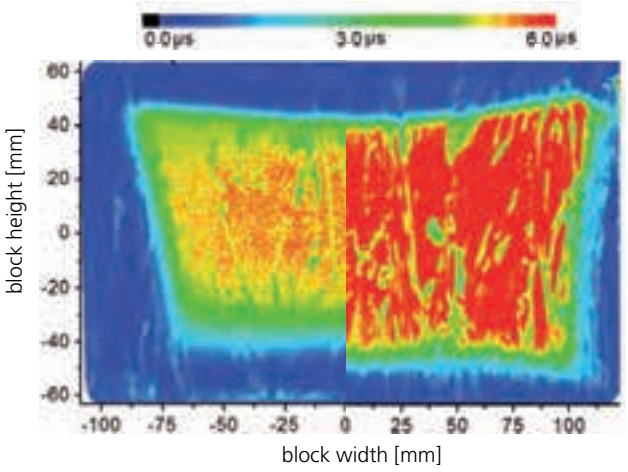
EXTREMELY PURE SILICON BLOCKS FOR HIGH-EFFICIENCY SOLAR CELLS

A major challenge concerning directional solidification of block silicon with high material quality for use in high-efficiency solar cells is to reduce the introduction of impurities from the crucible system and the furnace chamber into the silicon during crystallisation. At the Silicon Material Technology and Evaluation Centre SIMTEC, we are studying the transfer mechanisms for impurity elements from various crucible materials and coatings and the introduction of volatile impurities via the gas phase into the silicon. By using new materials in the crucible systems and optimising the gas management, we have achieved a significant improvement in the electrical properties of multicrystalline silicon.

Fridolin Haas, **Stephan Riepe**, Claudia Schmid, Mark Schumann, Evariste Wete, Andreas Bett

1 *Side view of an experimental silicon block after crystallisation with a modified crucible coating.*

2 *Reflective surface of an experimental silicon block after optimisation of the gas management.*

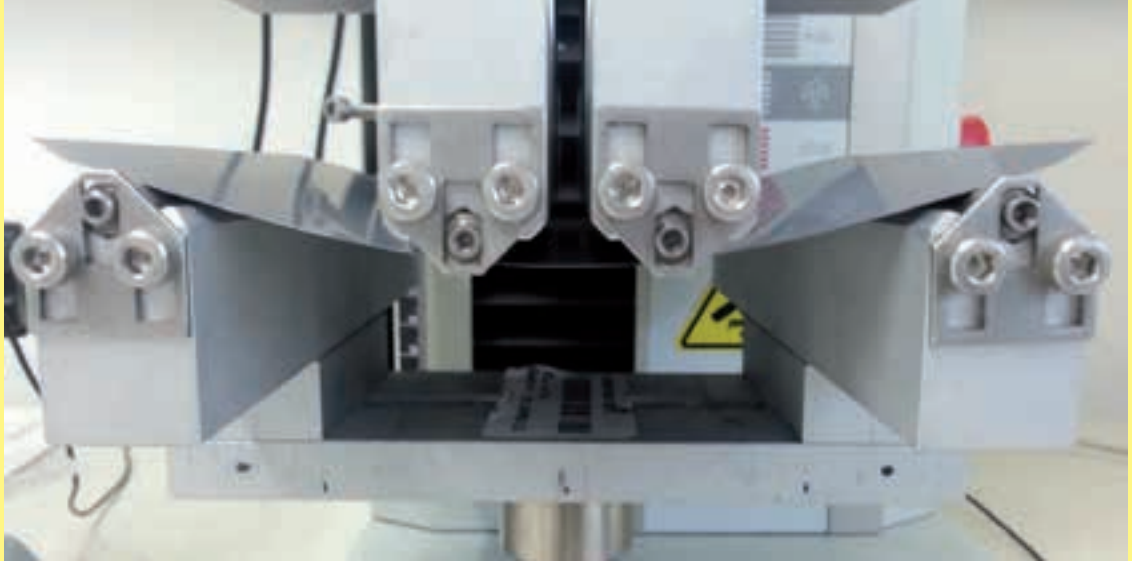


3 *Spatial distribution of charge carrier lifetimes in a vertical cross-section of a G1 block with a conventional, industrial crucible system (left half) and an extremely pure, experimental crucible system (right half).*

The crucible system used today industrially consists of a quartz crucible, which is surrounded by a support system usually constructed of graphite. The quartz crucible is coated with a separating layer of silicon nitride to allow the silicon block to be extracted from the crucible. When the silicon is melted and solidified, impurity atoms or small particles can dissolve out of the crucible system and enter the silicon. This introduces elements into the silicon, particularly in the edge and cap zones of the block, which reduce the material quality and create regions with short charge carrier lifetimes.

By applying experimental crucibles made of extremely pure quartz material in an appropriately adapted crystallisation process, and by using purified silicon nitride powder to produce the crucible coating, we were able to prepare silicon blocks of great material purity with significantly reduced concentrations of damaging impurities such as iron and other transition metals (Fig. 3). We reduced the concentration of oxygen and carbon significantly by optimising the gas management in the furnace chamber with the help of fluid simulation and further development of the crucible system. This is evident from the reflective surfaces of the silicon blocks (Fig. 2).

The work is supported by the Fraunhofer Foundation and the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) within the "Solar-Wins" project.



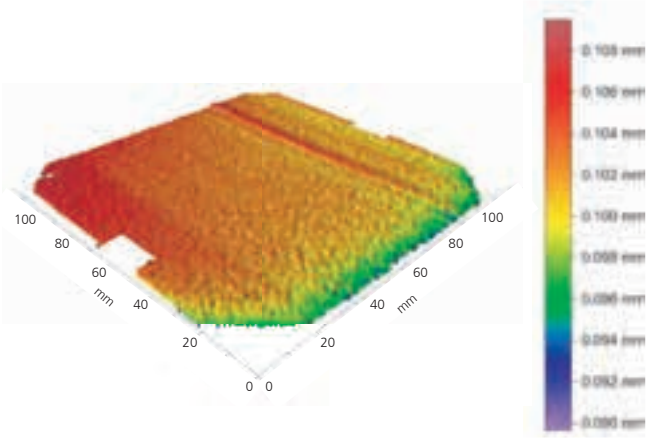
DEVELOPMENT OF SLURRY-BASED WIRE-SAWING PROCESSES FOR THIN WAFERS

Silicon wafers for photovoltaics are produced industrially by sawing crystalline material with a multi-slit wire saw. In this process, the silicon material is fed through a field of several hundred wire loops and sawed into wafers with the aid of an abrasive medium. At the Silicon Material Technology and Evaluation Centre SIMTEC, we are working on the further development of slurry-based wire-sawing processes to produce thin wafers. We are investigating the influence of process parameters which affect the wafer morphology and can reduce the mechanical stability of wafers. On this basis, we have been able to establish a process to produce wafers with an average thickness of 110 µm.

Philipp Häuber, Teresa Orellana, Stephan Riepe, Devid Sabo, **Bernd Weber**, Andreas Bett

1 *Monocrystalline wafer, 110 µm thick, being tested for mechanical stability in the four-blade test.*

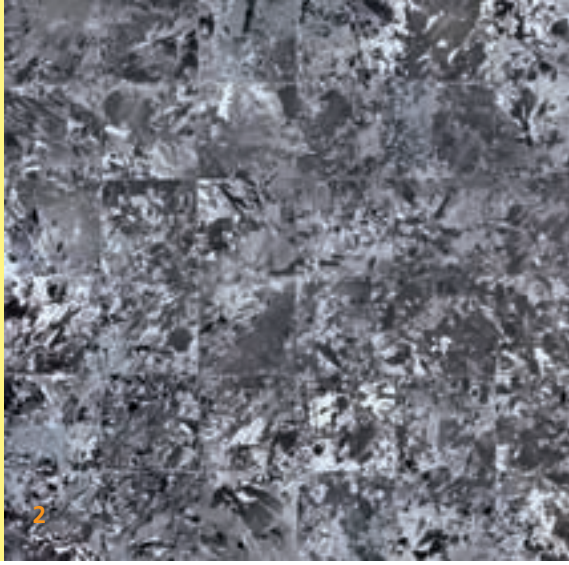
Thinner and thinner wafers for solar cells are being produced with multi-slit wire saws in the industrial wire-sawing process. On the one hand, the cost per wafer is reduced by a higher wafer yield per silicon ingot. On the other hand, thinner solar cells can be advantageous for the efficiency. However, the demands on the sawing process become more stringent if homogeneous wafers with a thickness of less than 160 µm are to be obtained. By further developing the slurry-based sawing process, we have produced wafers with an average thickness of less than 110 µm and little variation of thickness over the wafer area (Fig. 2).



2 *Thickness distribution of a monocrystalline wafer with an area of 125 x 125 mm² and a nominal thickness of 110 µm.*

A further important aspect is the rapidly increasing risk of wafer breakage during the wire-sawing process and the following process steps. As part of our development work, we have thus investigated the effect of factors which reduce the mechanical stability of wafers. Damage to the edge of the wafer has a particularly strong effect, so that further treatment of the block surface after separation of the ingot is unavoidable. Analysis of the mechanical stability of 110 µm thick wafers with the four-blade measurement device (Fig. 1) show that band-sawing causes great damage to the surface. This can be significantly reduced by polishing and etching or a combination of both.

The work was supported by the Fraunhofer Foundation and the European Commission within the "20plµs" project.



ProConCVD – COST-EFFECTIVE SILICON EPITAXY FOR PHOTOVOLTAICS

Epitaxial growth of silicon is a key technology to enable future production of thin crystalline silicon solar cells. For several years, we have been developing a high-throughput reactor for a cost-effective epitaxial process suitable for production. Now we have succeeded for the first time in epitaxially coating several square metres of substrate with silicon in a single run. This means that the basis has been laid to successfully combine the best of microelectronic, thin-film and crystalline silicon solar cell technology with each other.

Martin Arnold, Philipp Barth, Dirk Krogull, David Pocza, **Stefan Reber**, Norbert Schillinger, Andreas Bett

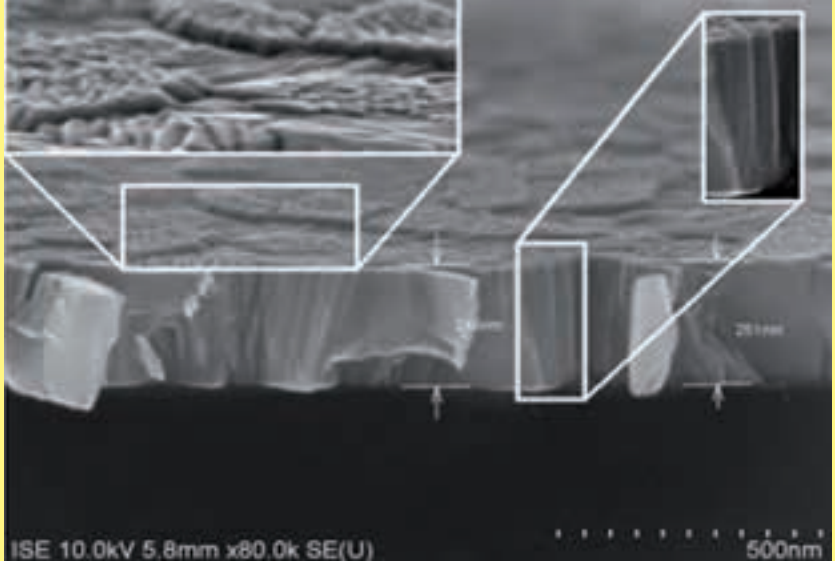
A series of new solar cell concepts is currently under development, which is based on thin, high-quality crystalline silicon films. Either extremely thin wafers ("kerfless wafers") are used or areas with module dimensions are coated. For all concepts, deposition technology is required which provides high-quality silicon films. To this purpose, we have developed the ProConCVD equipment (Production Continuous Chemical Vapour Deposition), which was specified to result in low manufacturing and production costs and a high throughput.

The equipment consists of three individual tracks, in which each two rows of substrate carriers with an area of about 0.5 x 0.5 m² can be lined up next to each other. The rows of substrates are then pushed through a loading zone, then through two heated deposition zones and finally through the unloading zone. Gas curtains at the loading and unloading zones ensure that there is no gas exchange between the interior of the equipment and the outer area, and that transport can take place continuously without any interruption. The substrates are coated with silicon from the gas phase as they pass through the equipment, without any interruptions for loading and unloading processes, and the special pairwise configuration of the tracks ensures that maximum usage of the gas is made. With an area of about 5 m² in the deposition zones and a maximum transport rate of twelve metres per hour, we can achieve a throughput of more than 30 m² or 1200 wafers per hour with our high-temperature processes – about 100 times higher than with commercially available microelectronic reactors.

The project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) as well as the Fraunhofer Future Foundation.

1 *ProConCVD: Substrate carriers in the loading station can be seen at the right of the photo. To their left are the entrance gas curtain and the heating furnace. The carriers leave the ProConCVD at the left-hand end.*

2 *Multicrystalline wafers with an area of 156 x 156 mm² that were epitaxially coated in the ProConCVD reactor. During the process, which lasts 30 minutes, 72 wafers were coated with approximately 13 µm silicon.*



SOLAR CELLS WITH BACK-SURFACE AMORPHOUS SILICON HETERO-EMITTERS

N-type silicon solar cells featuring an amorphous-crystalline silicon heterojunction have enormous potential for high efficiency due to the effective surface passivation and the resulting very high voltages. However, a limiting effect is the reduction in current caused by parasitic absorption in the amorphous silicon hetero-emitter and the transparent conductive oxide (TCO) on the solar cell surface facing the sun. This drawback can be reduced by positioning the silicon hetero-emitter on the back-surface of the solar cell and employing a transparent diffused front-surface as in conventional solar cells. This opens up new possibilities to optimise the doping and thickness of the amorphous silicon layer and obviates the need for a TCO on the front-surface.

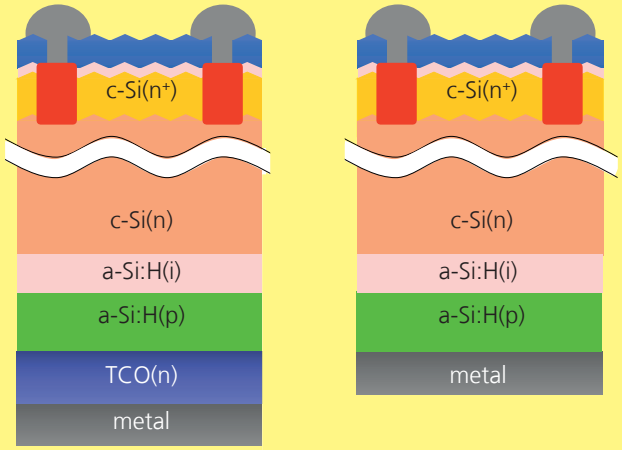
Martin Bivour, Lena Breitenstein, Frank Feldmann, **Martin Hermle**, Nicolas König, Antonio Leimenstoll, **Christian Reichel**, Markus Reusch, Kurt-Ulrich Ritzau, Felix Schätzle, Christian Schetter, Sonja Seitz, Sebastian Schröer, Harald Steidl, Nadine Weber, Karin Zimmermann, Stefan Glunz

Solar cells with an amorphous-crystalline silicon heterojunction are distinguished by a high efficiency potential due to the low level of surface recombination and thus form an important part of our research activities on n-type silicon. Very high voltages are achieved for these solar cells due to the effective passivation of the crystalline Si surfaces with amorphous Si layers. However, the high voltages are usually accompanied by reduced current, as parasitic absorption occurs on the light-facing surface in the amorphous Si layers and the required TCO coating, so some absorbed light is not converted into electricity.

1 *Cluster system to deposit amorphous Si hetero-emitters, applying plasma-enhanced chemical vapour deposition (PECVD) and sputtered TCO coatings (left). In the SEM image of a TCO coating, the columnar structure and the large grains are clearly evident (right).*
2 *N-type Si solar cell with an amorphous Si hetero-emitter, a-Si:H(p), with (left) and without (right) a TCO(n) coating on the back-surface. To passivate the front surface, a front-surface field, c-Si(n^+), is used with passivating dielectric layers.*

Thus, the efficiency value of the solar cells is limited, despite the high voltages. One possibility to avoid parasitic absorption in the amorphous Si layers is to position the amorphous Si hetero-emitter on the back-surface of the solar cell and to use well-known transparent approaches to passivate the front-surface, such as the application of a diffused or implanted front-surface field and/or passivating dielectric layers.

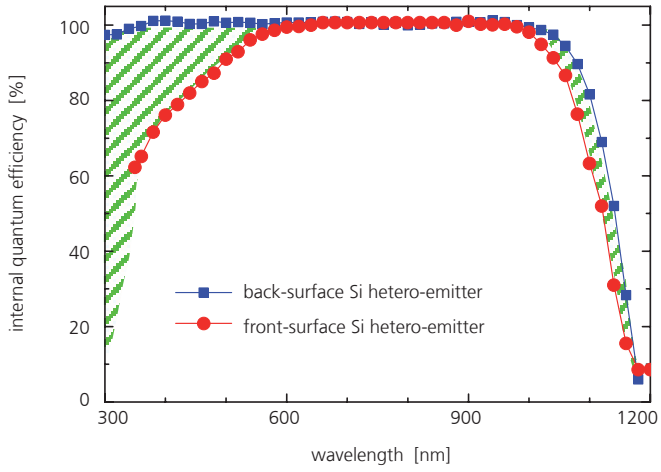
A back-surface Si hetero-emitter opens up new possibilities for optimisation regarding the doping and film thickness, as the Si hetero-emitter does not have to be designed to achieve excellent optical properties. In conventional heterojunction solar cells, the p-type amorphous Si hetero-emitter is contacted with n-conductive TCO. This creates a Schottky barrier which hinders the transport of charge carriers and can strongly reduce the fill factor of the solar cells. We were able to demonstrate that an illumination-dependent voltage measurement is a simple and valuable method to investigate these barriers. Figure 4 illustrates that high emitter doping can reduce the effect of this Schottky barrier, thus increasing the fill factors.



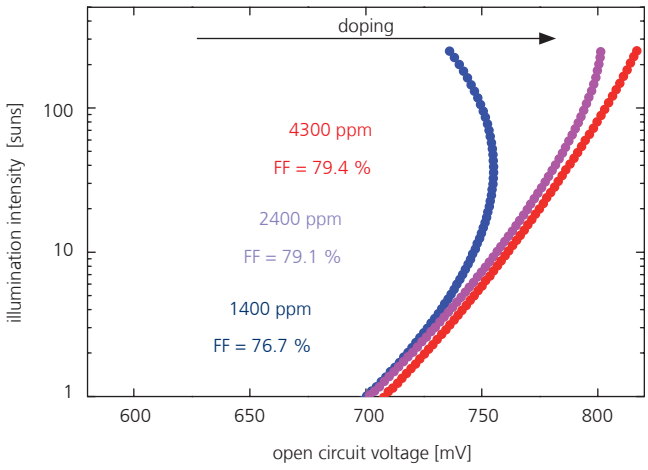
2

A further advantage of cells with back-surface p-type emitters is that in principle a TCO contact layer is no longer needed. Currently TCOs employed on the front-side contain the scarce and expensive Indium. This new cell concept allows hetero-junction solar cells without TCO to be produced, offering more degrees of freedom in the electrical characterisation of the contact properties. The investigation of contact properties can be extended to opaque contact layers and can thus allow deeper insight into the limiting mechanisms. In addition to the advantages already mentioned for the solar cell with a back-surface amorphous Si hetero-emitter, the base conductivity aids the collection of charge carriers at the front surface, raising the fill factor. With this type of concept, we increased the efficiency value of solar cells in our laboratories up to 22.8 %. These cells are characterised not only by a high open circuit voltage of up to 705 mV and a short circuit current density of 39.9 mA/cm² but also feature very high fill factors, particularly for hetero-contacts, of up to 81.2 %.

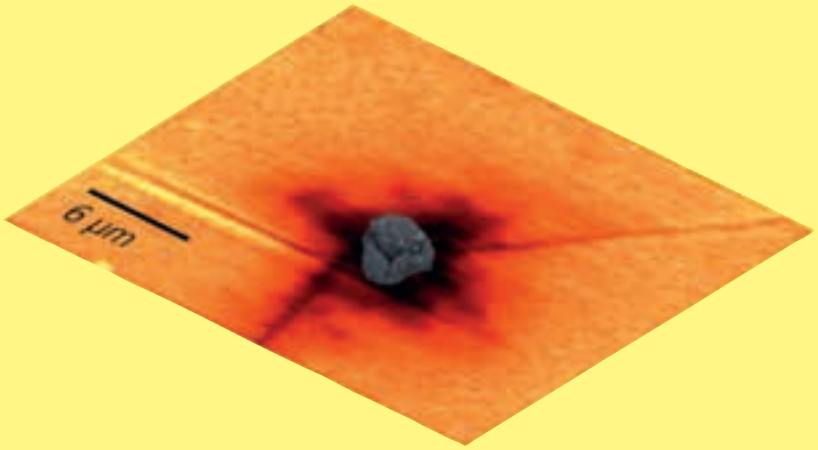
The work is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).



3 *Comparison of the internal quantum efficiency of solar cells with amorphous-crystalline Si hetero-emitters on the front-surface (red) and the back-surface (blue), whereby the front-surface of the latter features a transparent, diffused front-surface field. The shaded region symbolises the current gain which can be achieved by having a transparent front-surface coating.*



4 *Illumination-dependent open circuit voltage of solar cells with amorphous-crystalline Si heterojunctions for lightly doped (blue) and heavily doped (red) amorphous silicon hetero-emitters.*



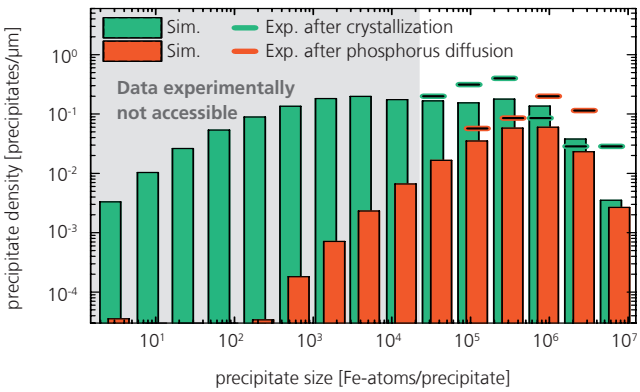
1

INFLUENCE OF PRECIPITATE DISTRIBUTIONS ON SILICON MATERIAL QUALITY

In solar cells made of block-cast silicon, metal impurities limit the achievable material quality and thus the efficiency potential. The effect of impurities on the charge carrier lifetime and thus on the solar cell quality depends essentially on their distribution. The density and size distribution of metal precipitates are very sensitive to the temperatures experienced during the crystallisation and cell processes. With the help of the models we have developed, the production processes can be optimised in this respect, resulting in improved material quality.

Alireza Abdollahinia, **Jonas Schön**, Martin C. Schubert, Wilhelm Warta, Stefan Glunz

The extent to which the efficiency potential of solar cells is limited by metal impurities depends on the feedstock material. Nevertheless, even when extremely pure silicon has been used, the diffusion of metal impurities from the crucible walls into the block during crystallisation leads to limitation of the material quality due to metals throughout the entire volume and particularly in regions close to the crucible.



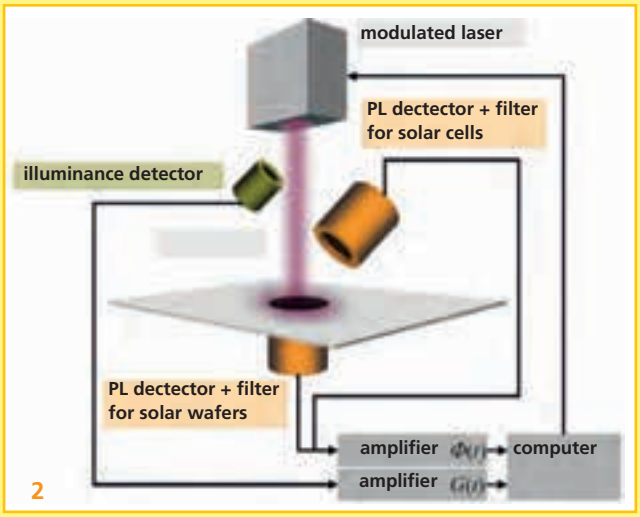
1 *The micro-spectroscopic measurement around a sketched metal precipitate near the junction of three grain boundaries reveals a clear decrease in the charge carrier lifetime near the precipitate.*

In general, metals which are concentrated into precipitates are less harmful to the solar cell than dissolved metals, but the concentration of precipitated impurities in solar cells made of block-cast silicon is often orders of magnitude higher than that of dissolved metals. The process steps which cause purification during solar cell production primarily remove dissolved metals, so that the significance of precipitates increases during processing.

With the help of a two-dimensional model developed at Fraunhofer ISE, the distribution of selected metal impurities is simulated in dependence on the feedstock material and the production process. In addition to its excellent prediction quality for the concentration of dissolved iron, comparison with recent measurements of the size distribution of iron precipitates demonstrates the high quality of the model (Fig. 2). From these results, the limitation of the charge carrier lifetime due to the various precipitates and the homogeneously distributed atoms is determined, and this in turn serves as the basis for optimisation procedures.

The project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

2 *Comparison of simulated and measured precipitate density along a grain boundary as a function of the precipitate size before and after emitter diffusion. Mainly small and medium-sized precipitates are removed during emitter diffusion.*



CHARACTERISATION BASED ON TIME-MODULATED LUMINESCENCE

Time-modulated luminescence is a procedure to determine charge carrier lifetimes in silicon wafers and solar cells. It is very robust against the artefacts which often appear in lifetime measurements and can be applied in material science applications in many different ways. Drawing on the work and theoretical insight gained in the previous year, we were able to deepen our understanding of this method in 2012 and develop new applications.

Johannes Giesecke, Martin Schubert, Wilhelm Warta, Stefan Glunz

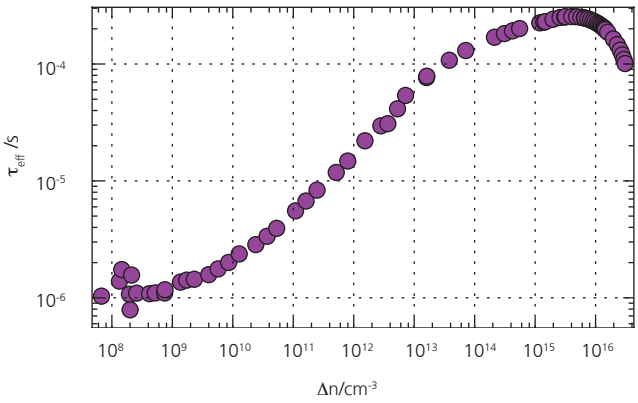
In time-modulated (quasi-steady-state) luminescence, the charge carrier lifetime of an optically or electrically excited semiconductor substrate is determined from the phase shift between the time-dependent profile for exciting free charge carriers and their radiative recombination. Although this phase shift is generally not identical with the charge carrier lifetime, the actual injection-dependent lifetime can be determined from this phase shift with an iteration procedure developed at Fraunhofer ISE. Further, it was demonstrated that the phase shift of a quasi-steady-state, time-modulated experiment corresponds to a so-called differential lifetime. The underlying theory enables the actual lifetime to be determined analytically from the measurable differential lifetime. This means a drastic reduction in the experimental effort needed for all differential lifetime measurements.

The following applications of time-modulated luminescence were newly developed:

- A procedure to determine the effective lifetime over a very wide injection range (Fig. 2). The measurement at very low injection density is highly relevant for diverse applications in materials science.

1 *Multicrystalline silicon wafer in our experimental setup – time-modulated luminescence is used for carrier lifetime measurements of wafers and solar cells.*

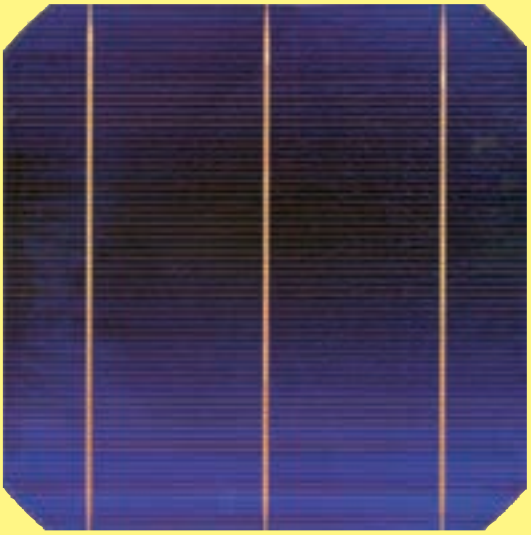
2 *Schematic diagram of the equipment used at Fraunhofer ISE for time-modulated luminescence measurements.*

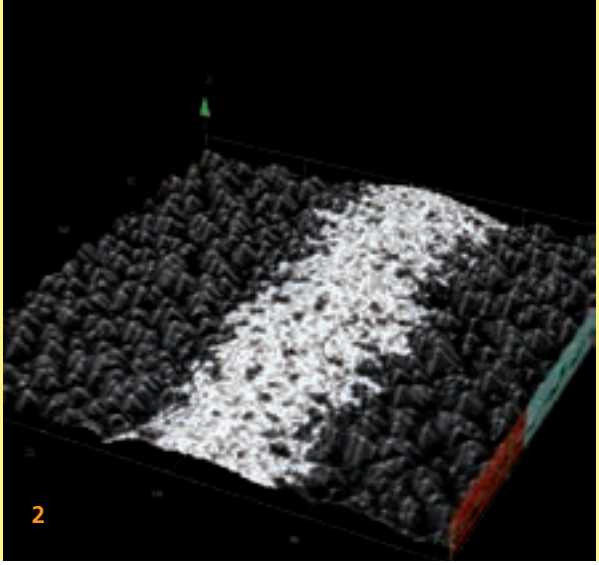


3 *Effective charge carrier lifetime τ_{eff} of a silicon wafer, determined as a function of the excess charge carrier density Δn by application of a procedure developed at Fraunhofer ISE on the basis of dynamic photoluminescence.*

- procedures to determine the net doping of silicon substrates
- lifetime determination in solar cells applying dynamic electroluminescence

The work was supported by the Fraunhofer-Gesellschaft within the "SiliconBEACON" project.





HYBRID PRINTED-GALVANIC CONTACTS WITH COST-EFFECTIVE MATERIALS

Material costs, particularly those for metallisation, offer the greatest potential to reduce the costs of crystalline silicon standard solar cells. Replacing expensive silver for the front-surface metallisation by cost-effective copper offers great opportunities but is technologically challenging. Hybrid contacts facilitate the introduction of copper, but require detailed understanding of the interaction between the printing pastes for contacting and the galvanic reinforcement solutions. With this knowledge, it is possible to produce hybrid contacts of silver, nickel and copper, which adhere well, are durable and allow savings of up to 90 % in the material costs.

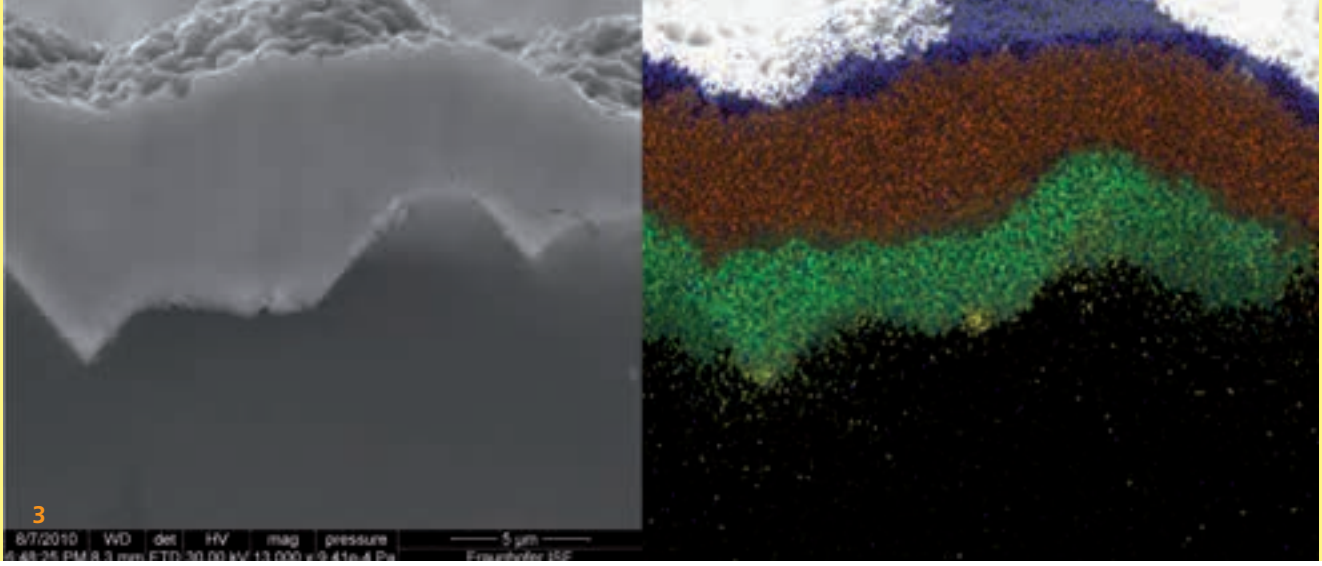
Jonas Bartsch, Markus Glatthaar, Achim Kraft, Andrew Mondon, Markus Wendling, Stefan Glunz

1 *Solar cell after copper-plating, before growth of the cover layer of silver or tin.*

2 *Example for a printed seed layer with very narrow width (app. 30 µm) and very little material usage (app. 40 mg paste).*

Multiple-layer contact stacks for solar cells have been intensively researched for many years due to the flexibility that they offer. One of the most interesting techniques to apply the metals is galvanic deposition due to the high conductivity of the metal coatings, the low processing temperatures and the low costs.

The process of this type which can be most simply introduced into solar cell production is galvanic reinforcement of printed contact seed layers. Only very slight modifications to existing production lines need to be made for the resulting hybrid contact, as the seed layers can usually be printed with the technology already employed today. Nevertheless, major savings in material costs can be achieved with this technology. These features agree well with present demands of the solar cell industry for cost reduction strategies without major investments or far-reaching changes to the production sequence. The cost reduction potential is provided by the opportunity to replace much of the silver used as a contact material by copper. Depending on the printing method used to create



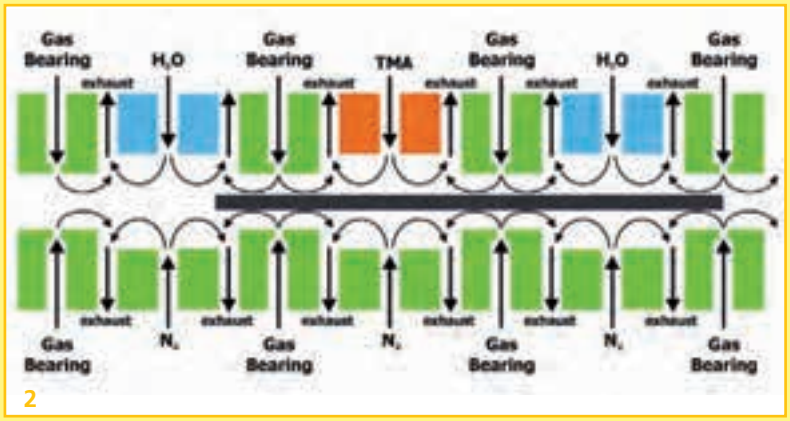
the seed layer, only about 30 mg of silver paste (fine-line screen-printed seed layer) or even only 8–15 mg of silver paste (aerosol printing or ink-jet printing) is needed instead of approximately 100 mg of silver (industrial screen-printing completely of silver). This allows production costs to be reduced significantly. In addition, the future availability of copper should be much more favourable than for silver.

Whereas galvanic deposition of silver onto printed seed layers is already largely mastered technologically, there are still open questions concerning the usage of copper in hybrid contacts. Firstly, a barrier layer of nickel must be grown to prevent copper from diffusing into the solar cell. Here, the required consistency (thickness, homogeneity, imperfections) of this layer must be determined. Another aspect is that both galvanic nickel and copper electrolytes reduce the adhesion of printed contact layers to the wafer surface under certain conditions.

Detailed understanding of the interactions between the paste and the electrolyte were gained by chemical analyses and microstructural investigations. Reactions between the glass matrix of the contact and also some reaction products of contact firing and certain ionic species of the electrolyte solutions, as well as moisture and elevated temperatures affect the contact adhesion negatively. By adapting the galvanisation process, we have succeeded in increasing the adhesion to the required level, enabling this metallisation strategy to be applied even in the module. Following predictions of very good long-term stability based on initial estimates, it is planned to confirm these results with module tests according to the IEC 61215 standard. This will pave the way for industrial application of this cost-effective metallisation approach.

3 *Polished section and SEM image of a solar cell hybrid contact (left) and the corresponding element mapping from energy-dispersive X-ray spectroscopy (EDX, right). The following features can be recognised in the EDX image: printed silver seed layer (yellow), nickel diffusion barrier (green), copper conductive layer (red) and tin capping layer (blue).*

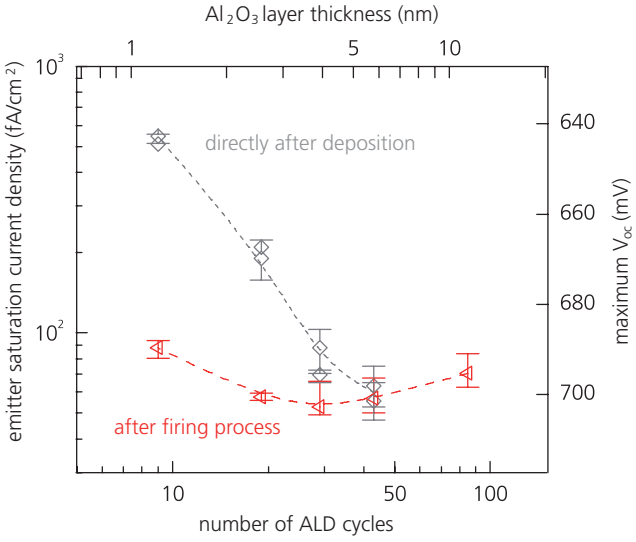
The work was supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) within the "KuLi" and "Sonne" projects.



RAPID IN-LINE ALD DEPOSITION OF ALUMINIUM OXIDE

Atomic Layer Deposition (ALD) of Al_2O_3 to passivate p-doped surfaces, particularly heavily doped surfaces, leads to excellent passivation results already with minimal layer thicknesses. With an in-line ALD reactor, in which sequential deposition of the processing gases is implemented by spatial separation of the reaction zones, we succeeded in obtaining layers of the same quality with industrially applicable equipment as from a laboratory unit.

Jan Benick, **Martin Hermle**, Antonio Leimenstoll, **Armin Richter**, Felix Schätzle, Christian Schetter, David Schuldis, Harald Steidl, Karin Zimmermann, Stefan Glunz



3 *Emitter saturation current density as a function of the Al_2O_3 layer thickness, measured on boron-doped emitters which were passivated with Al_2O_3/SiN_x stacks.*

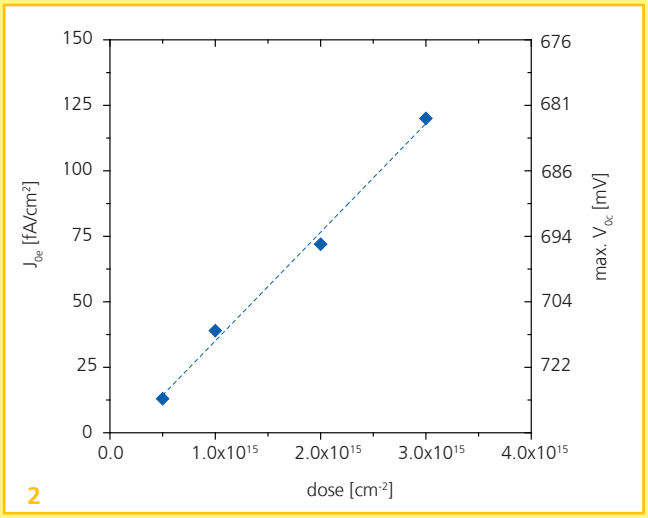
1 *In-line ALD reactor.*

2 *Schematic cross-section through the reactor zone of the in-line ALD reactor.*

In recent years, interest in aluminium oxide (Al_2O_3) for silicon photovoltaics has increased strongly. The reason is the fact that aluminium oxide passivates boron-doped surfaces very effectively. Al_2O_3 is thus interesting for very diverse solar cell concepts, particularly for the back-surface of p-type solar cells or the passivation of the boron emitter of n-type solar cells.

The best results to date have been achieved with atomic layer deposition. Due to sequential deposition of aluminium and oxygen, Al_2O_3 grows monolayer for monolayer. The processing time can be significantly shortened with the in-line ALD reactors recently developed by the industry, so that application in industrial solar cell production becomes feasible. In contrast to sequentially operating ALD, the reactions in an in-line ALD reactor are distributed among different reactor zones, through which the wafers move on an air cushion (Fig. 3). Typical layer thicknesses of 4 nm can be obtained in a processing time of approximately 15 seconds.

We used an in-line ALD reactor produced by the SoLayTec company to optimise the processes and develop Al_2O_3 layers which enable very effective passivation on both lightly and heavily doped p-type surfaces. In particular, excellent results could be obtained after the firing process that is needed to form contacts with printed metal pastes. This is shown in Fig. 2, taking a boron emitter as an example, which was passivated with a layer stack of Al_2O_3/SiN_x. For n-type solar cells, this passivation makes a V_{OC} potential exceeding 700 mV feasible.



ION IMPLANTATION FOR PHOTOVOLTAICS

Many cell concepts for highly efficient silicon solar cells feature local doping, e.g. heavily doped zones beneath the contacts. Ion implantation proves to be an ideal technology for creating such locally heavily doped regions, as the structuring can be created in situ by using shadow masks. However, the crystal surface is damaged or made completely amorphous during implantation due to the high energy of the implanted ions. This surface damage must be healed in a subsequent high-temperature annealing step, during which a SiO_2 passivation layer can also be created. By optimising the implantation process and the annealing step, we have succeeded in making a completely implanted silicon solar cell with an efficiency value exceeding 22 %.

Jan Benick, Martin Hermle, Antonio Leimenstoll, Andreas Lösel, Ralf Müller, Felix Schätzle, Christian Schetter, Sonja Seitz, Nadine Weber, Stefan Glunz

Doped zones are conventionally created in photovoltaics by diffusion (tube furnaces). However, the entire wafer is covered with dopant in this process, so that local doping can be achieved only by the use of structured diffusion barriers. By contrast, local doping can be implemented with ion implantation by use of a shadow mask, i.e. without additional processing steps. Implantation is also superior to other doping processes, e.g. diffusion in a tube furnace, with regard to reproducibility and homogeneity of the doping. A high-temperature annealing step is needed to heal the crystal damage caused by implantation. However, this step can be used simultaneously in the solar cell process to deposit a high-quality thermal oxide for surface passivation.

1 *The ion implanter, which was recently installed in the clean room of Fraunhofer ISE, allows silicon to be doped with boron and phosphorus at very exactly defined positions.*

2 *Emitter saturation current density and maximal open-circuit voltage as a function of the implantation dose for phosphorus profiles passivated with SiO_2.*

The electrical quality of such implanted emitters is illustrated by Fig. 1. It shows the saturation current densities and the resulting maximal open-circuit voltages for different implanted phosphorus emitters (varying implantation dose), which were passivated with SiO_2 during the annealing step. It is evident that lower saturation current density (down to 20 fA / cm²) can be achieved with weaker doping and thus higher sheet resistance.

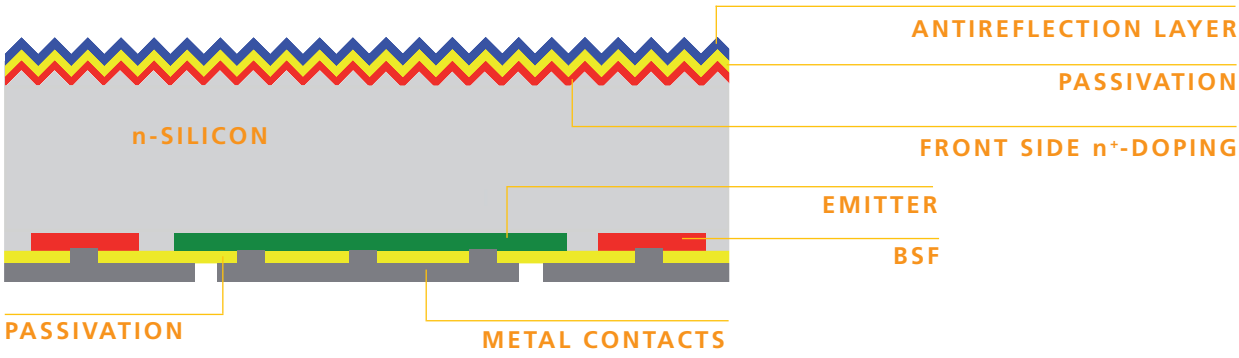
With an optimised annealing step, the crystal damage for both boron and phosphorus implantation can be healed together, so that only one high-temperature step is needed. To evaluate the developed processes, we have produced solar cells with boron implantation over the entire front-surface and phosphorus implantation over the entire back-surface. These cells reached efficiency values exceeding 22 %, the highest value ever achieved for a completely implanted solar cell with contacts on both surfaces. The ion implanter which has now been installed at Fraunhofer ISE enables us to evaluate very diverse concepts and technology, so that the efficiency of ion-implanted solar cells can be increased further in future.

CUSTOMISED DOPING STRUCTURES FOR BACK-CONTACT SOLAR CELLS

Very fine and precisely defined structures can be created by inkjet printing technology. At Fraunhofer ISE, we have co-operated with materials manufacturers to apply inks that can be used directly in inkjet printing and function as diffusion barriers. This elegant processing step is particularly interesting for so-called back-contact, back-junction (BC-BJ) solar cells, because it can significantly reduce the number of processing steps needed to produce such cells.

Daniel Biro, Raphael Efinger, Philip Hartmann, Mike Jahn, Roman Keding, Achim Kimmerle, Jan Specht, Benjamin Thaidigsmann, David Stüwe, Robert Woehl, **Andreas Wolf**, Ralf Preu

1 *BC-BJ solar cell (156 x 156 mm²) with front (left) and rear side (right), fabricated with industrially feasible processes in the PV-TEC laboratory.*

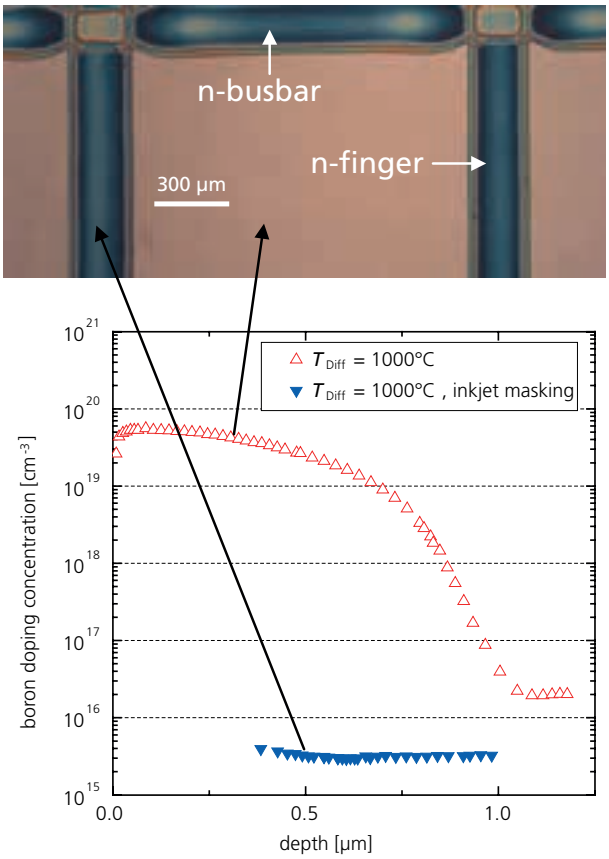


2 *The high efficiency BC-BJ solar cell uses n-type Si wafers and features a front-surface which is optimised for optical and electrical properties. The emitter, the back-surface field (BSF) and both metal contacts are located on the back-surface of the solar cell.*

The standard Al-BSF solar cell which is most commonly industrially produced today is manufactured with relatively few process steps, most of which are simple and affect the entire surface of the cell. However, this limits the efficiency value which can be achieved for such cells. The back-contact, back-junction (BC-BJ, Fig. 1 and 2) solar cell, with its emitter and contacts of both polarities on the back-surface, has potential for very high efficiency. The challenge now is to produce the more complex solar cell structure with as few processing steps as possible, which can be industrially implemented.

To meet this goal, we are developing process clusters which allow several doping structures to be realised in a single high-temperature step (co-diffusion). At the same time, these structures must be produced locally with great accuracy.

We use high throughput inkjet technology to carry out the patterning steps with the required precision. This contact-free printing technology allows dopant glasses to be etched back by using etching masks or enables local printing of dopant sources and diffusion barriers. Diverse processing parameters for the printing process, e.g. the printing resolution, were optimised to create fine structures. This allows the thickness and width of the diffusion barrier to be set reliably. Furthermore, parameters were determined for generating local structures which function as optimal barriers against phosphorus or boron diffusion (Fig. 3).

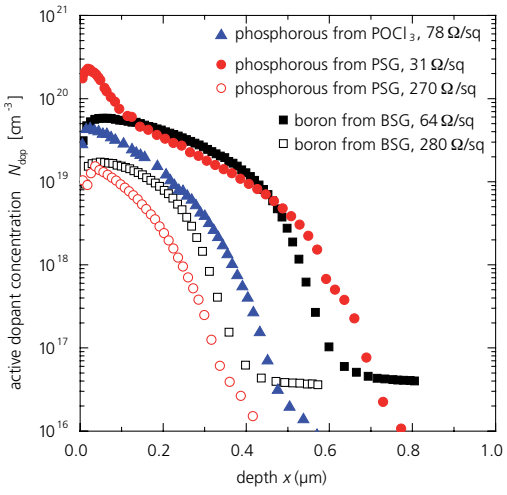


3 *Printed diffusion barrier that defines the n-doped regions (top). Even at diffusion temperatures T_{diff} ~1000°C, the printed diffusion barrier completely prevents the diffusion of boron into the Si wafer (ECV measurement, bottom).*

SIMULTANEOUS CO-DIFFUSION PROCESSES FOR N-TYPE SOLAR CELLS

In comparison to industrially produced solar cells made of p-type silicon, solar cells of n-type silicon have the potential for higher efficiency values. However, the process to manufacture highly efficient n-type solar cells is complex, as it typically needs several sequential masking and diffusion steps to form heavily n-doped or p-doped regions. One possibility to reduce the number of process steps required is to use simultaneous co-diffusion processes, in which previously deposited layers containing dopants serve as a diffusion source parallel to the diffusion from the vapour phase. The heavily doped regions are then formed in a single high-temperature step.

Daniel Biro, Arne Fallisch, Roman Keding, **Sebastian Mack**, Philip Rothhardt, Robert Woehl, Andreas Wolf, Ralf Preu



2 *Dopant depth profiles after diffusion from dopant sources deposited from the vapour phase ($POCl_3$) or as a solid (PSG or BSG). The same high-temperature step was used to generate all the depth profiles shown.*

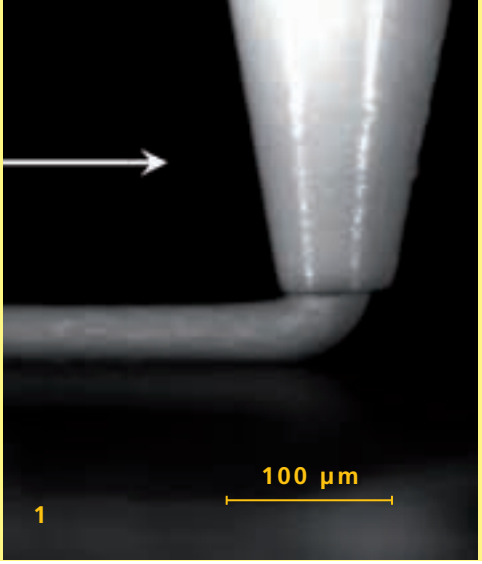
1 *Industrial quartz tube furnace for boron diffusion and co-diffusion processes to produce n-type Si solar cells in PV-TEC.*

At present, several different concepts for solar cells based on n-type silicon wafers are being intensively investigated. Most of them feature heavily doped regions with different dopants on the front and back-surfaces of the wafer. Depending on the solar cell concept, diverse specifications are made for the surface concentration and depth of the doping profile. The heavily doped regions are typically formed by diffusion from the vapour phase. For simultaneous co-diffusion processes, a solid diffusion source in the form of a thin film is deposited onto the sample already before the high-temperature step, e.g. by plasma-enhanced chemical vapour deposition (PECVD) or atmospheric pressure chemical vapour deposition (APCVD).

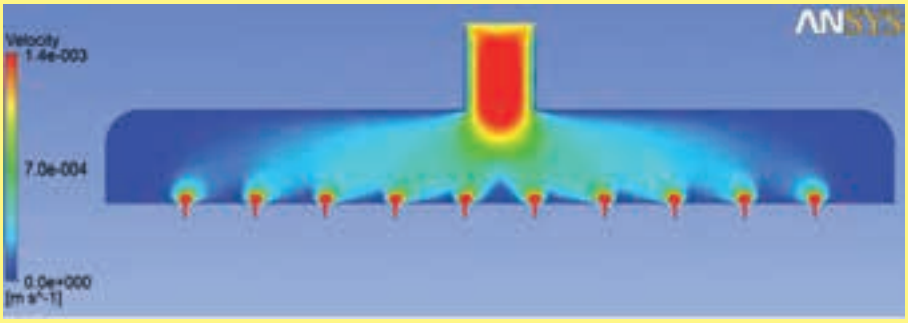
The choice of processing gases during deposition allows phosphorus silicate (PSG) or boron silicate glasses (BSG) to be deposited as the solid diffusion source with different dopant concentrations, which then causes n-type or p-type doping of the wafer in the subsequent high-temperature step.

In combination with conventional vapour phase diffusion, e.g. diffusion of $POCl_3$ or BBr_3, different depth profiles of various dopants can be generated simultaneously and very cost-effectively in a single high-temperature step on a single sample by adapting the processing parameters for this method (Fig. 2). Industrial quartz tube furnaces are available in PV-TEC at Fraunhofer ISE for such processes (Fig. 1). By combining the diffusion from three different sources in one single high temperature step, back-junction back-contact (BJ-BC) solar cells with 19.8 % conversion efficiency have been processed.

The work is supported by the European Union and the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).



1



2

NOVEL PRINTING PROCESSES FOR INDUSTRIAL SILICON SOLAR CELLS

Metal contacts are deposited onto the front- and back-surfaces of silicon solar cells to conduct the generated electricity out of the cell. On the front-surface, it is essential to achieve highly conductive contact fingers while simultaneously reducing shading of the solar cell to a minimum. In addition to continually improving the screen-printing process, which is used almost exclusively in industrial manufacturing of solar cells for metallisation, we are working intensively on the development of novel printing processes, particularly stencil printing, the dispensing process and rotary printing.

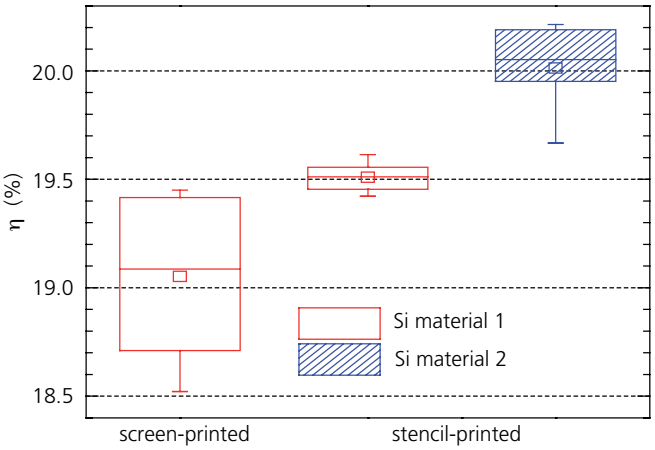
Daniel Biro, Florian Clement, Denis Erath, Harald Gentischer, Boris Hamouda, Markus Klawitter, Martin Kuchler, Michael Linse, Elmar Lohmüller, Andreas Lorenz, **Maximilian Pospischil**, Jan Specht, Benjamin Thaidigsmann, Ralf Preu

In stencil printing with hybrid stencils, the metallic paste is pressed in a single printing step through a finely structured metal sheet, which is coated with an emulsion on the lower surface. The grid structure of the metal sheet is held together by thin bars. With this process, it is possible both to improve the homogeneity of the contact fingers and to increase the finger height for constant contact width. The resulting increase in contact conductivity raises the absolute efficiency value by up to 0.3 % in comparison to standard screen-printing processes. With HIP-MWT solar cells, that were produced of large-area p-type Czochralski silicon wafers and passivated on both surfaces, efficiency values of up to 20.2 % have already been achieved with the stencil-printing approach.

A further possible alternative to the established screen-printing procedure is offered by the dispensing process, which has already enabled efficiency values of up to 20.6 % when

1 *High-speed camera image of a dispensing nozzle.*

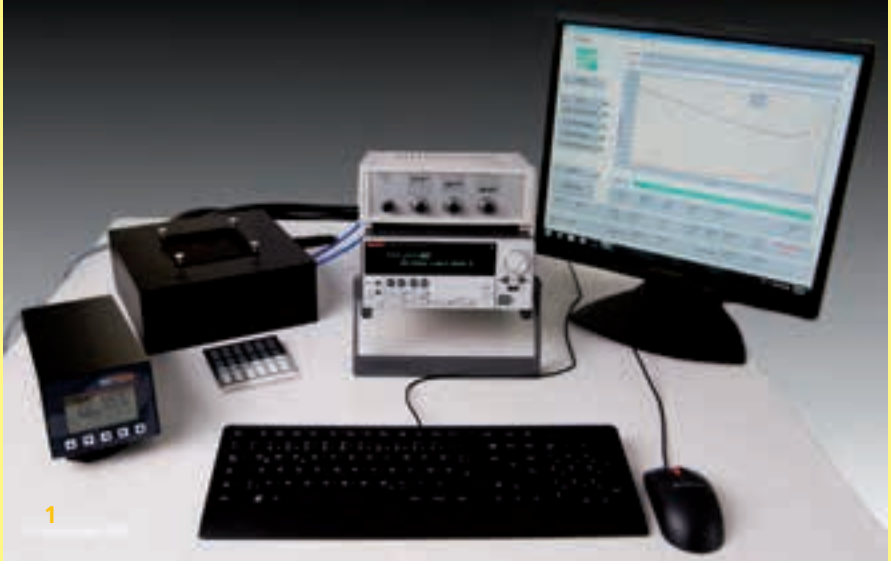
2 *Simulated speed profile of a 10-nozzle parallel-dispensing print head.*



3 *Distribution of efficiency values for large-area HIP-MWT solar cells made of two different types of Czochralski Si (cell area: 156 x 156 mm²). The front-surface metallisation with hybrid stencils leads to increased efficiency and greater process stability.*

applied to MWT-PERC solar cells made of p-doped float-zone silicon. In this process, the metallic paste is ejected through a thin dispensing nozzle which moves over the wafer and deposits a narrow line (Fig. 1). This allows the homogeneity and finger morphology to be improved again (line widths of less than 40 µm already demonstrated) and the mechanical load on the wafer is significantly reduced. Drawing on rheological investigations and subsequent fluid dynamic simulations (Fig. 2), we have succeeded in modelling the dispensing process realistically and in drawing conclusions for scaling up the print head in future.

The work is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) and an industrial consortium.



MEASUREMENT TECHNOLOGY FOR SILICON THIN-FILM TECHNOLOGY

At the Fraunhofer ISE Laboratory and Service Centre (LSC) in Gelsenkirchen, we have further extended our measurement technology for film characterisation and measurement of thin-film solar cells in 2012, parallel to expansion of the silicon thin-film technology itself. The aim is to be able to measure the most important properties of amorphous and microcrystalline silicon films on site. A newly developed measurement block allows us to measure the illuminated and dark IV curves of our thin-film solar cells fully automatically.

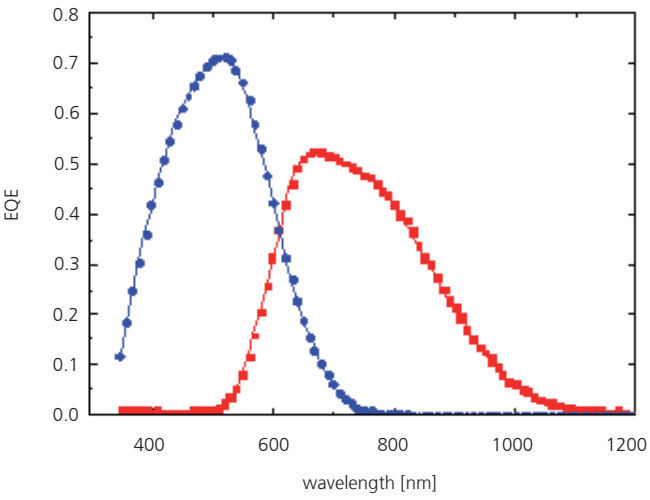
Dietmar Borchert, Martina Dörenthal, Stefan Hohage, Sven Holinski, Sinje Keipert-Colberg, Britt-Marie Meiners, Amada L. Montesdeoca-Santana, Markus Rinio, Petra Schäfer, Ralf Preu

1 *BlockIV system to measure illuminated and dark IV curves of silicon thin-film cells.*

We have optimised our **FAKIR System** for rapid measurement of sheet resistance especially for transparent, conductive oxide layers. The FAKIR system is ten times faster than conventional systems.

To determine the film quality of our amorphous and microcrystalline silicon films, we measure the temperature dependence of conductivity with our **SigmaT** measurement set-up. The light and dark conductivity values determined from these measurements at room temperature are important criteria for the quality of our deposition processes.

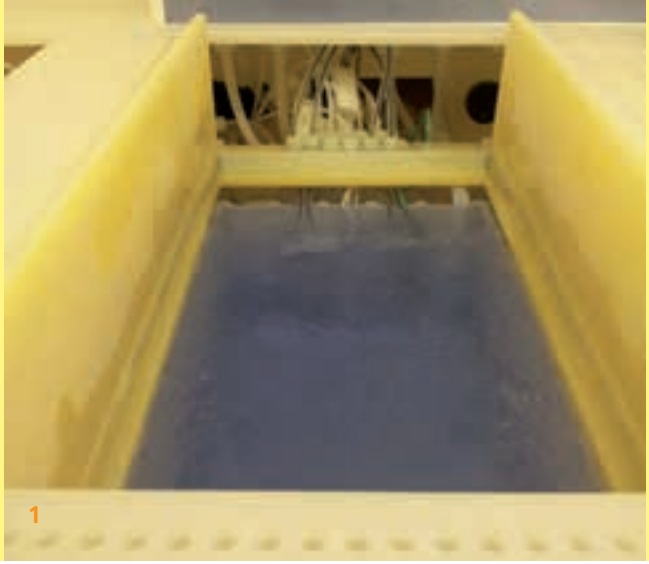
We have implemented two measurement methods with our **SpecLab System**. One is measurement of the spectral response or the external quantum efficiency (EQE) of our thin-film solar cells. The other is the constant photocurrent method (CPM), which we have integrated into the system. It allows the defect density in amorphous silicon to be determined.



2 *External quantum efficiency (EQE) of a silicon tandem cell measured with the SpecLab System. The quantum efficiency of the upper sub-cell is shown in blue, that of the lower sub-cell in red.*

We have developed a special **measurement block (BlockIV)** for the measurement of illuminated and dark IV curves, which allows all individual cells on our test substrates to be measured automatically. The block is internally temperature-controlled. The individual cells are identified by the measurement software via an automatic control box.

We also construct measurement systems of the types we have developed on demand for our project partners and external customers.



MULTIFUNCTIONAL O_3-BASED CLEANING FOR SOLAR CELLS

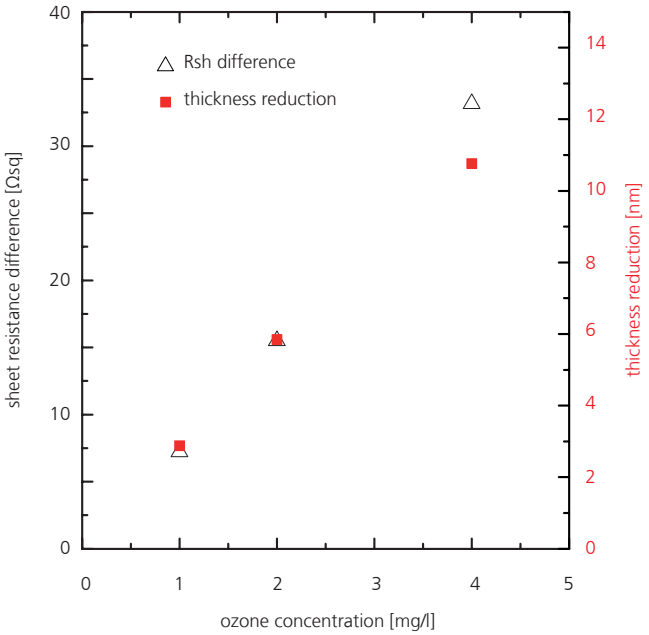
Effective cleaning to remove metal impurities is an important pre-condition for high-quality passivation of the surface of highly efficient, crystalline silicon solar cells. Cleaning baths based on hydrogen peroxide are operated at high temperatures and clean very efficiently. However, the high processing temperatures cause the hydrogen peroxide to decompose rapidly. By replacing the decomposed hydrogen peroxide, the concentration can be kept constant but the high consumption of chemicals makes this type of process uneconomic. Ozone-based cleaning baths can be used in many applications and are cost-effective.

Anamaria Moldovan, Jochen Rentsch, **Martin Zimmer**, Ralf Preu

Replacing hydrogen peroxide by ozone opens up completely new chemical engineering possibilities: Ozone, being a strong oxidising agent, can already provide the functionality of hydrogen peroxide at low temperature and concentration levels. An ozone generator prototype, which continuously generates ozone from oxygen and feeds it into the processing bath, was installed in an automated batch-processing system, that had been adapted to the needs of the photovoltaic industry.

A mixture of dilute hydrochloric and hydrofluoric acids is used to dissolve the oxidised impurities. The addition of hydrochloric acid increases the solubility of oxidised metals, while the hydrofluoric acid, combined with ozone, etches away several nanometres of the silicon surface in a controlled fashion. This exposes impurities which are located immediately below the surface and ensures that the cleaning is not only superficially effective. The effect can also be used to adjust the surface concentration on an emitter which may already be present. As the etching and cleaning effects can be adjusted

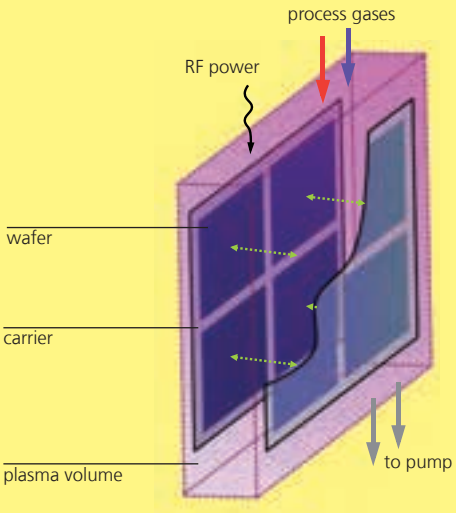
1 *Processing bath with water glowing blue-violet due to its ozone content.*



2 *Dependence of the difference in sheet resistance and the thickness reduction due to etching on the ozone concentration (for 1 minute processing time and constant concentration of hydrochloric and hydrofluoric acids).*

independently of each other by different parameters, this type of ozone-based cleaning process can result not only in simplification and cost reduction compared to previous cleaning processes, but also in the combination of cleaning and conditioning steps, which would allow the processing sequences for highly efficient solar cells to be simplified further.

The project was supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).



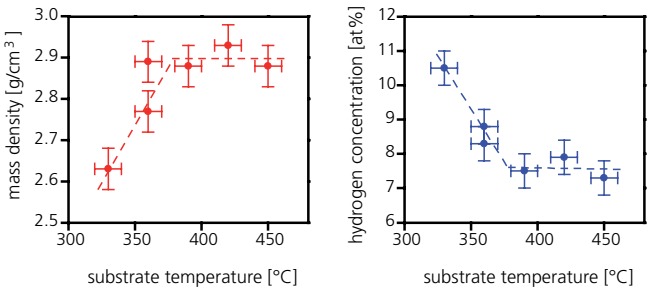
ANTI-REFLECTION AND PASSIVATION COATINGS FROM PLASMA DEPOSITION

In co-operation with Manz AG, we have developed a high-turnover concept for vacuum systems and processes to produce thin functional coatings for the c-Si photovoltaic industry. The first project goal was to produce high-quality silicon nitride films as anti-reflection coatings for solar cells. We succeeded in achieving high coating density already at low processing temperatures and high coating rates.

Marc Hofmann, Norbert Kohn, Saskia Kühnhold, Jochen Rentsch, Pierre Saint-Cast, Daniel Trogus, Dirk Wagenmann, Ralf Preu

1 *Coating equipment on an industrial scale, as was developed by Manz AG on the basis of the project results. View of the wafer handling system of the PECVD coater (left). Schematic diagram of the processing chamber where coating takes place (right).*

The reflection from crystalline silicon solar cells can be reduced by coating them with a thin film of material having a refractive index of about 2.1 and a thickness of about 80 nm. Hydrogenated silicon nitride (SiN_x:H) is a very suitable material, as it not only provides the desired optical effects but also improves the bulk quality of multicrystalline solar cells (bulk passivation) and passivates the surface. For this reason, SiN_x:H coatings are frequently applied in the c-Si PV industry.



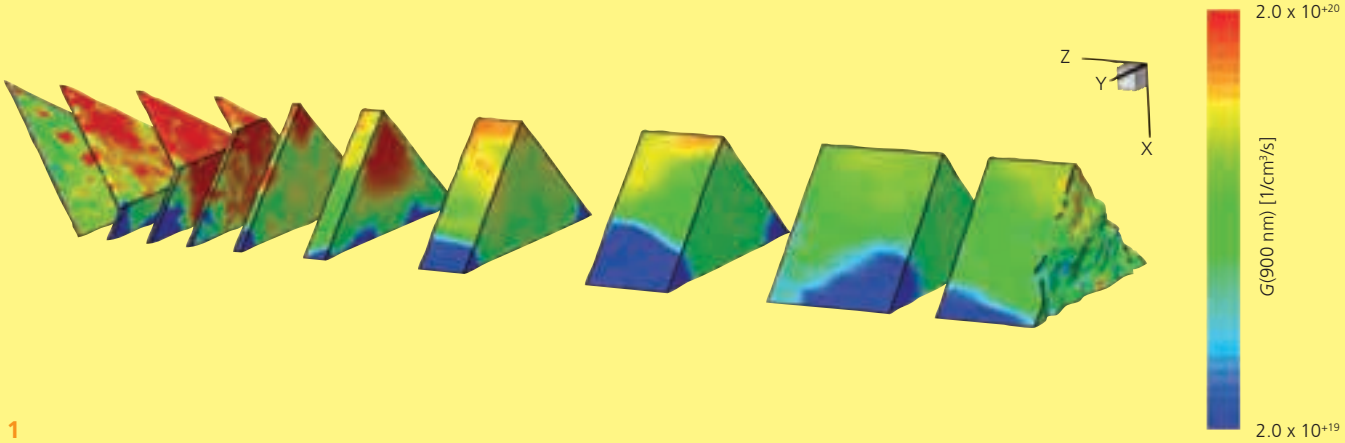
2 *Mass density of the SiN_x:H coatings as a function of substrate temperature during deposition (left). Hydrogen content of the SiN_x:H coatings as a function of the substrate temperature during deposition (right). All coatings have approximately the same refractive index of 2.1.*

In co-operation with Fraunhofer ISE, Manz AG developed a new, innovative system concept for vacuum deposition of thin functional coatings via plasma-enhanced chemical vapour deposition (PECVD). The system is distinguished by the following specifications:

- high-power plasma: very efficient decomposition of the processing gases and thus a high gas utilisation factor and high deposition rates
- vertical, shadow-free mounting of the wafers during the coating process: homogeneous deposition of the coatings without carrier marks
- simultaneous coating of wafers on two carriers to the right and left of the plasma zone: very high gas utilisation factor

An additional advantage of the high-power plasma technology is the opportunity to produce films with a high mass density also at relatively low processing temperatures below 400 °C.

The work is supported by the German Federal Ministry of Education and Research (BMBF).



1

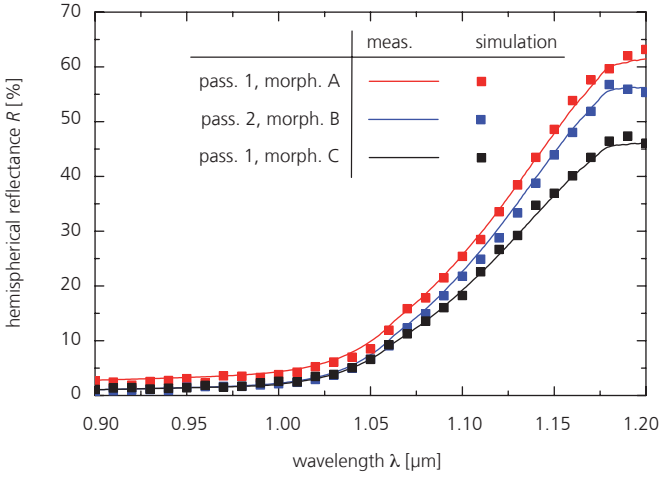
OPTICAL SIMULATION OF PASSIVATED SOLAR CELLS WITH A ROUGH BACK-SURFACE

Solar cells with dielectric front-surface and back-surface passivation combine excellent electrical and optical properties with each other. The roughness and the coating of the back-surface of the solar cell are the decisive parameters for the efficiency value. The physically based simulation which we use to model the optical effect of these parameters allows the spectral hemispherical reflectance and the current generated in the cell to be predicted for the first time for given passivation layers and surface structures, as the comparison of simulated and measured results shows. The optical properties of various coating materials and back-surface morphologies for the solar cell can thus already be analysed and optimised by computer simulation.

Johannes Greulich, Stefan Rein, Christoph Schwab, Nico Wöhrle, Ralf Preu

1 *The spatially resolved generation rate, which is shown here for λ = 900 nm only at selected depths within the optical symmetry element with a quarter pyramid (left) and the rough back-surface (right), can be accurately simulated with the physical model.*

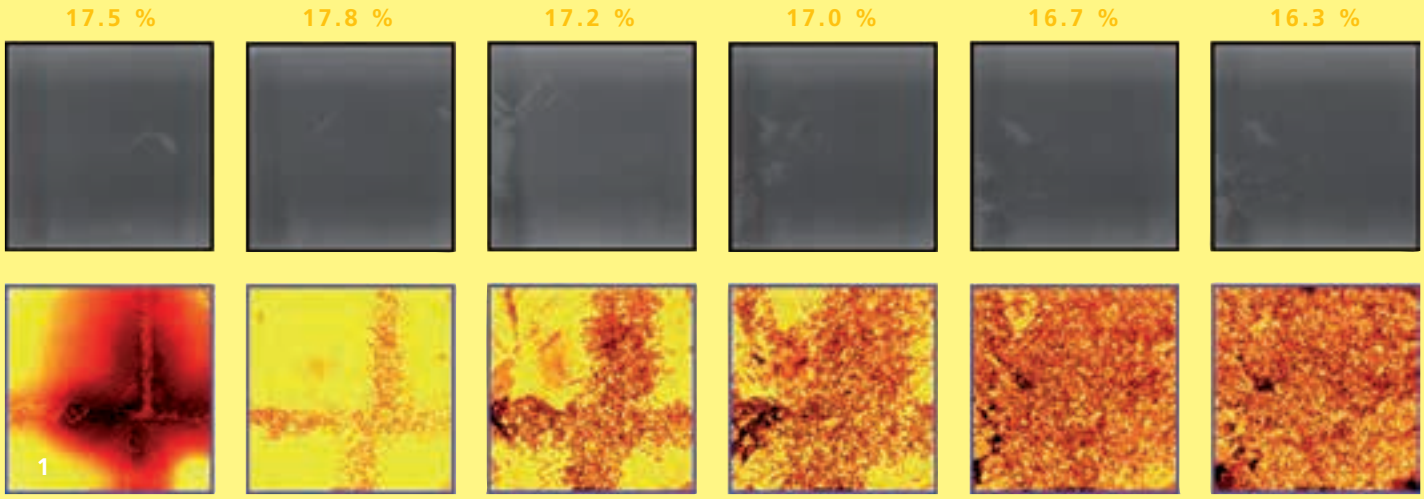
In order to describe the properties of rough back-surfaces of solar cells, the Phong illumination model has been used up to now. Usually the two free parameters of the Phong model could be chosen such that the simulated reflectance of the solar cell to be modelled agreed with the measured result. However, due to the empirical character of the Phong model, the possibilities of applying it to predict the optical properties of solar cells with rough back-surfaces are very limited.



2 *The simulated reflectance agrees accurately with measured results, shown here for three back-surface morphologies (A, B, C) and two passivation stacks (1, 2) as examples.*

The new approach to simulate the optical properties of rough surfaces with dielectric passivation layers consists of initially determining the three-dimensional surface profile very accurately, e.g. with a confocal microscope. The surface profile is subsequently divided up into small triangles and introduced into the symmetry element of optical simulation (Fig. 1). In the ray-tracing simulation, the course of a beam incident on such a small triangle is described with the transfer matrix formalism corresponding to Snell's law of refraction and the Fresnel equations. Only the refractive indices and thicknesses of the back-surface coating are required as input quantities. This allows the charge carrier generation rate (Fig. 1) and the reflectance (Fig. 2) to be predicted, which agree accurately with measurements without further parameter adaptation.

The project is supported by the German Federal Ministry of Education and Research (BMBF).



PHOTOLUMINESCENCE-BASED QUALITY CONTROL OF QUASI-MONOCRYSTALLINE WAFERS

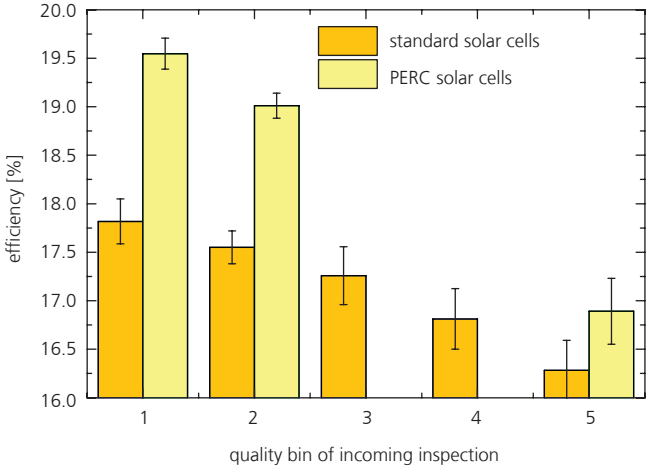
Quasi-monocrystalline silicon, which has entered solar cell production as a new input material over the past two years, is intended to combine the cost advantages of multicrystalline silicon with the quality advantages of monocrystalline silicon and thus enable high efficiency values for lower production costs. Fraunhofer ISE has investigated quasi-monocrystalline wafers from various manufacturers and identified significant differences in quality. Efficiency values range from 15.7 % to 18.1 % for standard solar cells and from 16.3 % to 19.7 % for solar cells with passivated back-surfaces. These differences were attributed to diverse material defects, opening up possibilities for reliable quality assessment before solar cell production starts.

Juliane Broisch, Teodora Chipei, **Jonas Haunschild**, Stefan Rein, Isolde Reis, Ralf Preu

1 *Photos (above) and PL images (below) of quasi-monocrystalline wafers from various positions in the silicon brick from the base (left) to the cap (right). Whereas the photos indicate constantly high quality, the PL images show a strong increase in dislocations toward the cap.*

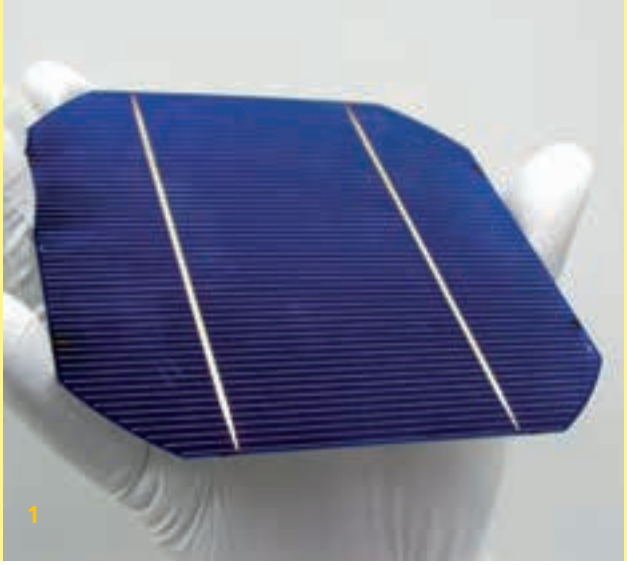
Fraunhofer ISE has investigated quasi-monocrystalline wafers from various manufacturers, in order to test the suitability of this new class of materials, identify performance-limiting defects and develop methods of quality assessment.

Figure 1 shows a series of wafers from the base to the cap of a silicon brick. As can be seen in the digital photos (above), the monocrystalline structure of the wafers is well preserved along the height of the brick. Despite this, recombination-active defects are visible in the photoluminescence (PL) images, starting at the base in a cross-shaped region and extending across the entire wafer with increasing height in the brick. These result in a continuous decrease of the resulting efficiency values from 17.8 % to 16.3 %. The physical causes are crystal structural defects, so-called dislocations, which originate at the adjacent edges of seed plates which were not optimally orientated.

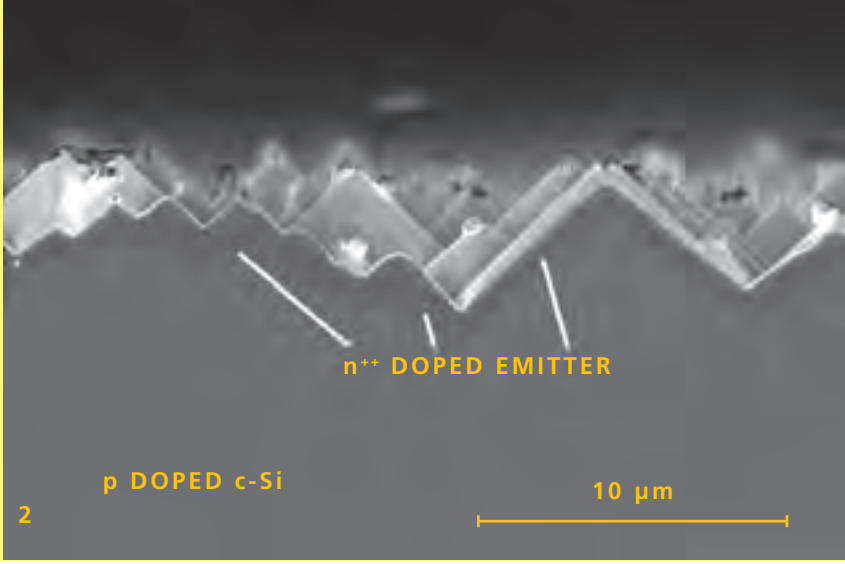


2 *Average solar cell efficiency value for two solar cell processes as a function of the quality bin determined by PL imaging of the as-cut wafers. (1 = highest quality, 5 = lowest quality).*

As the limiting defects can already be identified in PL images of the as-cut wafers, it is theoretically possible to evaluate their quality before further processing. Based on the structures in the PL images, the wafers were divided for testing into five different classes and then processed into standard solar cells with aluminium back-surface fields (Al-BSF) or solar cells with passivated emitter and rear contacts (PERC). Figure 2 shows that the experimentally determined category for the as-cut wafers is clearly reflected by the continuous decrease in efficiency value for both processes. In addition, PL analysis allows the crystallisation process to be optimised, as the origin, dissemination and effect of defects in the crystal can be determined accurately.



1



2

LASER DIFFUSION FOR SOLAR CELLS MADE OF CRYSTALLINE SILICON

Locally modified doping structures can be generated in crystalline silicon solar cells by selective laser diffusion. At Fraunhofer ISE, processes were developed which allow heavily doped zones to be generated beneath the metal contacts in high-efficiency solar cells, improving the contact quality. In addition, the introduced heavy doping suppresses losses due to recombination of charge carriers at the metal-semiconductor interface.

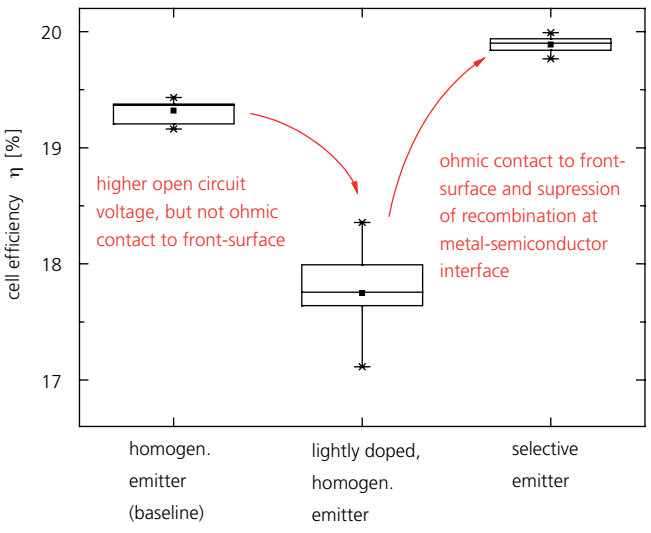
Susana Fernandez Robledo, **Ulrich Jäger**, Jan Nekarda, Andreas Wolf, Ralf Preu

Doping to a depth of several micrometers can be achieved in a short time (t < 10 µs) by laser-induced diffusion. The reason is that the diffusion rate in crystalline silicon is up to ten orders of magnitude higher in the liquid than in the solid phase. Solar cells with passivated surfaces have potential for high efficiency values, because this concept not only optimises the optical properties of the back-surface of the solar cell, but also reduces recombination losses. This is achieved by passivating the surfaces and using lightly doped phosphorus emitters. However, these do not establish sufficient electrical contact to the silver pastes which are usually screen-printed onto the front-surface of solar cells. By selective over-doping with the laser, a higher concentration of dopants can be introduced under the contacts, ensuring an ohmic contact between the emitter and the front-surface electrodes. Due to the heavy doping under the metal contact, the field effect prevents the minority charge carriers from reaching the recombination-active metal-semiconductor contact. This additionally reduces the recombination current of the cell and makes higher open circuit voltages feasible. Thus, highest efficiency values can be achieved by laser-doped, selective emitter structures. In comparison to a homogeneously doped emitter, the efficiency value of solar cells with passivated surfaces and contacts on both surfaces was increased by up to 0.6 %, so that peak values of up to 20.0 % were achieved.

1 *Front-surface of a monocrystalline p-type solar cell with passivated surfaces and laser-doped, selective emitter, with a conversion efficiency of 20 %.*

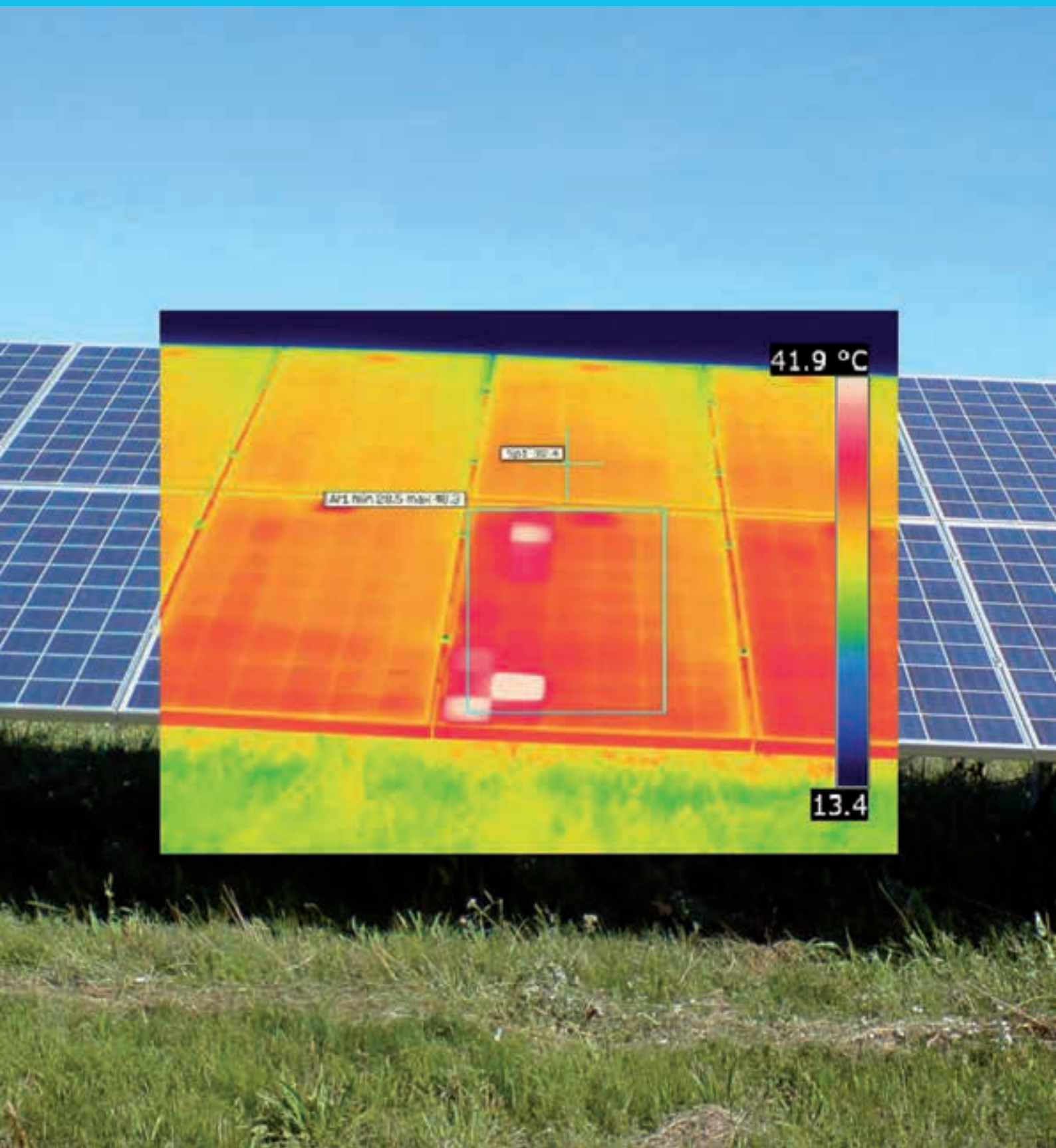
2 *SEM image of a heavily laser-doped emitter on a textured, monocrystalline silicon surface.*

The work was supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).



3 *Efficiency improvement obtained by implementing a selective emitter in solar cells with passivated surfaces. By introducing a heavily doped zone beneath the contacts, the cell efficiency can be increased compared to the reference.*

ELECTRICITY FROM SUNLIGHT



PHOTOVOLTAIC MODULES AND SYSTEMS

Module technology converts solar cells into durable products for safe operation in PV power plants. We support product development toward optimal efficiency, reduced costs and enhanced reliability. We offer comprehensive services for quality control of modules and power plants from accurate laboratory measurement to monitoring in the field.

Module technology

Our Photovoltaic Module Technology Centre (MTC) is equipped with a wide range of processing and analytical platforms for testing materials and developing products and processes. Scientists have direct access from the laboratory to industrially relevant module formats and production volumes. A fully automated tabber-stringer serves as a reference for cell connection. Laminators with usable areas of up to 1700 mm x 1000 mm are available for module production.

Comprehensive characterisation at all stages of production makes targeted optimisation of products and processes feasible. Quality control begins with investigation of the incoming materials, from the cell through cell connectors and polymer films to glass. The quality of joints can be tested in the Photovoltaic Module Technology Centre (MTC) by solder wetting investigations, peeling tests, micrographs of polished sections and high-resolution X-ray images; the quality of the lamination process is evaluated by DMA, DSC and gel content determination. The performance and integrity of a cell can be traced by characterisation at all stages from initial delivery through stringing and encapsulation to the finished module.

The experimental methods are complemented by numerous simulation models. They allow the loss and gain factors in the connection and encapsulation of solar cells to be analysed and provide information on mechanical loads and electrical and optical effects in the module.

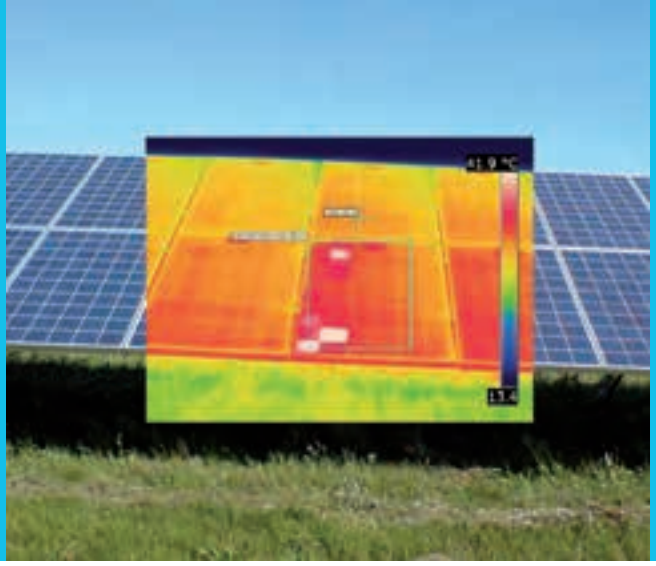
Durability analysis and environmental simulation

In addition to the system efficiency, the lifetime of the components in a PV power plant is decisive in determining its profitability. We investigate the behaviour of products, components and materials over their service life. This includes materials testing and computer simulation of load tests and aging effects for various materials, components and products, e.g. PV modules.

We investigate the effect of weathering with analytical methods. The aim is to recognise aging mechanisms, their causes and effects on materials, product components and entire products as early as possible. Most of these investigations apply non-destructive methods such as optical microscopy, Raman spectroscopy, Fourier transform infrared (FTIR) spectroscopy and electroluminescence imaging. The development of new or combined characterisation methods is also part of our work. One of the aims of these efforts is to replace destructive measurement methods by non-destructive methods in future.

Understanding and identifying the causes of aging is the task of environmental simulation, in which the behaviour of test objects such as PV modules is observed and documented in detail in the field at selected locations. We use sites in Freiburg (temperate climate), near the Zugspitze (Alpine climate), in the Negev desert (subtropical climate), on Gran Canaria (maritime climate) and in Jakarta (tropical climate). The work on environmental simulation is intended to allow the aging behaviour of new materials, components and products over their lifetime or service life to be better understood and predicted.

Not only the equipment of TestLab PV Modules, which has been accredited since 2006, is available for testing, but also special testing facilities for combined loads or accelerated aging.



Thermographic investigation of a solar generator in a photovoltaic power plant. The high-resolution infrared image of a faulty module is superimposed over the digital photo and reveals individual solar cells with noticeably higher operating temperatures. The result is a clear indicator for yield losses and risks affecting the reliability of the affected module.

Quality assurance for PV modules, systems and power plants

With the four phases of the Fraunhofer ISE quality cycle – yield assessment, module measurements, system testing and monitoring – we ensure comprehensive quality control of PV modules and power plants. Together with good planning and the usage of high-quality components, this is decisive for efficient operation of a PV system.

In the planning phase of a PV power plant, we draw on reliable radiation and meteorological data and simulate the system configuration exactly. Yield-reducing factors like soiling and shading are determined accurately. Strong networking within Fraunhofer ISE and international projects ensure that current research results are continually implemented in the simulation software that we develop.

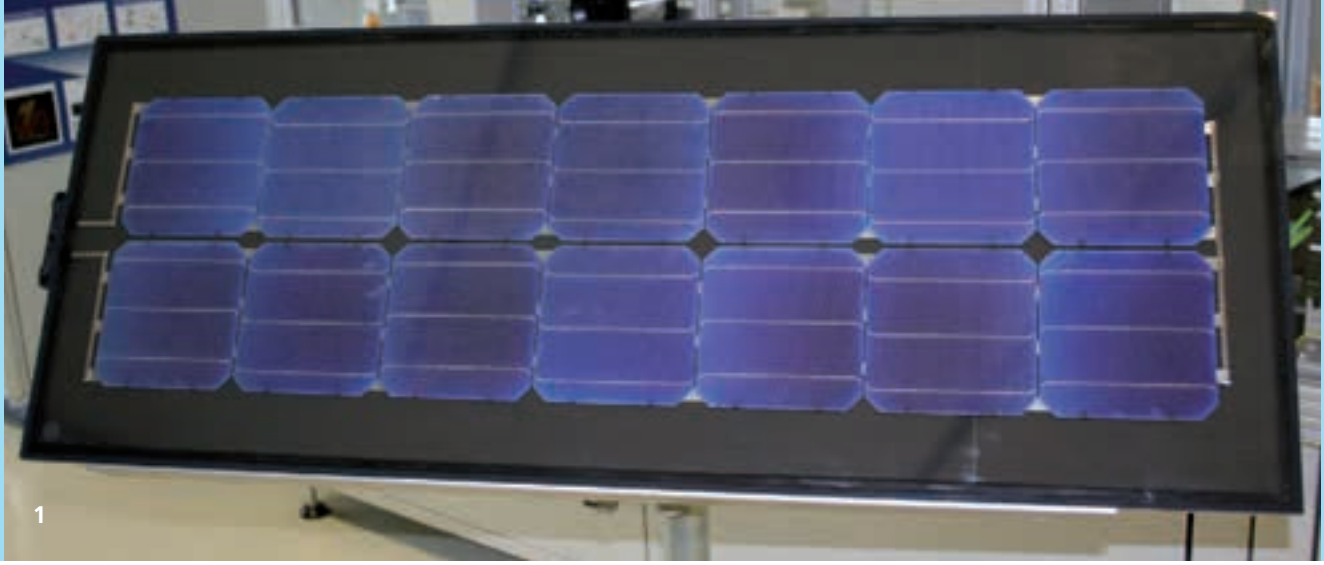
For accurate measurement and characterisation of PV modules, our CalLab PV Modules offers many different types of standard and high-accuracy measurements for research, development and production. The CalLab PV Modules at Fraunhofer ISE is one of the internationally leading laboratories in this field, with its measurement accuracy of better than 1.8 % for crystalline modules. We calibrate reference modules for production lines and test compliance of random samples with the guaranteed power according to international standards.

Once a PV system has started operation, comprehensive on-site analysis provides information about the quality of the system. Our spectrum of services includes visual inspection, thermographic imaging and determination of the actual power supplied. Reduced power, weaknesses and deviation from technical standards can thus be detected early and suitable counter-measures can be taken.

Throughout the complete service life of a PV system, our customised PV monitoring offers accurate analysis of system and component efficiency. It is based on long-term experience with national and international projects and the high scientific level of our work. Fraunhofer ISE ensures optimal yields from PV modules and power plants by consistent quality assurance.

CONTACT

Module technology	Dr Ulrich Eitner	Phone +49 761 4588-5825 ulrich.eitner@ise.fraunhofer.de
Durability analysis and environmental simulation	Claudio Ferrara	Phone +49 761 4588-5650 claudio.ferrara@ise.fraunhofer.de
Quality assurance for PV modules, systems and power plants	Klaus Kiefer	Phone +49 761 4588-5218 klaus.kiefer@ise.fraunhofer.de



BACK-CONTACT MODULE TECHNOLOGY WITH STRUCTURED INTERCONNECTORS

Novel high-efficiency cells with back-contacts present a great challenge to module manufacturing technology. Single-sided connection with conventional connector ribbons leads to strong mechanical stresses and bowing. The concept of a structured interconnector developed at Fraunhofer ISE avoids this with a special design. It was successfully applied to thin MWT (metal wrap-through) cells with a thickness of 120 µm. The demonstration modules achieve efficiency values of 17 % with an absolute efficiency loss from cell to module of only 1 %. The advantage of this concept compared to a conductive back-sheet is that it requires only slight modification of the standard module concept. This significantly reduces the risk of additional costs or decreased durability.

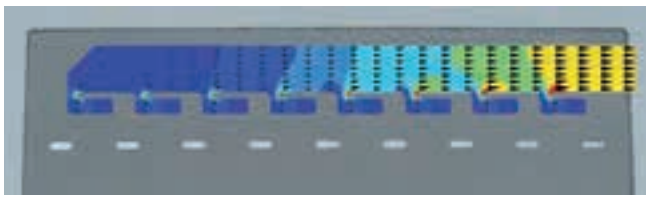
Dirk Eberlein, **Ulrich Eitner**, Ingrid Hädrich, Marco Tranitz, Martin Wiese, Harry Wirth

1 *MWT back-contact module with connection technology based on the structured interconnector.*

High cell efficiency helps to reduce the area-proportional costs of a module and consequently the PV system – both reduce the levellised cost of PV electricity. Various concepts exist to integrate highly efficient MWT back-contact solar cells into modules, but none has established itself on the market yet. Our module concept is designed such that the production processes and materials used are very similar to those for the standard module concept. This lowers the threshold for market penetration and minimises the risks associated with module reliability.

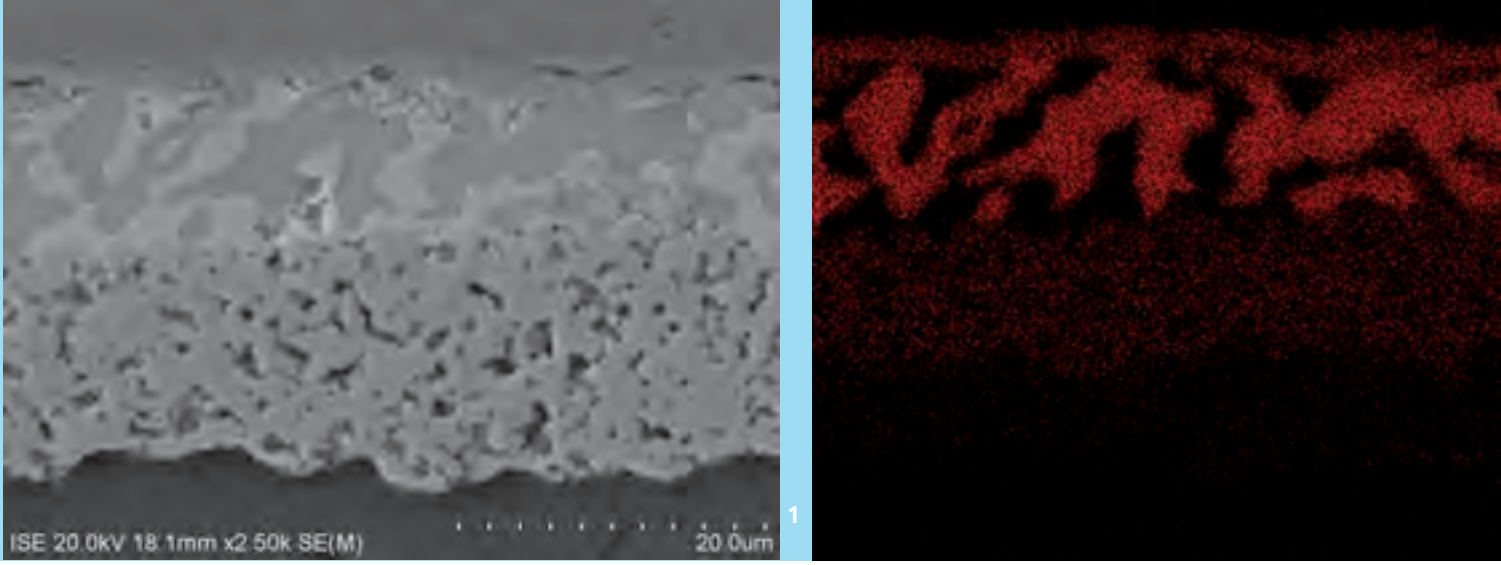
The interconnector design is based on the separation of electrically conducting elements from the contact points for soldering. It ensures low ohmic losses due to sufficiently large cross-sections for conduction and simultaneously reduces thermomechanical stress after the soldering process. A special EVA layer between the back of the cell and the interconnector prevents short circuits. The design is optimised by using a FEM simulation model, which is based on partial differential equations from the discipline of electrostatics.

An efficiency value of 17.0 % and a fill factor of 77.7 % are obtained for demonstrator modules in 10-cell and 16-cell formats. Qualitative investigations such as electroluminescence (EL) imaging confirms that the modules remain undamaged after the various production processes. Also after accelerated aging with 200 temperature cycles between -40°C and +85 °C, the performance remains unchanged and there is no evidence of damage in the EL images.



2 *FEM simulation of the current transport in a structured interconnector: ohmic losses (colours), current direction (arrows).*

The work was supported by the European Union in the project "Ultimate" within the 7th Framework Programme.



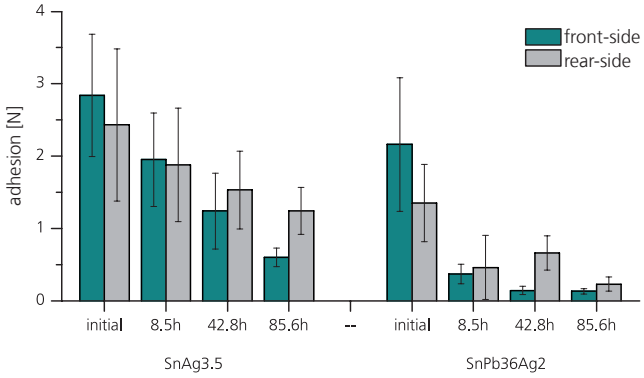
RELIABILITY OF CELL METALLISATION IN PV MODULE CONSTRUCTION

Metallised areas on solar cells serve as the substrates for electrical contacts and are thus central to module integration. Soldering is the contact technology which has established and proven itself in the industrial context. Currently, novel metallisation concepts, assembly technology and materials are being intensively evaluated for their application in photovoltaics. The driving forces for substitution are cost pressure (e.g. for expensive input materials like silver) and ecological risks. It is particularly important to thoroughly investigate the reliability of solder joints. We found diffusion processes in the solder joint components to have a major effect on stability.

Dirk Eberlein, Ulrich Eitner, **Peter Schmitt**, Marco Tranitz, Harry Wirth

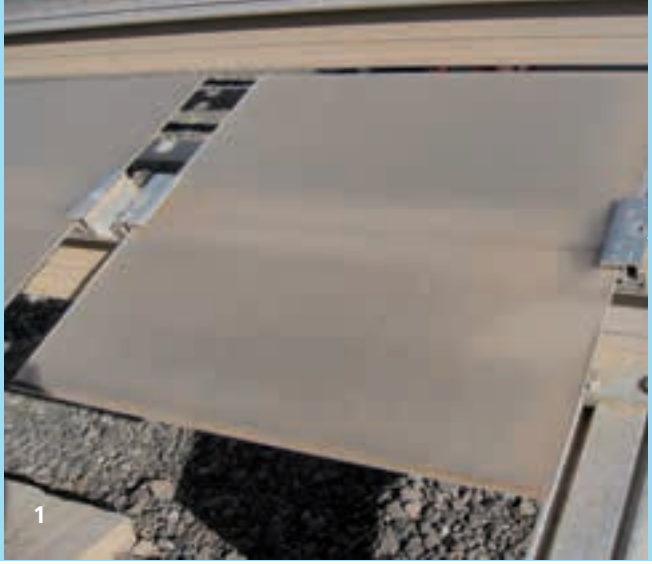
The quality and reliability of solder joints are greatly influenced by diffusion processes throughout their lifetime. This leads to the formation of intermetallic phases and to diffusion of solder components (tin) into the metallisation. Intermetallic phases are alloys consisting of materials from the solder joint (e.g. tin, silver and copper) and which have different properties than the initial metals. These phases form within the solder and at the interfaces to the cell metallisation and the copper core of the cell connector. They affect the mechanical and electrical properties of the solder joint. The clear effect of tin diffusion into the porous matrix of the metallisation on mechanical properties was proven. A correlation between diffusion and the mechanical reliability of the solder joints is determined by optical quality-testing methods and peeling tests. The degradation processes are accelerated by isothermal storage at elevated temperatures over differing lengths of time. It is evident that the adhesion of the metal contacts to the wafer

1 *SEM image of a polished cross-section of a solder joint containing lead after isothermal storage at elevated temperatures (left) and the corresponding tin distribution, measured by EDX (right).*



2 *Solder joints of differing composition show a reduced adhesion after isothermal storage at elevated temperatures.*

decreases when the amount and penetration depth of tin into the porous matrix increases. This behaviour varies for different soldering alloys and metallisation techniques. The main parameters are the porosity of the metal contacts and the composition of the soldering alloy. Our results allow the solder joints to be optimised by the choice of materials, the composition of the components and the processing parameters.



TESTING OF ANTI-SOILING COATINGS ON GLAZING MATERIALS

Investigations by Fraunhofer ISE of a heavily soiled photovoltaic system on Gran Canaria identified a yield reduction of up to 80 % in 2010. Anti-soiling coatings are intended to prevent dirt from accumulating and to guarantee the yield of solar thermal and photovoltaic systems. To do so, the coatings must be stable under the local weathering conditions. In addition, the coatings may not reduce the solar transmittance. Many coatings which are currently commercially available do not meet these two specifications.

Thomas Kaltenbach, Christian Schill, Karolina Slamova, Harry Wirth

1 *Heavily soiled glass sample after exposure on Gran Canaria.*

2 *Glass samples before soiling and after deposition of Arizona dust.*

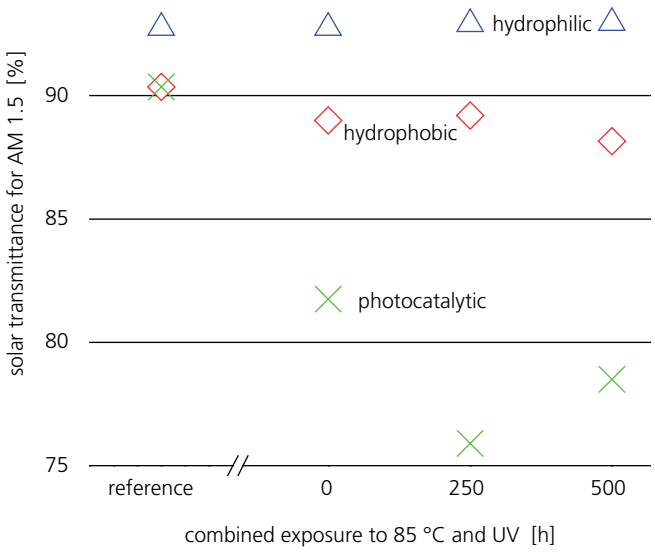
The conditions prevailing in deserts promote soiling of solar systems located there. However, these regions are particularly favourable for collecting solar energy because of the high irradiance totals.

Fraunhofer ISE co-operates with local institutions to maintain outdoor exposure test sites both in the Negev desert and on the Canary Islands (Fig. 1), where soiling effects are investigated within the joint research project "SpeedColl". The SpeedColl project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) as well as an industrial consortium (www.speedcoll.de).

Fraunhofer ISE conducted a market survey to determine which coatings are currently available. A procedure to cause reproducible soiling of test samples with standard dust types (Fig. 2) was developed and tested with selected samples.

To test the stability of the coatings, the samples were subjected to various accelerated aging tests (temperature of 85 °C, with and without UV radiation). Possible degradation of the anti-soiling properties was investigated by measurements of transmittance and contact angles, as well as by the specially developed soiling test.

With this testing procedure, it was proven that none of the investigated coatings reduce the solar transmittance initially (Fig. 3). However, some of the coatings already lose their anti-soiling effect after 250 hours of UV irradiation and thus appear to be unsuitable for solar thermal systems.



3 *Solar transmittance of three investigated coatings. Reference: clean sample. Further points: soiled and cleaned samples at 0 h and after accelerated aging for 250 h and 500 h at 85 °C with UV irradiation.*

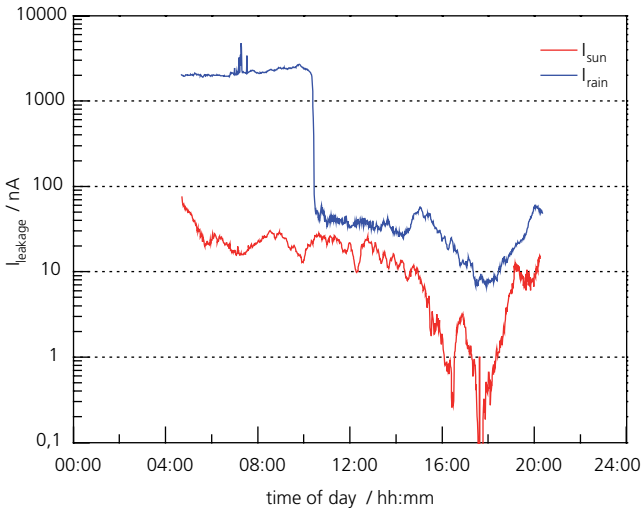
LABORATORY AND OUTDOOR TESTING OF POTENTIAL-INDUCED DEGRADATION

In recent years, the PV industry has become increasingly aware of a phenomenon which causes a gradual but reversible loss of performance from PV generators. This phenomenon, which can occur at the negative end of a string of PV modules, is known by the name of potential-induced degradation (PID). To avoid limitations on circuit design or inverter selection for system planning, the PID problem should already be solved by stabilisation measures at the cell and module level. In order to test their effectiveness quickly, we are working within a project supported by the German Federal Ministry of Education and Research (BMBF) on both rapid tests and long-term tests under outdoor exposure for verification.

Stephan Hoffmann, Michael Köhl, Harry Wirth

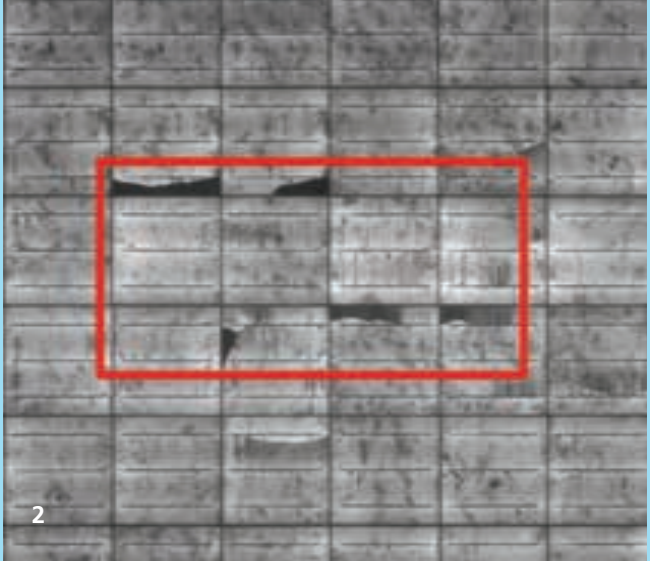
With rapid tests based on the IEC draft standard 62804, we can test the resistance of a PV module to PID. We apply a potential difference between earth and cells with the help of an earthed, conductive film on the glass under dry room conditions or in climatic chambers maintained at a given temperature and high, well-defined air humidity. Our investigations allow us to model the leakage current as a function of the temperature and relative air humidity near the module. We were able to demonstrate that the same exponential temperature dependence for the leakage current and thus the same activation energy applies for different earthing variants. However, the leakage current is an order of magnitude higher for high air humidity (85 %) than for dry air, and yet a further order of magnitude higher when the whole surface of the glass cover is earthed with aluminium foil. Adequate, reproducible earthing is achieved only with relative humidity values exceeding 60 %, as then the moisture film covering the glass pane passes the percolation point.

1 *Outdoor test stand on Gran Canaria to determine climatic effects on potential-induced degradation. The power and leakage current data for the modules as well as meteorological data are continuously recorded.*



2 *Comparison of the leakage current on a day with rainfall (until about 10.30 a.m.) and a dry day. The leakage current which flows through the water film on the module is two orders of magnitude higher than for the dry module. After drying during the course of the day, the measured leakage current returns to a similar level as on the dry day.*

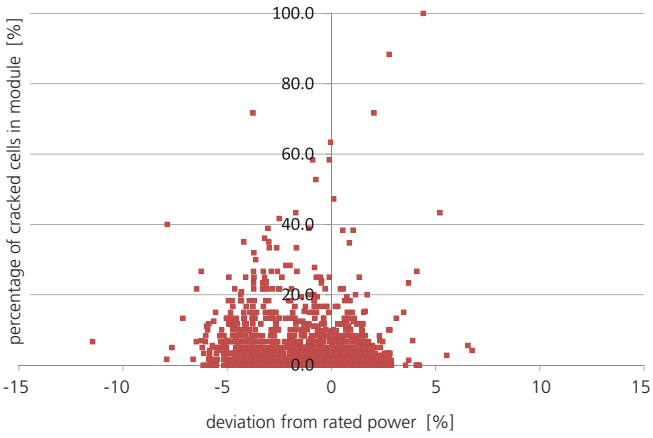
In addition to the laboratory tests, the long-term performance of the modules is investigated by outdoor exposure to the widely differing meteorological conditions of Freiburg and Gran Canaria (Fig. 1). Rainfall, causing high electric conductivity, was identified as a major risk at the Freiburg site (Fig. 2), whereas on Gran Canaria the high salt concentration and dust levels created an encrustation over the entire module area which lead to permanently high conductivity over the glass surface and thus to high leakage currents.



ELECTROLUMINESCENCE TESTS OF PV MODULES

Electroluminescence measurements have been carried out at Fraunhofer ISE since 2007 to investigate and characterise PV modules. These measurements make faults or effects visible, which cannot be detected by the naked eye. Thus, electroluminescence measurements are playing an increasingly important role in quality control of PV modules. However, it is not always clear which conclusions can be drawn from the images. The increasing expectations and questions raised by our clients demand well-founded evaluation of the effects, particularly with regard to long-term stability.

Daniela Dirnberger, Boris Farnung, Stephan Hoffmann, Klaus Kiefer, Carlos Moschella, Frank Neuberger, **Sandor Stecklum**, Daniel Philipp, Karl-Anders Weiß, Harry Wirth



3 *Percentage of cracked cells per module versus the deviation of the measured module power from the rated power.*

1 *EL image of a newly manufactured polycrystalline module.*
2 *The EL image of the same module after a temperature-cycling test reveals inactive cell regions (red).*

Electroluminescence tests (EL tests) play an important role in applications ranging from cell development up to quality control for commercially available PV modules. The test provides information on defects or conspicuous features in the solar cells. Typical abnormalities include cell cracks, inactive cell regions or defective contact areas.

To date, about 4750 modules in their initial state have been subjected to the EL test in addition to performance measurements. Detailed analysis of 1830 modules revealed that 62 % of the modules have cell cracks. Inactive cell regions were discovered in some of the affected modules (12 % of the complete testing batch). A correlation between the proportion of cracked cells and deviations from the rated power could not be determined (Fig. 3).

Additional accelerated aging tests are applied to identify which images of damage correspond to an increase in cracks and thus loss of performance in subsequent operation. In Fig. 1, several cracks can be seen which led to deactivation of cell regions after accelerated aging (Fig. 2). After exposure, the module power had decreased by 3.9 %.

Not all conspicuous features must be regarded as critical with regard to the long-term stability of the PV module performance. An important aspect of our investigations is thus the further growth of existing defects during module operation and their effect on lifetime and yield.

"ENERGY RATING" – NEW EVALUATION CRITERIA FOR PV MODULES

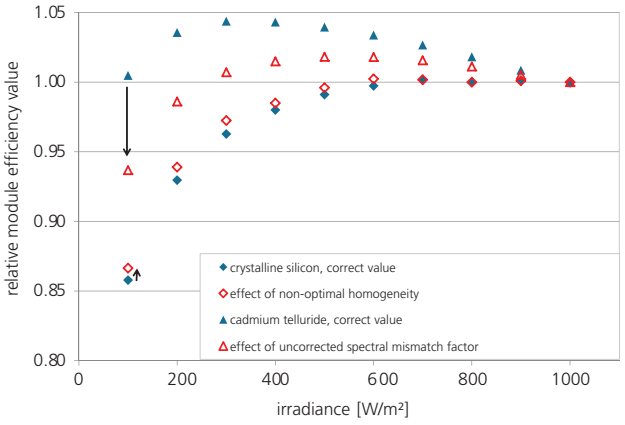
With falling investment costs, the return from a PV power plant is being determined increasingly by its yield over its entire lifetime. The "Energy Rating" concept does not only take account of the power delivered by solar modules under STC conditions but also provides a holistic evaluation of performance. Low-light behaviour and temperature dependence are the two most important influences on the annual yield. Both characteristics can be measured accurately in CalLab PV Modules and used for prediction models. In order to minimise the uncertainty in measuring these quantities, we have developed new procedures and optimised the measurement technology.

Daniela Dirnberger, Klaus Kiefer, Ulli Kräling, Björn Müller, Frank Neuberger, Christian Reise, Harry Wirth

High-quality meteorological data for the planned system location and complete characterisation of the PV components are essential for accurate yield predictions. Manufacturers' data sheets do not always provide sufficient information on the dependence of the efficiency value or module power on the solar irradiance. If these quantities are measured with the procedures that we have developed and an optimised measurement system, the measurement uncertainty for all measured points is ± 0.5 %. In the analysis which we made for three sites in northern Germany, southern Germany and southern Spain, the resulting contribution to the total uncertainty in the predicted yield was maximally ± 1 % for modules of crystalline silicon cells and ± 2 % for cadmium telluride modules. If previous methods or values from manufacturers' data sheets are used, additional deviations of 0.5 to 2.5 % can easily occur.

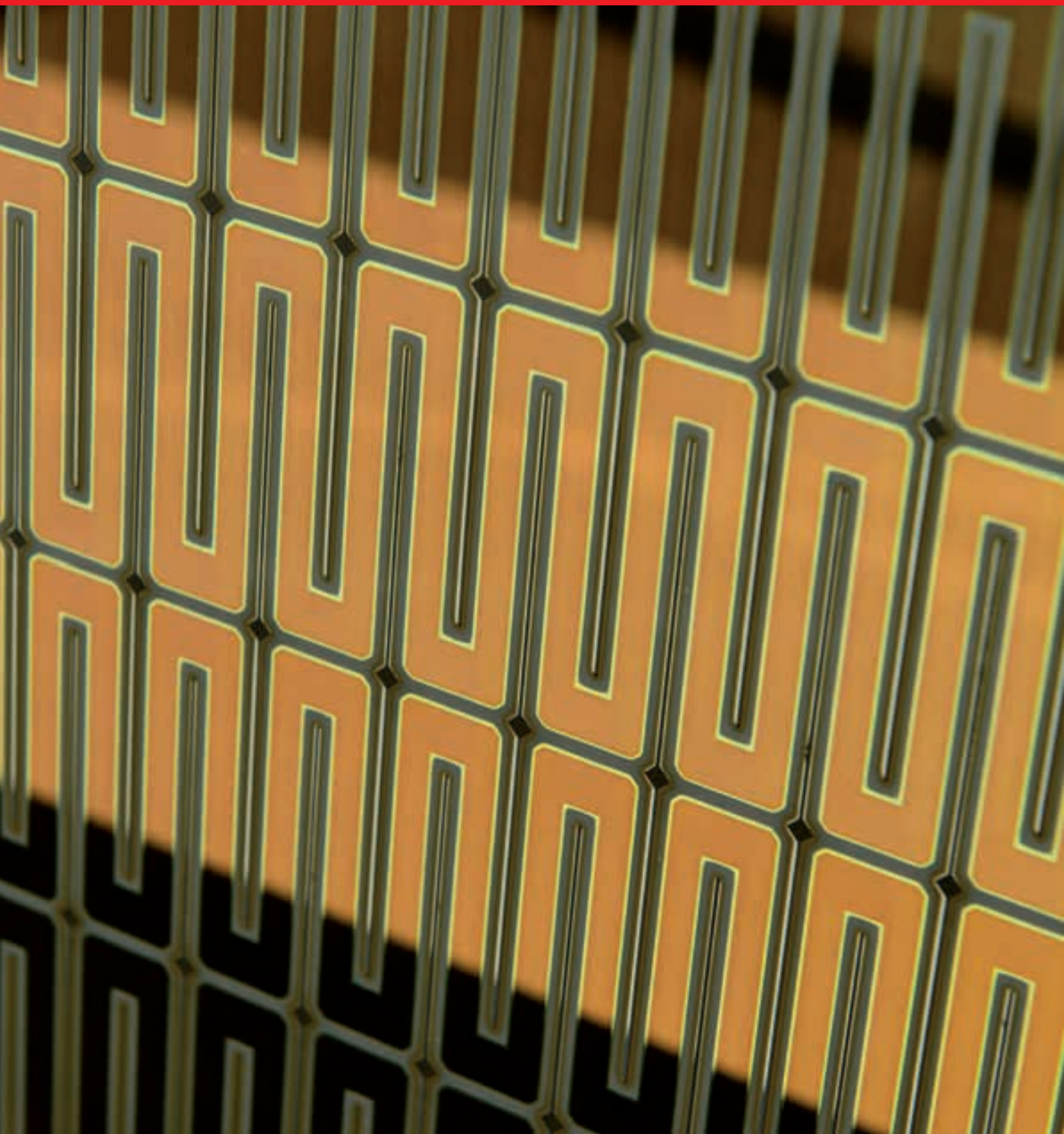
Accurate module characterisation is thus essential for "Energy Rating" and accurate yield prediction.

1 *PV power plant with a rated power of 10 MW.*



2 *If non-optimal measurement systems and procedures are used, significant errors (red) can be made in the measured dependence of module efficiency on irradiance.*

ELECTRICITY FROM SUNLIGHT



ALTERNATIVE PHOTOVOLTAIC TECHNOLOGIES

Complementing the work on silicon photovoltaics, our research and development on solar cells also covers other types of photovoltaic technology: III-V semiconductors, dye solar cells, organic solar cells, concentrator technology, nanomaterials and novel concepts for photovoltaics.

III-V semiconductors

Multi-junction solar cells, based on III-V semiconductors such as gallium indium phosphide, aluminium gallium arsenide, gallium arsenide or gallium indium nitride arsenide, achieve the highest efficiency values of all solar cells, up to 44 %. Triple-junction solar cells of GaInP/GaInAs/Ge have already been applied successfully on earth in combination with optical concentration and in space. In addition to these two PV market segments, we supply III-V solar cells to niche markets such as laser power beaming, thermophotovoltaics and other specialised applications.

For applications in satellites, we are concentrating on radiation-resistant, multi-junction cells (triple to sextuple). Cells with a low mass are particularly advantageous. We are thus developing very thin cells with a thickness of only a few micrometres. To this purpose, we apply techniques to separate the solar cell structures from one substrate and transfer them to other substrates. Among other approaches, we have applied so-called „wafer-bonding" very successfully and can create new material combinations in this way. We are continuing to work on producing III-V semiconductor structures directly on a silicon substrate by epitaxial growth. In doing so, we are investigating central questions of materials science, such as techniques to overcome lattice mismatch and stress compensation.

Dye solar cells

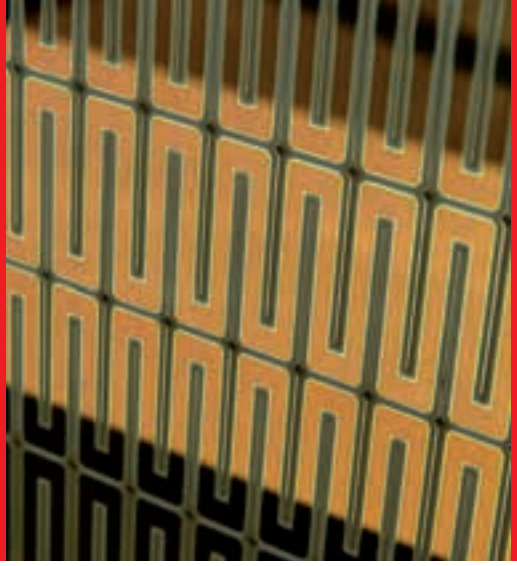
The technology for dye solar cells has developed well beyond the laboratory scale over the last few years. We were able to demonstrate that modules of dye solar cells can be produced with industrially relevant technology such as screen-printing and new sealing technology. The possibility for implementing design aspects was demonstrated in prototypes. The module durability is being tested in the laboratory and outdoors. Prototypes of dye solar modules with commercially interesting dimensions (60 cm x 100 cm) have already been produced on undivided substrates. This serves as proof that the production concept can be upscaled.

Organic solar cells

Organic solar cells are particularly attractive due to the anticipated low production costs. High mechanical flexibility and low mass will open up new application fields for photovoltaics in future. We are developing new cell structures which can be produced from cost-effective materials by efficient processes. The goal of these developments is production in a roll-to-roll process. We have produced the first solar cell modules with technology that can be transferred to continuous production. Aiming for higher efficiency and longer lifetimes, we are investigating new organic semiconductors and electrodes, and the durability of encapsulated solar cells in accelerated aging tests. Lifetimes of several years have become realistic.

Concentrator technology

In ConTEC, the Concentrator Technology and Evaluation Centre, we are developing modules and systems which concentrate sunlight by a factor of >300 for the terrestrial application of solar cells based on III-V semiconductors. Silicon solar cells are used for concentration factors of <100. We develop and investigate soldered and adhesive connections which withstand temperature cycling well and are very durable. In addition, we simulate thermo-mechanical effects in concentrator modules, carry out accelerated aging tests and develop new appropriate testing procedures. The FLATCON® technology, which was developed at Fraunhofer ISE, is an example of successful module development. It is now being produced commercially with success by Soitec Solar in Freiburg under the name of Concentrix™ Modul. In current research, we are investigating the co-generation of heat and electricity with a concentrating system.



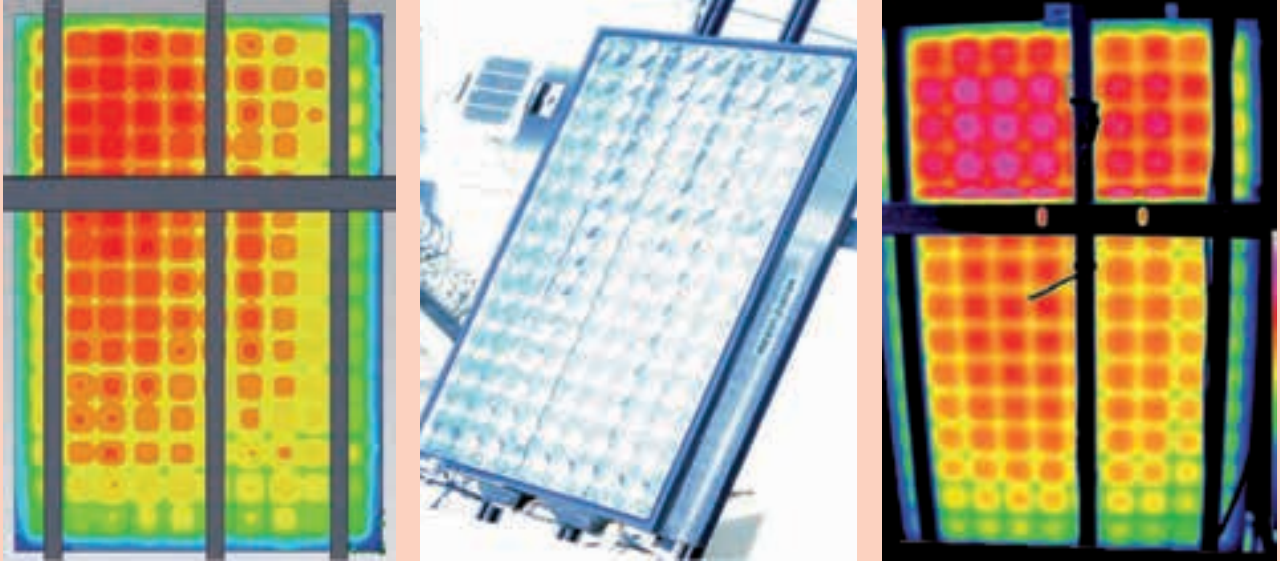
Novel solar cell concepts and photon management

We develop concepts and technology which can be applied to overcome fundamental limits on the efficiency of conventional solar cells. One concept is photon management. The aim is to raise the efficiency by splitting or shifting the solar spectral distribution before the radiation is absorbed by the solar cells. One example is up-conversion, in which unusable low-energy photons are transformed into high-energy photons. These can then be absorbed by standard solar cells. In addition, we are developing solar cells of quantum-dot materials. As their properties such as the band gap can be adjusted according to the application, silicon quantum-dot materials are very promising candidates for the production of tandem solar cells based on silicon. We have produced a quantum-dot membrane cell, which unequivocally confirmed for the first time in the world that this nanomaterial can be used as a solar cell. Further concepts include fluorescent concentrators, thermophotovoltaic systems and solar cells for wireless energy transmission with laser beams.

Dye solar cells will soon enter the market on a broad scale. As dye solar cells can be designed to be either transparent or opaque, they represent an interesting option primarily for building-integrated photovoltaics. In 2012 at Fraunhofer ISE, we reproducibly produced 60 cm x 100 cm modules with durable, glass-soldered sealing and internal series circuits in a screen-printing process (see page 106). Test modules have been integrated into the façade of a laboratory for demonstration purposes.

CONTACTS

III-V epitaxy, solar cells and components	Dr Frank Dimroth	Phone +49 761 4588-5258 frank.dimroth@ise.fraunhofer.de
Dye and organic solar cells	Dr Uli Würfel	Phone +49 761 203-4796 uli.wuerfel@ise.fraunhofer.de
Concentrator systems	Maike Wiesenfarth	Phone +49 761 4588-5470 maike.wiesenfarth@ise.fraunhofer.de
Novel solar cell concepts and photon management	Dr Jan Christoph Goldschmidt	Phone +49 761 4588-5475 jan.christoph.goldschmidt@ise.fraunhofer.de



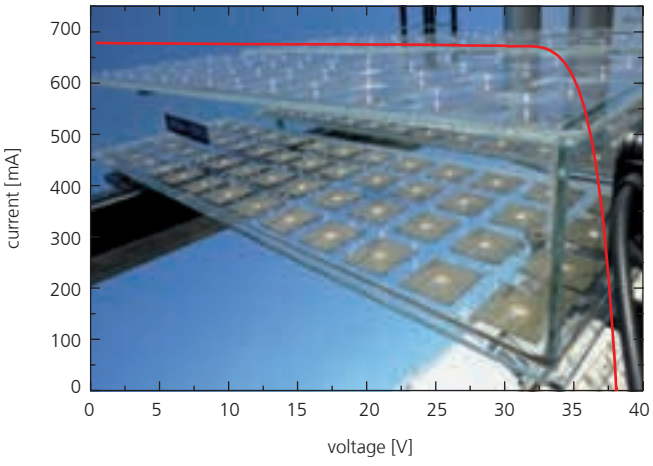
1

OPTIMISATION OF POINT-FOCUSSING CONCENTRATOR MODULES

In concentrator photovoltaics, lens-based optical systems are applied which focus the solar radiation onto very small solar cells. We have been developing and optimising point-focussing concentrator modules for many years. Our FLATCON® module achieved an efficiency value of 32.1 % in outdoor measurements. The thermal behaviour of these modules is an important design criterion for further optimisation. We apply finite element simulation and computational fluid dynamic models to design optimal modules. The simulation models are validated experimentally.

Armin Bösch, Tobias Dörsam, Harald Kraus, Marc Steiner, **Maike Wiesenfarth**, Andreas Bett

Concentration of the solar radiation means that the energy intensity incident on the solar cell is high. More than 30 % of the solar energy is converted into electricity by highly efficient, multi-junction solar cells. We have equipped our FLATCON® modules with industrially manufactured solar cells from AZUR Space Solar Power and achieved an efficiency value of 32.1 % (Fig. 2). The remaining energy is mainly converted to heat and dissipated to the surrounding environment. In order to ensure low solar cell temperatures, this heat transfer must be carefully designed. We apply simulations to predict the thermomechanical loads and temperature distributions, which are then compared to experimental results obtained under outdoor conditions. An example is shown in Fig. 1. The temperature distribution over the back surface of the module was simulated by computational fluid dynamic models. It agrees well with the temperature distribution measured with an infrared camera.

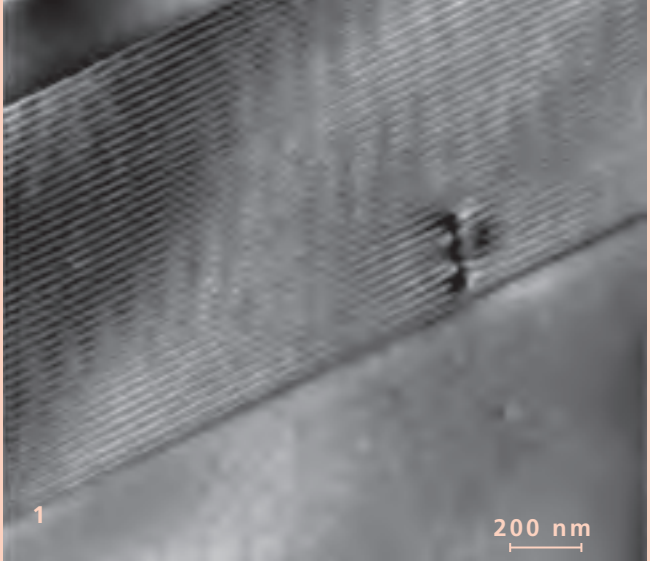


2 *I-V characteristic curve and photo of the FLATCON® module. The measurement was made on the outdoor test stand in Freiburg on 18.8.2012. The module with an area of 832 cm² has an efficiency value of 32.1 %.*

1 *The spatially resolved temperature distribution in a lens-based concentrator module is of great interest. The investigated concentrator module is shown in the centre; to the left and right respectively are the simulated and measured temperature distributions over the back-surface of the module. The two temperature distributions agree very well with each other.*

A further option for thermal management is to use the thermal energy. This is the most efficient way to use solar energy. The thermal energy is stored in heat-storage media and used as process heat. We also investigate these so-called CPVT systems (concentrator photovoltaic and thermal) at Fraunhofer ISE. Our main topics include development of the receiver and optimisation of the interaction between the optical system and the receiver.

Our work is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) and the Deutsche Bundesstiftung Umwelt (DBU).



SOLAR CELLS WITH MULTIPLE QUANTUM WELLS FOR SPACE APPLICATIONS

Triple-junction solar cells of III-V semiconductors represent the industrial standard for satellite applications in space. The stack structure is manufactured of different elements from groups III and V of the periodic table. This guarantees a high efficiency value exceeding 30 % for extraterrestrial radiation conditions. Together with our industrial partner in the "Nanospace II" project, AZUR Space Solar Power, we have investigated whether a new solar cell structure based on quantum wells could improve on previous efficiency values.

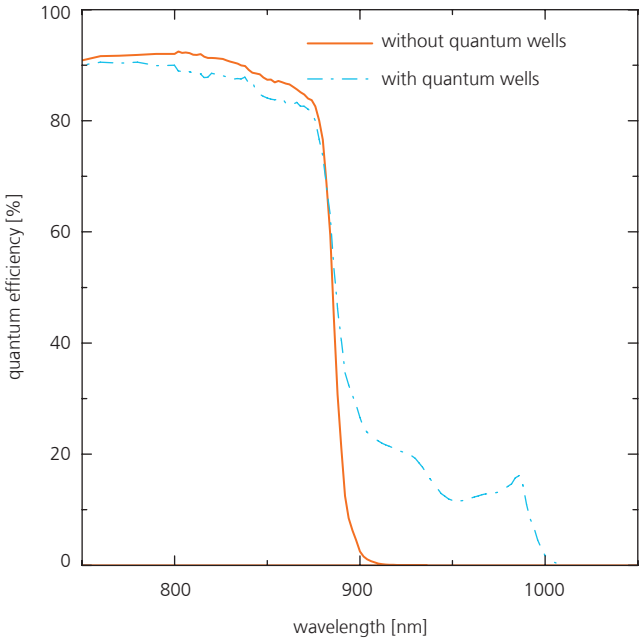
Stephanie Essig, **Peter Fuss-Kailuweit**, David Lackner, Gerald Siefer, Frank Dimroth, Andreas Bett

Current space solar cells consist of three sub-cells, each of which uses radiation from a different range of the solar spectrum. High-energy, cosmic particle radiation creates defects in the crystal structure, which continually decrease the efficiency of the solar cell. Thus, we had to take account of the radiation-induced damage already in designing the solar cell.

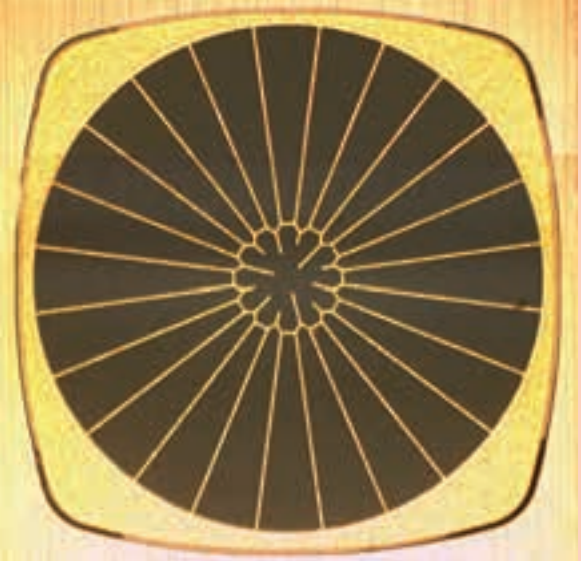
In a quantum-well solar cell, a multi-layer stack of two alternately deposited materials is inserted between the p-doped base and the n-doped emitter. The layer thickness corresponds to only a few atomic layers, so quantum mechanical effects can be observed. The configuration is thus called a quantum-well stack and has been designed by us to absorb more light at longer wavelengths than in a conventional solar cell (Fig. 1). This allows us to match the current generated by the individual sub-cells better to each other and counteracts the damaging effect of particle radiation in space.

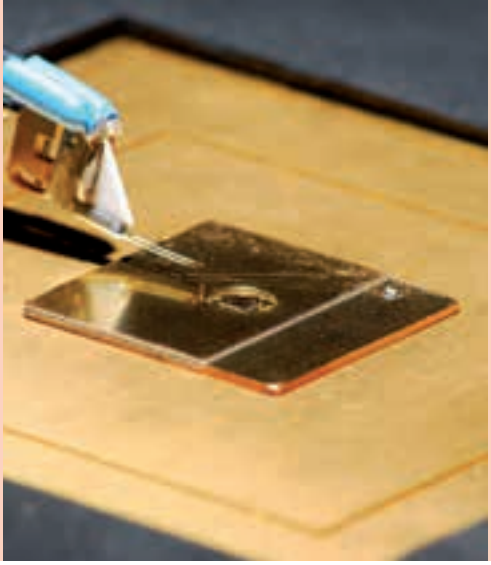
This project was financed by the European Space Agency.

1 *Electron micrograph of a cross-section through a solar cell with a quantum well stack. The image shows the alternating thin layers of the quantum well region, which is surrounded by the host solar cell material.*



2 *Light fraction which is converted into electric current by solar cells with and without quantum wells. The solar cell including quantum wells absorbs light in an additional spectral range, where the standard solar cell shows no response.*





DEVELOPMENT AND CHARACTERISATION OF CONCENTRATOR SOLAR CELLS

Multi-junction solar cells of III-V compound semiconductors achieve the highest efficiency values today for converting sunlight into electricity. We have been working for more than 15 years on this technology and in 2009, we achieved an efficiency value of 41.1 % under concentrated illumination, using a solar cell with three pn junctions. In a research project supported by the European Union, we are now working together with project partners in Europe and Japan to produce and accurately measure the next generation of multi-junction solar cells with four pn junctions.

Frank Dimroth, Stephanie Essig, Elvira Fehrenbacher, Stephan Heckelmann, Ranke Koch, David Lackner, Karin Mayer, Markus Niemeyer, Eduard Oliva, Inessa Semke, Gerald Siefer, Michael Schachtner, Manuela Scheer, Katrin Wagner, Alexander Wekkeli, Andreas Bett

In III-V multi-junction solar cells, several pn junctions with spectral responses ranging from the blue to the infrared regions of the solar spectrum are stacked on top of each other. These solar cells are used today in space and in terrestrial photovoltaic concentrator systems. The industrial standard is a triple solar cell with three separate pn junctions in GaInP, GaAs and Ge materials.

The next generation of these highly efficient cells should consist of four or five sub-cells, so that the efficiency of converting solar energy into electricity can be increased still further. We are working together with our project partners on these new solar cell concepts. They are created by inserting a new material with a band gap of 1.0 eV into the present structure. We are using lattice-mismatched $Ga_{1-x}In_xAs$ layers, whereby the band gap energy is determined by the concentration of indium in the crystal. A challenge is presented by the changes in atomic spacing in these crystal layers. These can cause dislocations which affect the material and solar cell properties negatively. One of our main research topics is the development of transitional layers between the materials. In addition, we optimise the material quality on the basis of test structures and solar cells.

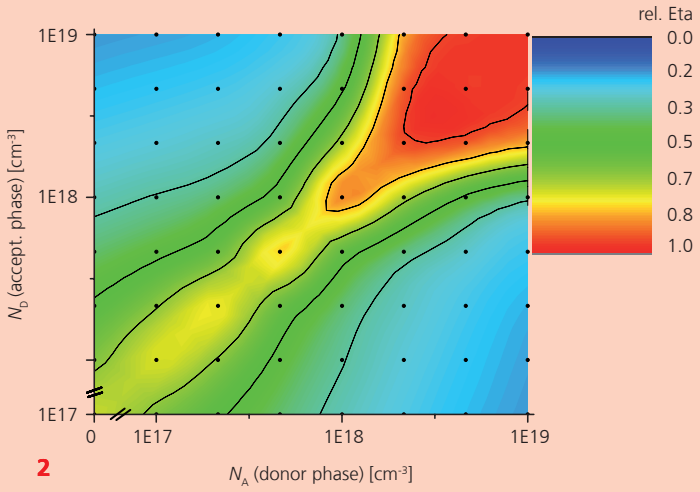
1 *Metal fingers of a concentrator solar cell with a diameter of 1 mm (left) and calibration of a cell under AM1.5d standard conditions.*
2 *XSIM solar simulator for exact measurement of solar cells with up to six pn junctions.*

The characterisation of quadruple solar cells is a further field of development. Because the sub-cells are connected in series, the spectrum of the solar simulator must be adjusted such that identical photocurrents are generated under the measurement conditions as for standard AM 1.5d conditions. New solar simulators that we have designed are used for this purpose (Fig. 2). They allow the spectral distribution to be adjusted separately in different spectral ranges. We also participated in international inter-laboratory comparisons, in which we demonstrated good agreement between measurements at Fraunhofer ISE and AIST in Japan.

The research work is supported by the European Union within the "NGCPV" project.

www.III-V.de

1



2

TWO-DIMENSIONAL MODELLING OF ORGANIC SOLAR CELLS

In contrast to conventional solar cells, the photoactive layer of organic solar cells consists of two different materials, a donor and an acceptor phase, which both contribute to the generation of charge carrier pairs. The holes are transported within the donor, the electrons within the acceptor. Organic solar cells are usually described theoretically with one-dimensional models, which do not represent the two-phase character of the photoactive layer. To overcome this weakness, we have developed a two-dimensional model which explicitly takes account of both components of the photoactive layer. This was successfully applied to determine the effect of doping both components.

Martin Andreas Fischer, Felix Stelzl, **Uli Würfel,**
Birger Zimmermann, Stefan Glunz

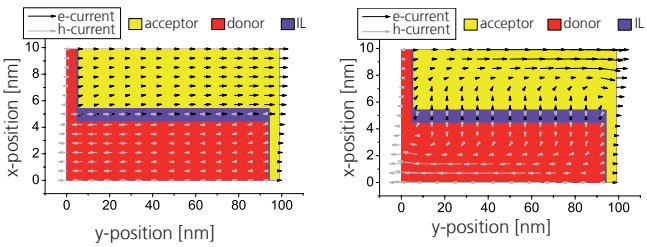
In previous simulations, the effective semiconductor model was used, in which the electron (hole) transport level corresponds to that of the acceptor (donor). The effects of charge carrier mobility, contact selectivity or p-type or n-type doping of the photoactive layer are already well represented with this model. However, the effect of doping both phases cannot be investigated with this model, as then compensation occurs.

Our extended 2-D model allows this investigation, as it takes account of both phases explicitly. Figure 2 shows that the simulated efficiency can be significantly increased by this measure. The reason is that an organic solar cell is a component relying only on majority charge carriers, as the electrons are located exclusively in the acceptor phase and the holes purely in the donor phase. Generation and recombination of charge carriers occurs exclusively at the interface between the two phases. Differing doping concentrations result in the formation of a depletion zone with corresponding band bending. The charge carrier concentration is thus lowest at the interface and reaches its highest value in the centre of each phase. This enables significantly more effective transport to the contacts, which positively influences the fill factor and thus the efficiency value. Figure 3 shows that the charge carriers are transported to the electrodes with a relatively homogeneous distribution in the undoped case. By contrast, in heavily doped phases the charge carriers initially move perpendicularly to the interface into the centre of the respective phase, before they are transported to the electrodes in the most highly conductive zones.

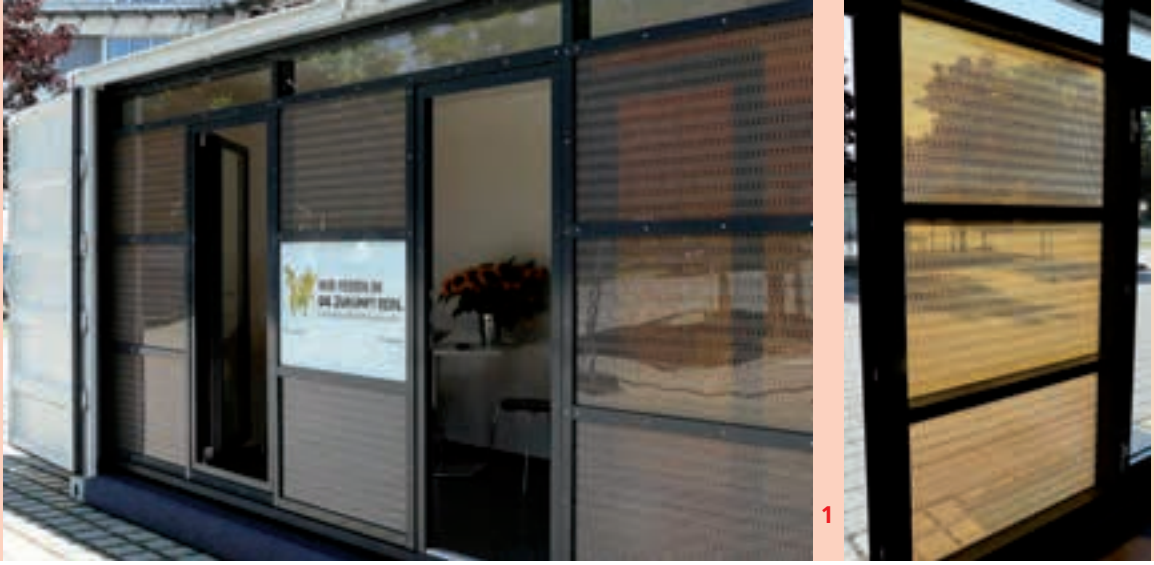
The project is supported by the German Federal Ministry of Education and Research (BMBF) and the Deutsche Forschungsgemeinschaft (DFG).

1 *Organic solar cell module without ITO on a flexible substrate.*

2 *Relative efficiency value of an organic donor/acceptor solar cell as a function of the p-type doping of the donor phase and the n-type doping of the acceptor phase.*



3 *Spatially resolved distribution of the short circuit current for the case of undoped phases (left) and the case of a heavily n-doped acceptor and a heavily p-doped donor (right). IL stands for the interfacial layer, where the charge carriers recombine.*



PRODUCT DEVELOPMENT OF DYE SOLAR MODULES

Dye solar cells will soon enter the market on a broad scale. Applications in lifestyle products have already been implemented. As dye solar cells can be designed to be either transparent or opaque, they also represent an interesting option for building-integrated photovoltaics. Photovoltaically active architectural glazing is being developed at Fraunhofer ISE. The modules with durable glass-soldered sealing and internal series circuits can now be reproducibly produced in dimensions of 60 cm x 100 cm.

Katarzyna Bialecka, **Henning Brandt**, Katrine Flarup-Jensen, **Andreas Hinsch**, Ramiro Loayza Aguirre, Welmoed Veurman, Stefan Glunz

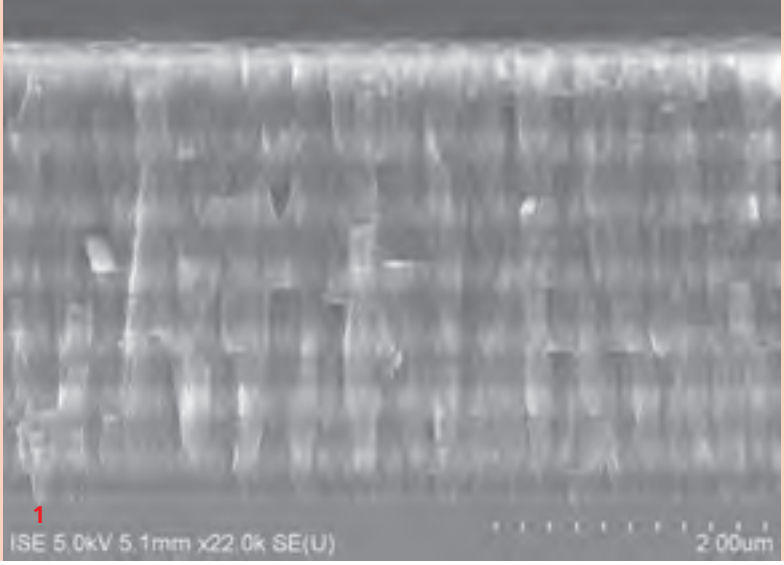
In contrast to conventional solar cells, an organic dye is used to convert light into electricity in dye solar cells. The modules are produced by simple screen-printing and are sealed with glass solder in a thermal process. The active layer is coloured with dye and the module is filled with electrolyte using prototype equipment which was developed at Fraunhofer ISE and is continually being optimised. The manufacturing of dye solar modules can be integrated into existing processes for production of architectural glazing.

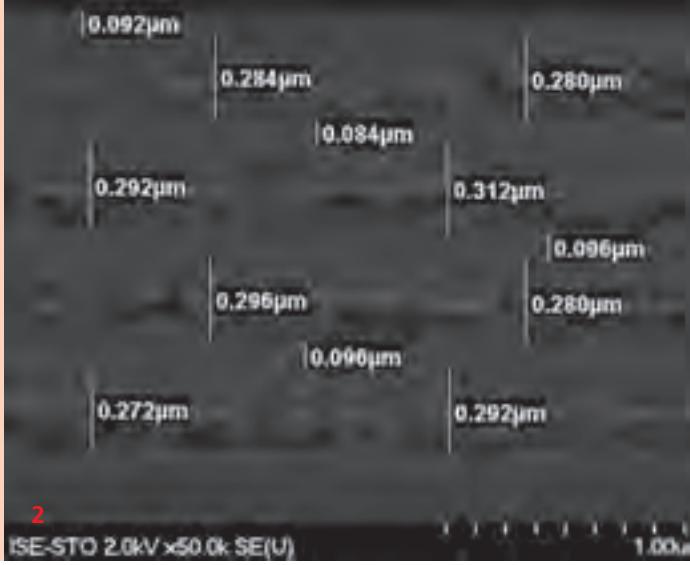
The large-area screen-printing process was reproduced in a small prototype production series by project partners. Furthermore, we demonstrated that earlier results for 10 cm x 10 cm modules could be reproduced for the up-scaled modules with an area of 60 cm x 100 cm. An efficiency value of 6.6 % relative to the active area has already been achieved. Development of the electrolyte is important for the long-term stability of dye solar cells. In co-operation with project partners, we have tested the stability of a wide range of materials in standardised test cells with conventional PV standard test procedures. Promising materials are now used in the large-area modules.

In addition to materials development, our current work is concentrating on optimising the module concept and further implementation of the processing steps in an industrially applicable environment. Here, we are co-operating specifically with those enterprises from sectors which are interested in producing and marketing dye solar cells.

The work within joint research projects is supported by the Baden-Württemberg Foundation, the German Federal Ministry of Education and Research (BMBF) and the Fraunhofer-Gesellschaft.

1 *Mobile showroom to present large-area dye solar modules at trade exhibitions and conferences.*





NANO-STRUCTURES FOR EFFICIENT PHOTON MANAGEMENT

Photon management denotes techniques which influence the light path and its spectral distribution with the aim of overcoming fundamental limits on the efficiency of conventional solar cells. Spectrally selectively reflecting structures are important components of systems for photon management. These can be applied e.g. to increase the efficiency of up-conversion, to improve light collection in fluorescent concentrators or directly to raise the absorptance of solar cells.

Benedikt Bläsi, Johannes Eisenlohr, Stefan Fischer, Judith Frank, Benjamin Fröhlich, Johannes Gutmann, **Jan Christoph Goldschmidt**, Martin Hermle, Barbara Herter, Stefan Janz, Janina Löffler, Janina Posdziech, Tim Rist, Heiko Steinkemper, Sebastian Wolf, Stefan Glunz

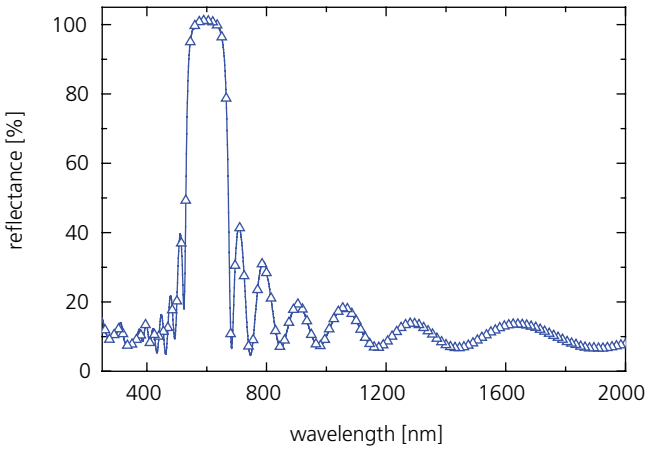
Depending on the intended application, we produce selectively reflecting structures from different materials. Multi-layer stacks of different silicon carbide compounds (SiC) with differing refractive indices are suitable for the near-infrared range (Fig. 1). These can be prepared by plasma-enhanced chemical vapour deposition (PECVD). PECV deposition of SiC is well suited to integration into solar-cell manufacturing processes. For instance, back-surface reflectors for solar cells can be produced which simultaneously support the electrical surface passivation. Resonator structures to increase the efficiency of up-conversion processes represent another application possibility. In this case, low-energy photons that cannot be absorbed by silicon are converted into usable photons of higher energy. By clever design of the resonance wavelengths, the multi-layer systems can amplify both the absorption of incident photons and the desired emission of usable photons.

1 *SEM image of a filter structure consisting of amorphous SiC compounds. The films are deposited onto silicon by PECVD. The structure is optimised for strong reflection of light with wavelengths exceeding 1500 nm.*

2 *Selective reflector for the visible spectral range, which was produced by alternately spin-coating with PMMA and TiO_2 nanoparticles.*

For visible light, multi-layer stacks can also be produced by cost-effective spin-coating (Fig. 2). These stacks can achieve selective reflectance of almost 100 % (Fig. 3). The spectral position of the reflectance peak can be shifted and secondary maxima suppressed by variation of the layer thicknesses.

The work on photon management is supported by the Deutsche Forschungsgemeinschaft, the German Federal Ministry of Education and Research (BMBF) and the European Union.



3 *Reflectance of a so-called Bragg filter, which was produced by PECVD of SiO_2 and SiN. Spectrally selective reflectance of almost 100 % is achieved.*

SUPPLYING POWER EFFICIENTLY

RENEWABLE POWER GENERATION

In the first half of 2012, the share of electricity generated in Germany from renewable sources exceeded 25 percent for the first time. This share should increase to 80 percent by 2050. The main growth is in the wind energy and photovoltaic sectors. As the electricity generated from both sources fluctuates according to the weather conditions, further expansion in these sectors will demand major adaptation of the energy supply system. In order to cope with the associated technical, ecological and economic demands, we are developing new concepts and components based on modern communications technology for energy management of distributed generators and loads in the distribution grid. Involvement of the electricity customers with regard to usage behaviour, consumption visualisation and efficient billing methods (smart metering) are playing an increasingly significant role in this process.

Storage of electricity to compensate for differences between supply and demand is a particularly important aspect when the amount of electricity generated from renewable sources increases. Storage solutions are also needed in autonomous, off-grid electricity systems and for electric vehicles. Thus, we are working intensively on developing and optimising battery systems for stationary and mobile applications. Our work concentrates on increasing the performance and storage capacity, improving operation management strategies and developing control systems for all common types of battery technology.

The development of photovoltaics is the most dynamic of the renewable energy sectors. Already at the end of June 2012, it accounted for 5.1 percent of the electricity generated in Germany. To also maintain this market growth now that feed-in payments are decreasing, the costs for the systems technology must be reduced further. This applies particularly to inverters to feed photovoltaic electricity into the grid, a product sector in which German manufacturers continue to dominate the market. Nevertheless, there is still considerable potential for increasing efficiency and reducing costs, which can be exploited with new circuit designs, digital controls technology, advances in power semiconductor components and passive components. In addition, as the share of electricity that is generated from fluctuating sources and fed into the grid increases, inverters will have to provide more and more grid-stabilising features in future. To this purpose, we offer specialised know how for the entire power spectrum up to the MW range in the fields of circuit design, as well as dimensioning and implementing analog and digital controllers. Beyond this, as a new service to our clients, we carry out all tests demanded by the new grid-connection regulation for transformers with power ratings up to more than 1 MW.

Around 1.4 thousand million people in rural areas, innumerable technical systems for telecommunications, environmental measurement technology or telematics, and four thousand million portable electronic devices all have one feature in common: They require off-grid electricity. Increasingly, regenerative energy sources or other innovative energy converters are being used to supply it. An increasing share of the photovoltaic modules sold world-wide is used in these markets, some of which are already economically viable without external subsidies. In addition, there is an enormous market for decentralised water desalination and purification technology based on renewable energy sources. For this broad spectrum of applications, we develop concepts, components and systems for off-grid power supplies based on photovoltaics, fuel cells, wind energy and hydroelectricity.

In future, vehicles will run partly or completely on electricity and draw their energy from the grid (electric and plug-in vehicles). Fraunhofer ISE is working at the interface between

the vehicles and the grid on concepts for an environmentally acceptable power supply and optimal integration of the vehicles into the electricity grid. Together with partners from the car and power industries, the institute is developing components for energy management and for bi-directional energy transfer between vehicles and the grid, as well as universal metering and billing systems.

For solar power generation on a large scale, predominantly for application in southern countries, Fraunhofer ISE is working on technology for solar-thermal power stations.

Our laboratory facilities include:
- power electronics laboratory with modern equipment and software for power up to 1 MW
- laboratory for inverter certification (fault ride-through, efficiency value measurement, power quality, etc.)
- development environments for micro-controllers, digital signal processors (DSP) and embedded systems
- measurement laboratory for electromagnetic compatibility (EMC)
- laboratory for information and communications technology for power plants and control systems
- SmartEnergyLab for developing and testing Smart Grid solutions
- measurement and calibration laboratory for solar modules
- outdoor test field for solar components
- battery laboratory for development and testing from the low-power to automotive range
- lighting laboratory
- test stands for fuel cells operating with hydrogen and methanol
- development laboratory for redox-flow battery systems
- testing and development laboratory for drinking water treatment systems

Engineers at Fraunhofer ISE developed a universal charging unit within the "Fraunhofer Systemforschung Elektromobilität" project (Fraunhofer systems research on electromobility). It offers both the infrastructure to charge electric vehicles via their on-board charge controllers and also rapid charging via a specially developed, extremely compact 22 kW converter which is integrated into the unit. In addition to charging and feeding electricity back into the grid, further functions such as energy metering and billing, vehicle identification and communication are integrated into the unit.

CONTACTS

Autonomous power supplies and mini-grids	Dr Matthias Vetter	Phone +49 761 4588-5600 matthias.vetter@ise.fraunhofer.de
Smart Grids	Dr Christof Wittwer	Phone +49 761 4588-5115 christof.wittwer@ise.fraunhofer.de
	Dr Thomas Erge	Phone +49 761 4588-5337 thomas.erge@ise.fraunhofer.de
Power electronics and control systems	Prof Bruno Burger	Phone +49 761 4588-5237 bruno.burger@ise.fraunhofer.de
Electric storage systems	Dr Matthias Vetter	Phone +49 761 4588-5600 matthias.vetter@ise.fraunhofer.de
Solar power plants	Dr Thomas Fluri	Phone +49 761 4588-5994 thomas.fluri@ise.fraunhofer.de
Decentralised PV water purification systems	Dr Joachim Koschikowski	Phone +49 761 4588-5294 joachim.koschikowski@ise.fraunhofer.de
	Dr Joachim Went	Phone +49 761 4588-5240 joachim.went@ise.fraunhofer.de
Electromobility	Dr Günther Ebert	Phone +49 761 4588-5229 guenther.ebert@ise.fraunhofer.de

FIELD TEST WITH PV-POWERED REVERSE-OSMOSIS PLANTS (PV-RO)

At the end of 2011, we took two photovoltaically powered, reverse-osmosis plants into operation for seawater desalination on Cyprus. They are the first reverse-osmosis plants in the world in which the power demand can be dynamically adapted to the instantaneous power supplied by the sun. Ideally, intermediate energy storage in batteries can be avoided completely due to the dynamic operation mode. After a year of operation, we can now draw predominantly positive conclusions concerning the system design, the specific energy demand, operation with minimised battery storage, control algorithms, membrane degradation and the reliability of the installed components.

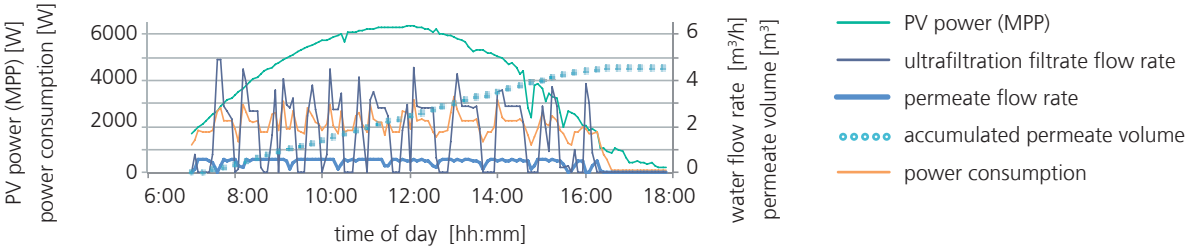
Julian Anhalt, Marcel Klemm, Sebastian Rauscher, Alexander Schies, Matthias Vetter, **Joachim Went**, Günther Ebert

1 *Corroded valve; pitting corrosion of the base plate for the 3/2 directional control valve, the key component of the energy recovery unit.*

2 *PV-RO plant on Cyprus (Pentakomo Lab).*

The field test confirmed that high accuracy can be achieved with the design method that we had developed. Although the dynamic operation mode meant that the systems frequently operate in the partial load range, a very low specific energy consumption of 4.6 kWh/m³ was achieved with the help of our flexible energy recovery unit (Fig. 3). The desalination process itself does not require battery storage. The use of a small battery storage unit is very advantageous for maintaining the automation function and Internet connection for remote monitoring and control. The fluctuating mechanical load on the membranes for reverse osmosis has not led to any premature degradation to date. Bio-fouling and scaling were reduced by flushing the system with fresh water overnight. The reliability of some externally purchased components was inadequate: A defective filling pump had to be replaced and a 3/2 directional control valve, the key component of the energy recovery unit, suffered heavy corrosion, although seawater-resistant steels were used. For future plants, we are planning to avoid these critical valve components by applying a new invention which promises still lower specific energy consumption accompanied by reduced complexity and system costs for PV-RO plants.

The project was supported by the German Federal Ministry of Economics and Technology (BMWi) within the InnoNet Programme and by our industrial partners, Pairan Elektronik GmbH, IBC Solar AG, Gather Industrie GmbH, MAT Plasmatec GmbH, Katadyn Produkte AG and Technisches Büro Becker.



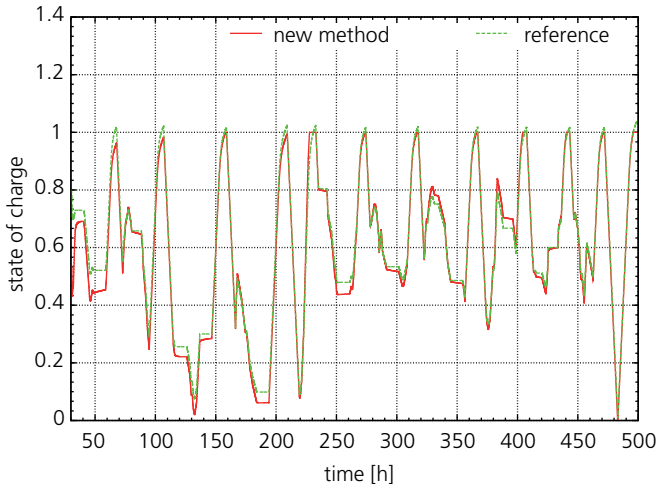
3 *Representative daily profile for plant operation on 24.05.2012. The supplied and consumed PV power, the permeate flow rate of the reverse-osmosis stage, the filtrate flow rate of the ultrafiltration and the accumulated volume of produced fresh water are plotted versus the local time of day.*

OPTIMISED DETERMINATION OF THE STATE OF CHARGE FOR LEAD-ACID BATTERIES

Lead-acid batteries are the most widely used type of rechargeable batteries. They are not only found in autonomous systems and island grids in threshold and developing countries, but they also present a storage option to increase the proportion of on-site consumption in grid-connected systems. In order to quantify the residual amount of stored energy accurately, algorithms to determine the state of charge are needed. Previous methods caused major difficulties, because the reliability and accuracy were inadequate for many operating conditions and states of charge. We have developed a new method based on stochastic filtering, which determines the state of charge for all types of lead-acid battery accurately and reliably.

Georg Bopp, Johannes Kehl, **Simon Schwunk**, Matthias Vetter, Günther Ebert

1 *The Rappenecker Hof is an example for an off-grid power supply.*

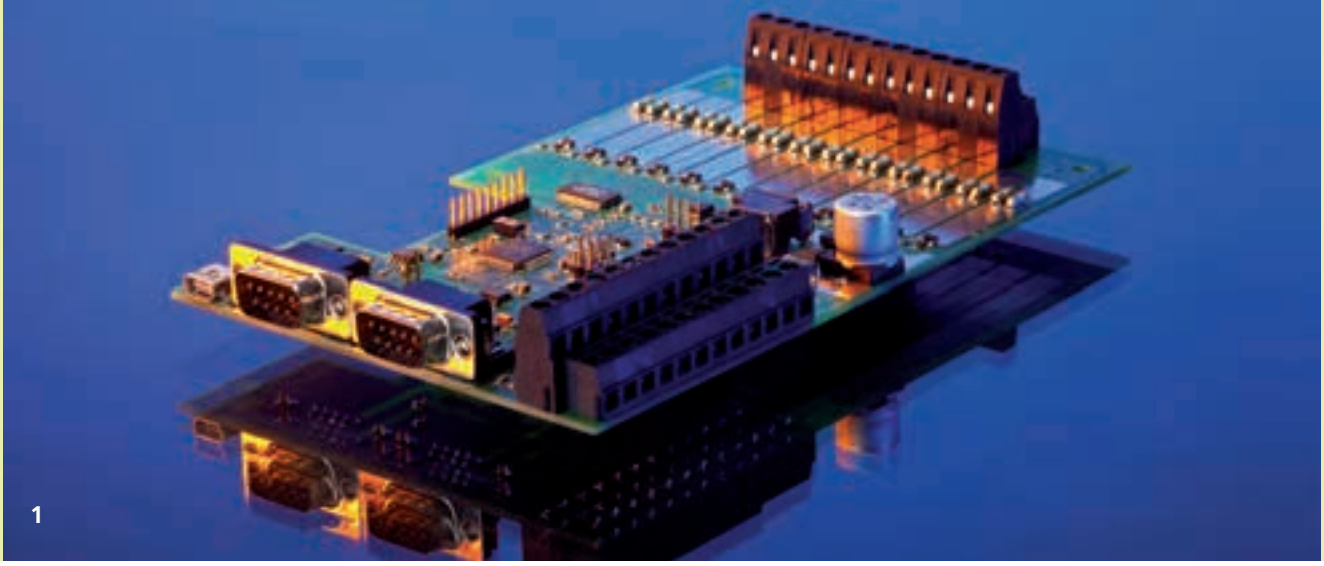


2 *The graph shows the state of charge determined accurately with the newly developed method and the reference. The application is an off-grid photovoltaic power supply.*

Determination of the state of charge is a challenge, particularly in off-grid power supplies. For applications in a forklift truck with very regular cycling operation or in uninterruptible power supplies, in which the batteries are almost always fully charged, it is relatively simple to determine the state of charge on the basis of identifying complete charging and integrating the battery current over time. The task is much more complex when it involves photovoltaic power supplies with long periods at an intermediate state of charge. When current is flowing, it is not possible to determine the state of charge directly from the terminal voltage of a battery. Many processes within the battery result in deviations from the open-circuit voltage.

The new method draws on many measurements of the terminal voltage, filters these measurements and combines them with integration of the battery current over time. In this way, a good estimation of the state of charge is finally obtained. Previous methods suffered either from the lack of possibilities for correction or were developed only for a specific type of lead-acid battery. Due to the work of Fraunhofer ISE, the method can now be applied to all types of lead-acid batteries and allows continuous correction for all operating points. Stochastic methods are also very suitable for application to other types of batteries.

The work in co-operation with the Steca company was supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) within the Pilebi project.



1

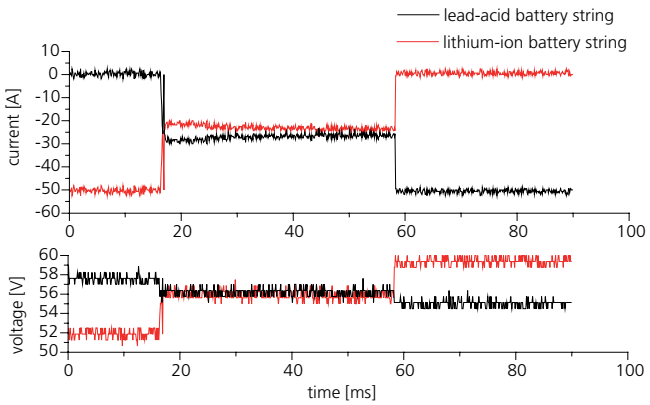
INNOVATIVE SYSTEMS TECHNOLOGY FOR FUTURE VILLAGE POWER SUPPLIES

A nationwide energy supply system does not exist in many regions of the world, either because they are very remote or the infrastructure is not sufficiently developed. Nevertheless, the demand for electricity also exists there and is mainly met by diesel generators. As these are associated with high costs and environmental disadvantages, we are working on new technical solutions with the goal of achieving more efficient, reliable and cost-effective power supplies. Photovoltaics provides a suitable method for generating electricity in the relevant areas. The systems technology for PV hybrid systems is being further developed in a research project, keeping this background in mind.

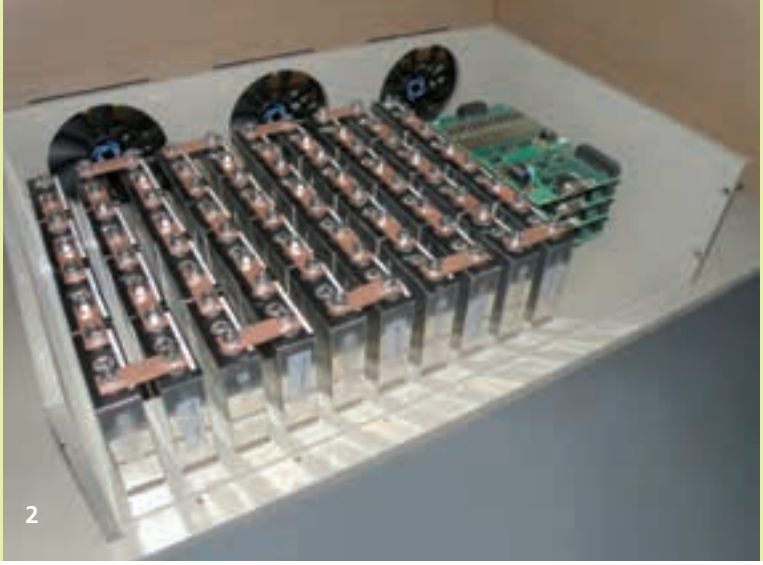
Bruno Burger, Michael Eberlin, Max Jung, Severin Philipp, **Florian Reiners, Simon Schwunk**, Olivier Stalter, Matthias Vetter, Günther Ebert

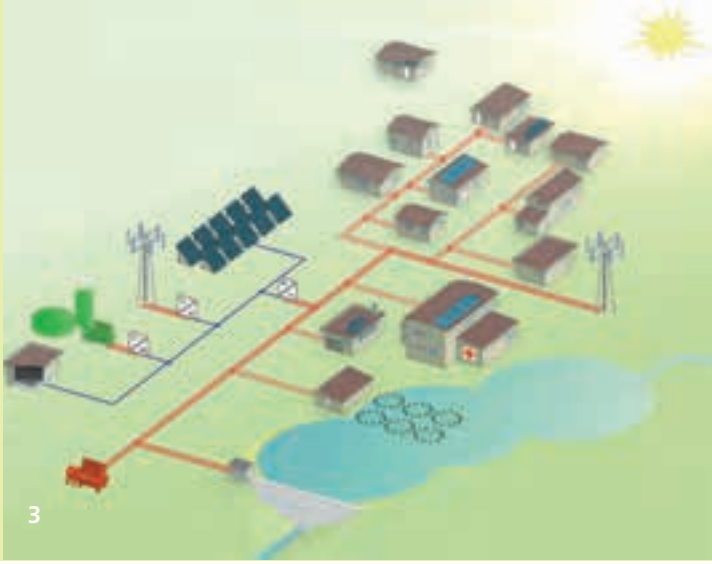
The essential components of the village power supply are the PV generator, a hybrid battery system, an inverter, a PV battery charge controller and a higher-level energy management system. The photovoltaically generated electricity is temporarily stored via the charge controller in the hybrid battery system if generation exceeds the instantaneous consumption. If the required energy cannot be supplied by the photovoltaic system, it is drawn from the battery. The system operates with voltages of up to 1000 V to achieve high efficiency.

The battery has represented a major cost factor over the system lifetime up to now. Usually lead-acid batteries are used, which have a favourable purchase price but often have a very limited lifetime in such applications. Due to their technical specifications, lithium-ion batteries would be much better suited for such systems, but they have been too expensive to date. By combining both systems, it is possible to reduce the aging of the lead-acid battery by up to 40 %. The additional system costs caused by combining them are low, as additional power electronics could be avoided. Figure 4 illustrates a typical switching process. It can be seen that both battery systems supply electricity for a short period of time. If a suitable switching strategy is applied, high switching currents which are disadvantageous for the battery can be avoided, so that no safety risk or lifetime reduction is caused.



4 *Switching process from the lithium-ion to the lead-acid battery string. Initially, the power to the load is supplied only by the lithium-ion battery; then the current is drawn from both batteries for a short period. After a short time, the lithium-ion battery is disconnected from the DC bus and the lead-acid battery is the sole source of current for the load.*





Fraunhofer ISE designed and developed the complete battery system, including the modular battery management system suited for high voltages, the systems to estimate the battery state of charge and state of health, the module construction, the switching devices and the switching strategies.

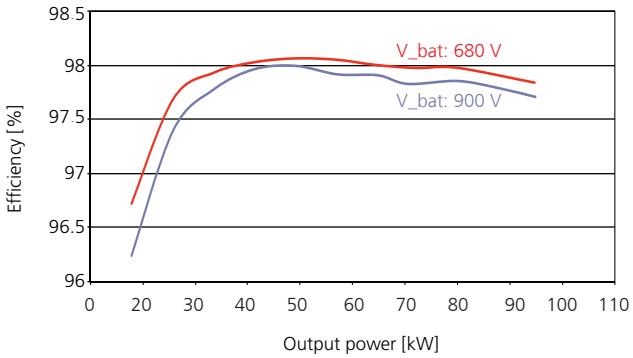
In addition to the battery system technology, the power-electronic components needed for a village power supply system were developed at Fraunhofer ISE: a 120 kW battery inverter and a 51 kW PV battery charge controller. The aim was to achieve a configuration which was as efficient, reliable and cost-effective as possible. Contrary to previously available stand-alone inverters, step-up converters and transformers were not included in the developed system. Instead, the concept was based on a high system voltage on the DC side. In combination with a highly efficient NPC topology, efficiency values exceeding 98 % were achieved. The maximum value today is usually 95 %. The high output power is also previously unattained.

The developed PV battery charge controller enables separate control of up to six different PV generators at their maximum power point (MPP). The selected topology with step-up and step-down converters results in a PV voltage range from 350 V to 1200 V, whereas the battery voltage can be between 650 V and 1000 V. This large voltage range contributes to great flexibility in the system dimensioning. In order to minimise transformation losses, superjunction field-effect transistors as well as the newest generation of silicon carbide diodes are used. As in the stand-alone inverter, transformers are not included. Efficiency values of up to 99 % were reached in the first measurements.

1 *Circuit board of a battery module management system for lithium-ion batteries, designed for high-voltage operation. The circuit measures the battery cell voltages, equalises the cells and determines the state of charge of the batteries.*

2 *Lithium-ion battery module for a hybrid battery system. The cells are connected in series, are air-cooled and monitored by several module management circuits.*

3 *Village power supply with photovoltaics, wind turbine, biomass and a diesel generator. The grid is managed by the central stand-alone inverter; operation of the distributed photovoltaic inverters is controlled by the grid.*



5 *Efficiency value of the developed stand-alone inverter versus output power for different voltages. The peak efficiency value is greater than 98 %. The efficiency value remains essentially constant over a wide range.*

1

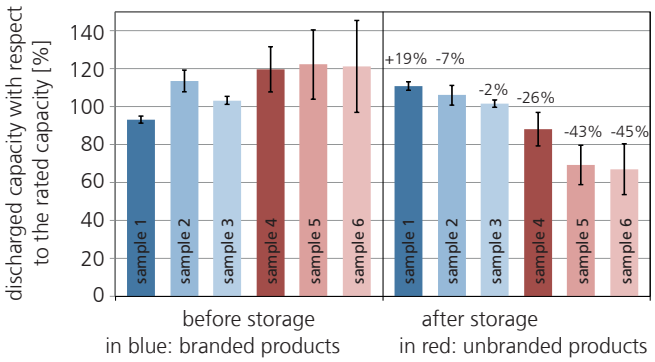
2

QUALITY ASSURANCE OF PV LAMPS: NEW TESTING METHODS FOR BATTERIES

Fraunhofer ISE was commissioned by the Gesellschaft für Internationale Zusammenarbeit (GIZ) to extend and improve the quality assurance procedures for PV-powered lamps which had been developed within the "Lighting Africa" programme of the World Bank / IFC. Various investigations and field tests had demonstrated that particularly the quality-control tests for batteries were not sufficiently comprehensive. New battery testing methods now allow the quality to be specified more accurately and realistically. In addition, the testing procedures were extended to include recent storage technologies such as lithium-ion batteries.

Georg Bopp, Evandro Augusto Dresch, **Norbert Pfanner**, Friedemar Schreiber, Matthias Vetter, Günther Ebert

1.4 thousand million people around the world have no access to electricity. Petroleum lamps, with high operation costs, are often used for lighting. Solar lamps present an environmentally friendly and cost-effective alternative, but demonstrate significant differences in quality.



3 *Results of a battery test: the samples of unbranded products showed significant reduction in capacity and large deviations in the results (black error bars).*

1 *Typical examples of PV-powered lamps corresponding to different power classes.*

2 *Electric storage devices that are used in solar lamps: nickel metal hydride, lithium-ion and lead-acid batteries (from left to right).*

Comprehensive testing methods to determine the quality of such products have been developed and are continually being improved by the "Lighting Africa" Organisation, GIZ and Fraunhofer ISE. However, field test results revealed the need for further optimisation concerning electric storage devices.

PV lamps make use of various types of battery technologies, ranging from lead-acid batteries to lithium-ion cells. In some products, only a very short lifetime was reached, although appropriate operating and storage conditions were observed. New test procedures were developed which can identify premature aging of lead-acid, NiMH and lithium-ion batteries. These test procedures simulate regular usage and storage of the lamps and take account of higher ambient temperatures.

We were able to demonstrate that the newly developed test procedures allow quick and simple quality control of both high-quality and low-quality batteries. In particular, accurate results concerning storage were obtained after only a few weeks. With the new test procedures, it can also be determined whether products with evidently good cycling lifetimes also can withstand special conditions such as long transportation periods.

The work was supported by the Gesellschaft für Internationale Zusammenarbeit, GIZ.

HIGHLY EFFICIENT POWER ELECTRONICS IN THE MEGAHERTZ RANGE

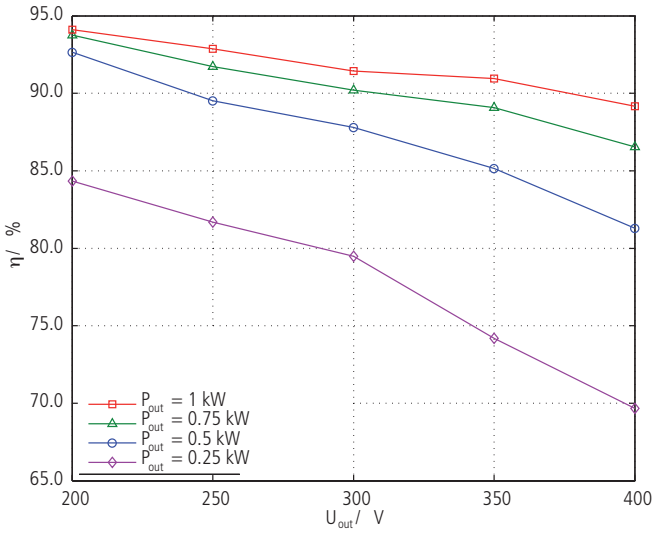
Wide band gap semiconductors are of great interest for power electronics applications. In addition to the power transistors made of silicon carbide (SiC), which have already become commercially established, the first 600 V power transistor prototypes of gallium nitride (GaN) have become available. Due to their lateral configuration, they feature very low switching energy and thus allow significantly higher switching frequencies than components of silicon (Si) or SiC. When the switching frequency is higher, the passive components of power electronic circuits can be smaller dimensioned. This increases the power density and reduces not only the volume and mass but also the production costs of the complete system.

Bruno Burger, Dirk Kranzer, **Arne Hendrik Wienhausen**, Günther Ebert

DC-DC converters can be found in very diverse power ranges and application areas from consumer electronics through solar inverters up to charging equipment for electric vehicles. Not only the electric conversion efficiency, but also the volume, mass and cost of the converter are highly relevant. In the case of mobile systems, e.g. vehicles for air and road transport, the efficiency of the complete system can be improved by reducing the mass. In addition, harmful emissions can be reduced. Modern resonant DC-DC converters with 600 V Si superjunction MOSFETs are operated with switching frequencies of up to 350 kHz.

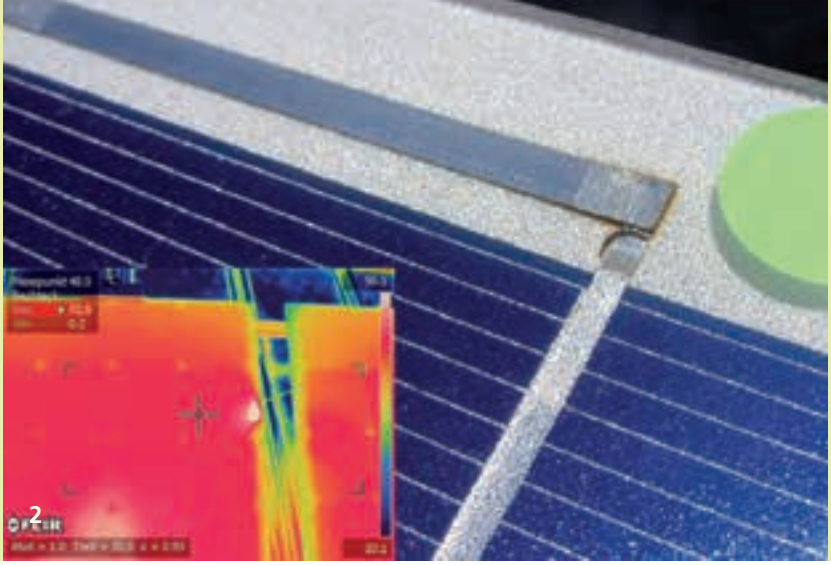
As part of an internal study at Fraunhofer ISE, a resonant LLC converter was developed with a maximum switching frequency of 1.4 MHz and a nominal output power of 1 kW (Fig. 1). By employing the most modern GaN power transistor prototypes, an efficiency value of 94.1 % was achieved, although the switching frequency was higher by a factor of 4

1 *First laboratory prototype of the developed resonant DC-DC converter employing 600 V GaN power transistor prototypes. The volume can be reduced further and the power density increased by further optimisation such as reduction of the cooling block and constructing a stack of circuit boards.*



2 *Efficiency of the developed resonant voltage converter versus output voltage for varying output power. The decrease for lower power values is determined by the topology.*

and the transformer was not yet optimised for this application. Almost all of the losses were localised in the coils of the transformer. A temperature increase of the GaN power transistors themselves was hardly measurable, even when power of 1 kW was transferred at a switching frequency of 1 MHz. This demonstrates the excellent semiconductor properties of GaN on the one hand but also reveals the great need for research on inductive components on the other. We can assume that gallium nitride will permanently change the world of power electronics – particularly in the field of photovoltaics and resonant voltage converters.

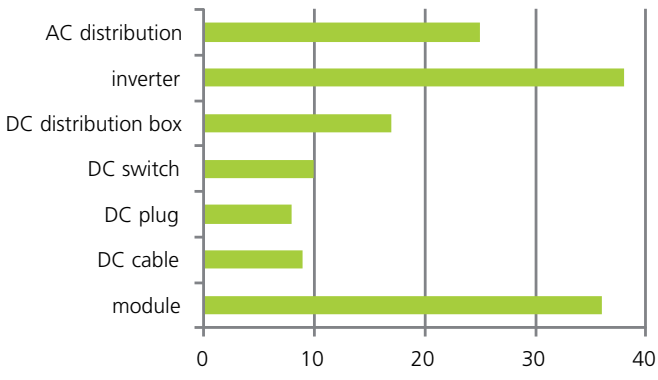


FIRE RISK, FIRE SAFETY AND FIRE PREVENTION IN PV SYSTEMS

In recent years, fires which affected buildings with photovoltaic systems made headlines in the German press. This stimulated Fraunhofer ISE, together with TÜV Rheinland and other partners, to make a systematic investigation of the risks associated with PV systems in the case of fire and the measures which can be taken to reduce these risks. We analysed some of the widely publicised cases of fires involving PV and conducted detailed research on the course of events leading to damage. Further work has concentrated on measures against the formation of electric arcs, methods to automatically detect and extinguish electric arcs, and reliable tests of associated procedures and devices.

Georg Bopp, Robin Grab, Hermann Laukamp, Severin Phillip, **Heribert Schmidt**, Günther Ebert

We systematically record and analyse reports of fire damage in PV systems in order to further improve systems technology and construction practice. We aim to determine the cause of damage in each case by means of an Internet-based survey conducted jointly with TÜV Rheinland, media research and contact to expert witnesses and insurance companies. Over a period of 20 years, among the approximately 1.3 million PV systems now installed in Germany, we are aware of about 75 cases in which major fire damage to a building was caused by a PV system. In about 40 further cases, components showed evidence of overheating without causing a fire. Figure 3 shows how often which part of the system was affected by damage due to fire or overheating. If the cases where buildings with PV systems caught fire due to other causes are also included, the fire brigade was involved in fighting a total number of 350 fires.



3 *Which component caused the damage? Number of defects based on about 100 cases of fire in PV systems.*

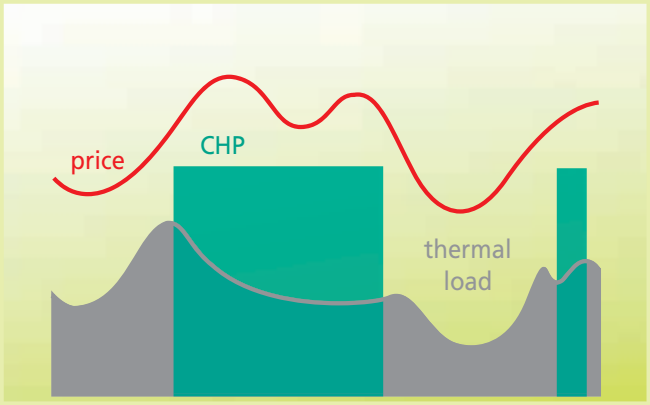
1 *Remains of a PV system on a flat roof after fire. An expert investigator found module remnants which indicated that faulty soldered connections were a highly probable cause of the fire.*
2 *Thermograph showing local overheating of a faulty soldered connection and a close-up photo of the same position.*

In several states of the USA, the installation of an electric arc detector in grid-connected PV systems has been required since 2012. It is intended to disconnect the system if an electric arc occurs. In order to support the German industry in developing and testing such detectors, experiments on the origin, expansion and detection of electric arcs are being carried out within the project. At Fraunhofer ISE, electric arcs are created under the most realistic test conditions possible in a real PV system. Our goal is to create reference spectra for reproducible testing of electric arc detectors.

The project is supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

www.pv-brandsicherheit.de

1



2

PREDICTION-BASED OPERATION MANAGEMENT STRATEGIES IN A SMART GRID

The development of smart grids is accompanied by increasing demands on distributed generators, consumers and storage systems. In addition to fulfilling their primary objectives (e.g. supplying heat in the case of a combined heat and power plant), distributed units should contribute to compensation of the fluctuating output from renewable energy sources and provide grid services. Innovative control strategies allow anticipatory operation, which reacts quickly to dynamic stimuli and makes optimal use of flexibility. To this purpose, we develop operation management algorithms which use predictions as the basis for calculating optimal system operation schedules and implement these as control commands.

Thomas Erge, **Raphael Hollinger**, Bernhard Wille-Haußmann, Christof Wittwer, Günther Ebert

Anticipatory planning, which is natural to human beings, does not play any role today in the control of distributed systems within the energy system. For conventional power plants, individual operation schedules must already be provided and registered. Thus, prediction-based schedule optimisation is standard for these power plants. By contrast, distributed power plants, consumers and storage units are usually operated on the basis of instantaneous power demands (e.g. heating-led operation of a combined heat and power plant).

1 *Web-based configuration interface of the OpenMUC software to control and monitor the systems.*

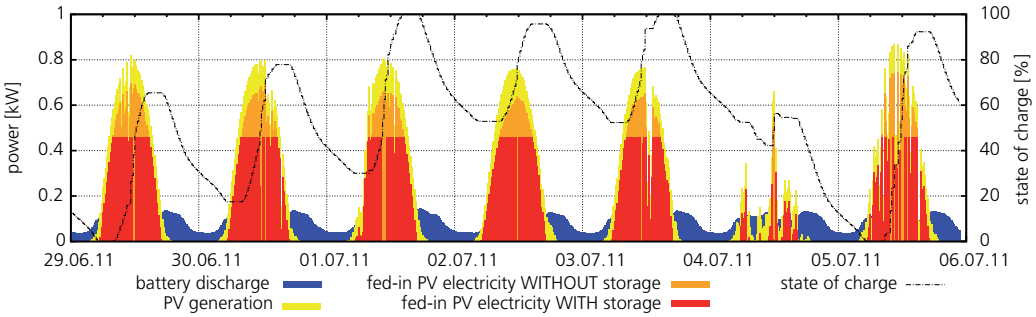
2 *Optimised schedule for a combined heat and power plant (CHP) based on the predicted thermal load and a price curve.*

However, only when anticipatory planning is applied to supply by local generators and to the usage of available storage systems, that e.g. electricity generation during high-demand periods, smoothing of PV generation and electricity consumption peaks as well as higher-priority usage of electricity generated from renewable sources can be optimised.

Our algorithm consists of three stages:

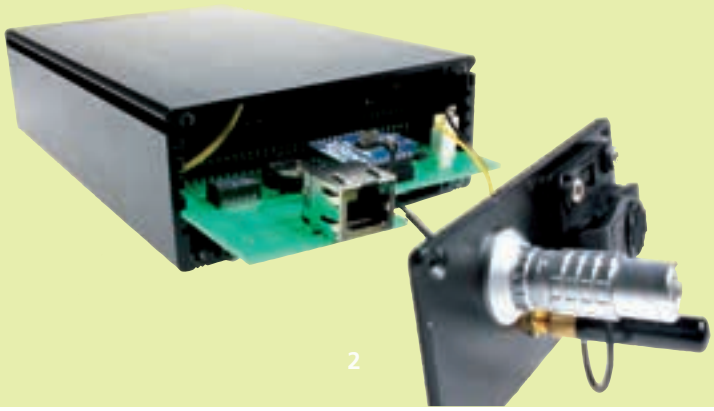
1. preparation of predictions (e.g. of local heating demand)
2. preparation of an ideal schedule based on the prediction and external stimuli if relevant
3. system control with the least possible deviation from the ideal schedule

During continuous operation, the three steps are regularly repeated according to the sliding horizon principle to allow dynamic reaction to changed stimuli and deviations from the predictions. The algorithm has already been applied successfully both to long-term horizons such as the day-ahead trading of electricity from distributed generators and to short-term horizons (optimisation every 15 minutes) as part of model-based predictive control strategies.



3 *Optimal battery charging strategy for a building with a PV system with the goal of reducing both the feed-in and consumption peaks and maximising on-site consumption.*

1



2

CONCEPTS AND FIELD TESTS FOR ELECTRIC VEHICLES IN THE SMART GRID

Widespread integration of electric vehicles into the electricity distribution grid is not only a challenge but also an opportunity for stable grid operation. The load shift potential of electric vehicles can be used both to avoid peak loads and to attenuate the solar peak around noon. The "Smart Grids" Department of Fraunhofer ISE is developing and testing innovative solutions and pilot systems to this purpose. In 2012, the "Electromobility Fleet Test" supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) was successfully completed. Several successor projects started during the course of the year.

Robert Kohrs, Michael Mierau, Dominik Noeren, Christof Wittwer, Günther Ebert

Electromobility is a serious market sector today; all major manufacturers are working on mass-produced vehicles and questions of grid integration. The German Federal Government also reconfirmed its goal of one million electric vehicles by 2020. As a result, concepts for load shifting, grid services and storage utilisation in the smart grid and grid codes for electric vehicles are highly relevant.

The focus of Fraunhofer ISE in the "Electromobility Fleet Test", a project supported by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU), was the development of a tariff-controlled charging system which also allowed electricity to be fed back into the electricity grid. The special feature of the implemented concept was that the optimisation algorithm operated in the vehicle, in the so-called mobile Smart Meter (mSM) developed for this purpose. Time-dependent tariffs reflect generation and consumption in the grid and are used, in combination with user specifications and battery parameters, to calculate a cost-optimised charging schedule. After extensive testing in the workshops of VW, the system was tried out successfully in a field test. Battery degradation is taken into account via a battery model which is stored in the mSM. Electricity is fed into the grid only when this is economically advantageous for the user.

1 *The charging station for electric vehicles at Fraunhofer ISE is connected with the Smart Energy Laboratory. This allows testing of communication protocols and operation management strategies in the Smart Home.*

2 *As the central charging manager, the mobile Smart Meter (mSM) is connected both within the vehicle (CAN bus) and via the charging station to the energy utility or grid operator.*

This concept is to be further developed and extended in the "iZEUS" project with the Adam Opel AG and other partners. The main aspect is high-resolution grid monitoring in the vehicle and automatic adaptation of the charging parameters derived from the measured data. This project is supported by German Federal Ministry of Economics and Technology (BMWi).

Also since the beginning of 2012, Fraunhofer ISE has been working on an intelligent, inductive charging system with a central energy management system for urban mobility within the "Gemeinschaftlich-e-Mobilität" project supported by the Fraunhofer programme for Topics of the Future.

In the town of Fellbach, the integration of electric vehicles into the energy system of a passive building complex is being demonstrated as a sub-project of the electromobility showcase in the "LivingLab BWe mobil" project. Among other aspects, this applies the openMUC energy management software framework developed at Fraunhofer ISE (www.openMUC.org).

www.izeus.de **www.gemo.fraunhofer.de**

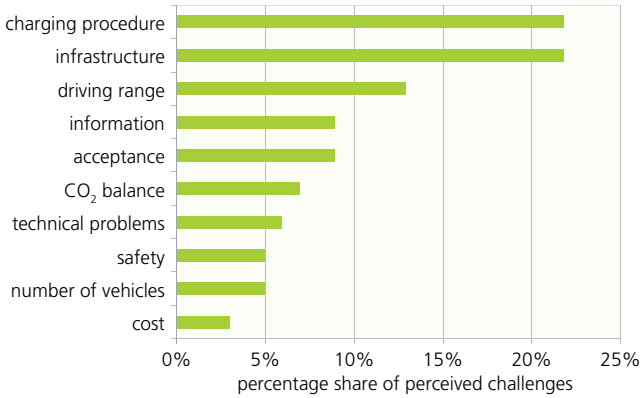
1

ANALYSING THE POTENTIAL OF ELECTRIC CARS IN A CAR-SHARING FLEET

Within the project entitled "Lörrach elektrisch mobil", Fraunhofer ISE investigated whether half of the cars in the fleet of the Stadtmobil car-sharing provider could be replaced by electric cars. Fraunhofer ISE conducted the analysis in two stages, of which the first involved determining the technical potential of electric cars. In the second stage, car-sharing users were interviewed to investigate their mobility requirements and the perceived matching with electromobility. Fraunhofer ISE identified a technical potential for electric cars in the car-sharing context which was confirmed by the survey: 80 % of customers rated the introduction of electric cars positively. More than 60 % could imagine preferential use of electric cars.

Sebastian Gölz, **Ulf Hahnel**, Dominik Noeren, Christof Wittwer, Günther Ebert

1 *A first taste of the planned introduction of electric vehicles into the car-sharing fleet of Stadtmobil. Project partners Michael Nowack (Stadtmobil), Christine Wegner-Sänger and Arne Lüers (both from the Town of Lörrach) next to an electric car.*



2 *Percentage share of the challenges perceived by car-sharing customers concerning the introduction of electric vehicles to the fleet.*

In keeping with its reputation as an "Energiestadt®", the town of Lörrach aims to support environmentally friendly mobility in co-operation with car-sharing providers. In a study for the project entitled "Lörrach elektrisch mobil", Fraunhofer ISE investigated whether half of the fleet of the local car-sharing company Stadtmobil could be replaced by electric cars. The project focussed on two questions: Are electric cars suitable vehicles for car-sharing, taking the previous mobility behaviour of car-sharing customers into account? And are electric cars accepted by the current car-sharing customers, or are they even considered to be particularly attractive? Based on existing mobility data, which were analysed under the supervision of Fraunhofer ISE, and the results of a customer survey conducted by Fraunhofer ISE, it was demonstrated that a potential for electric vehicles in the car-sharing pool can be assumed. Fraunhofer ISE identified that the main general concern of users is that they could "remain stranded" with a flat battery if they drive an electric car. The greatest perceived challenges were the time to charge the vehicle and the need for appropriate infrastructure (Fig. 2). Nevertheless, this does not seem to prevent most users from wanting to drive an electric car. Electric vehicles in the car-sharing fleet are perceived as an opportunity to try out electric cars and to gain previously lacking experience with electric vehicles. Following the positive results of the study conducted by Fraunhofer ISE, Stadtmobil is now introducing electric cars into its fleet.

The project, "Lörrach elektrisch mobil" was funded by the Innovation Foundation for Climate and Water Conservation of the local utility, badenova.

ELECTRICITY FROM HYDROGEN

HYDROGEN TECHNOLOGY

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

Although hydrogen is not a source of energy, as a universal fuel it will be an important component in the sustainable energy economy of the future. A long-term perspective is to store almost unlimited quantities of intermittently generated renewable energy as hydrogen, for example in underground caverns or the existing gas network. All desired energy services can then be provided with the accustomed reliability. The application potential of hydrogen is enormous: In distributed power supplies, fuel cells can supply heat and electricity from natural gas with a total efficiency value of up to 90 %. Fuel cells, combined with electric motors, serve as mobile, non-polluting drive units for cars, trucks and buses. In addition, fuel cells in auxiliary power units (APU) provide the power for on-board electrical systems independently of the drive unit. Finally, miniature fuel cells can supplement rechargeable batteries in off-grid power supplies or small electronic appliances, due to the high energy density of hydrogen or alcohol.

Research on innovative technology to produce hydrogen and convert it efficiently to electricity and heat in fuel-cell systems is the core activity of the „Hydrogen Technology" business unit at Fraunhofer ISE. Together with our partners from science and industry, we develop components and the intermediate stages up to complete, integrated systems, mainly for off-grid, portable and mobile applications.

We develop reformer and pyrolysis systems to convert liquid hydrocarbons or alcohols into hydrogen-rich reformate gas. The systems consist of the actual reforming reactor and, depending on the type of fuel cell connected, gas treatment to raise the hydrogen concentration and reduce the amount of catalyst-damaging carbon monoxide and sulphur in the reformate gas. Such systems can be used in applications that range from stationary combined heat and power plants (CHP) through auxiliary power units (APU) up to off-grid power supplies.

As our contribution to a sustainable energy supply, we are extending our portfolio with regard to the conversion and usage of biomass. We have commissioned a technical prototype for gasification of wood, and use it now to demonstrate the feasibility of a new process which was developed by Fraunhofer ISE in co-operation with other partners. Furthermore, we are using pyrolysis processes to produce synthetic fuels from biomass and conventional combustible materials.

To obtain hydrogen from water, we develop membrane electrolysis systems supplying power from a few watts up to several kW, corresponding to the production of several hundred litres of hydrogen per hour. To gain deeper understanding of the processes occurring at the electrodes, we apply different characterisation methods such as scanning

electron microscopy or cyclovoltammetry. At the beginning of 2012, we officially opened a public hydrogen filling station based on solar-generated hydrogen, to be used by fuel-cell bicycles, cars and buses.

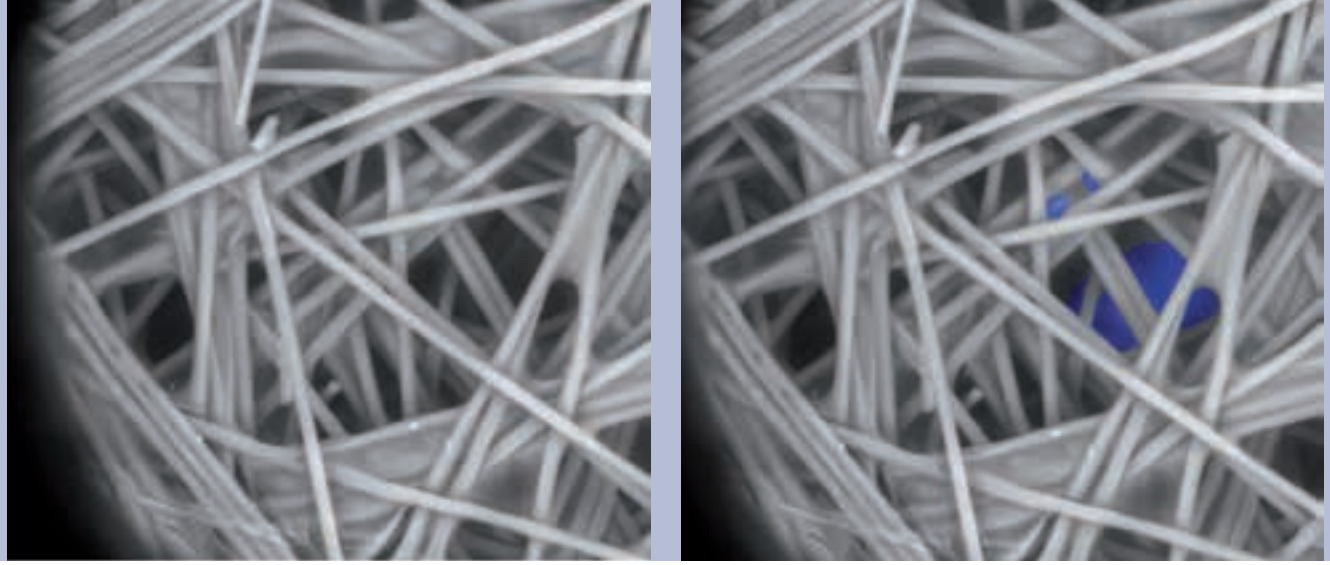
The membrane fuel cell, operated with hydrogen or methanol, is our favoured energy converter in the power range from mW to several kW, being efficient, environmentally friendly, quiet and requiring little maintenance. We have equipped our TestLab Fuel Cells to characterise this type of fuel cell. Furthermore, we cooperate with the VDE Testing and Certification Institute in providing advice on development and testing in compliance with existing standards and on the certification of fuel cells and systems.

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

Fraunhofer ISE officially opened a solar hydrogen station in 2012. Funded by the State Ministry for the Environment, the publicly accessible hydrogen station is not only a research platform; it also marks a milestone within the hydrogen fuelling network in the State of Baden-Württemberg. The solar hydrogen station in Freiburg is one of the few examples which include the complete energy chain, from renewably generating electricity, through electrolysis, to filling vehicle tanks with hydrogen (see page 131). Since its establishment, Fraunhofer ISE has investigated electrolyser technology and hydrogen as a fuel for fuel cells as well as a storage medium for renewably generated electricity.

CONTACTS

Fuel cell systems	Ulf Groos	Phone +49 761 4588-5202 ulf.groos@ise.fraunhofer.de
Micro-energy technology	Dr Christopher Hebling	Phone +49 761 4588-5195 christopher.hebling@ise.fraunhofer.de
Hydrogen production and storage	Dr Thomas Aicher	Phone +49 761 4588-5194 thomas.aicher@ise.fraunhofer.de
	Dr Tom Smolinka	Phone +49 761 4588-5212 tom.smolinka@ise.fraunhofer.de



1

WATER MANAGEMENT IN POLYMER-ELECTROLYTE MEMBRANE FUEL CELLS

Within the "PEM-Ca-D" project, we are co-operating closely with leading Canadian and German research organisations to optimise water management in polymer-electrolyte membrane fuel cells. With the help of innovative in situ and ex situ characterisation techniques, combined with computer-assisted modelling, fundamental questions concerning the transport and distribution of water and its effect on fuel cell performance and stability are being investigated. Our goal is to identify potential for optimisation, as a basis for developing improved material structures.

Robert Alink, **Dietmar Gerteisen**, Ulf Groos, Nada Zamel, Christopher Hebling

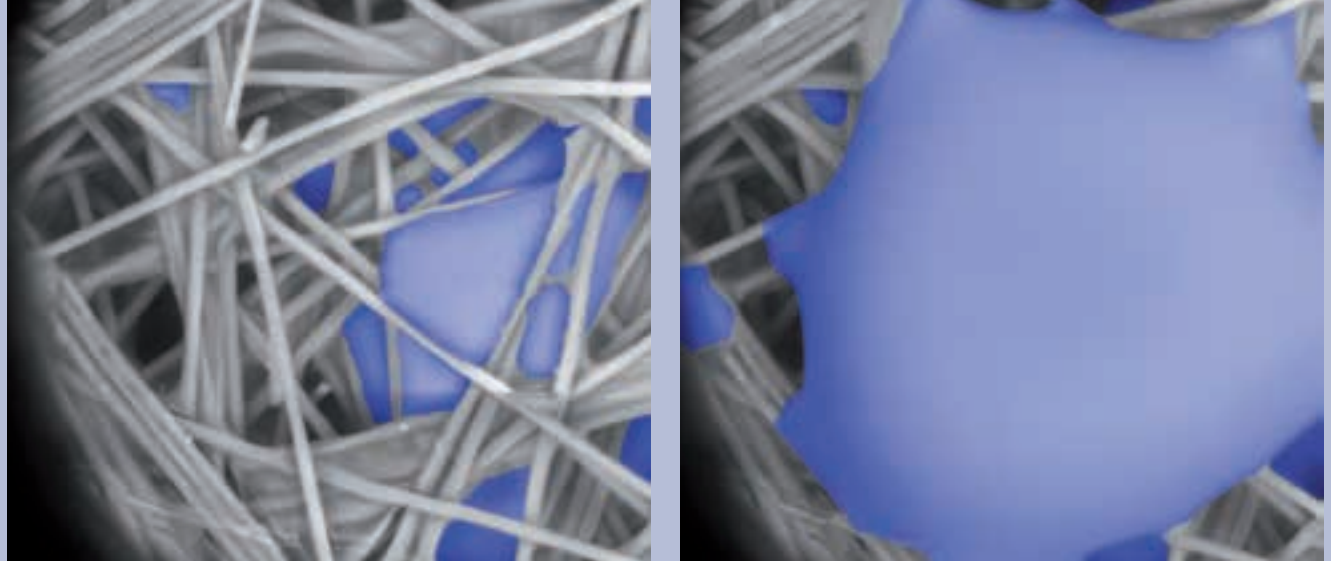
Water is essential for polymer-electrolyte membrane fuel cells. It is created by the redox reaction between hydrogen and oxygen and is necessary for proton conduction in the membrane and catalyst layer. At the same time, flooding of the porous structures needed for gas transport must be prevented. Inadequate water management during fuel cell operation can reduce the power density, cause temporary power interruptions and shorten lifetime. Water management is thus a decisive factor which influences the processes in fuel cell components at all scales.

A wide range of expertise, including 3D reconstruction of the catalyst layer applying FIB-SEM, visualisation of liquid water in operando by synchrotron radiography, spatially resolved current density measurement and electrochemical impedance spectroscopy, is introduced to the project by our partners. The consortium includes the Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW), the Institute for Microsystems Technology (IMTEK) of the University of Freiburg, Fraunhofer ITWM, the DLR Institute for Technical Thermodynamics and Fraunhofer ISE.

1 *Time sequence based on highly resolved ESEM images to illustrate the development of capillary transport of liquid water through a gas diffusion layer.*

At Fraunhofer ISE, we are working on optimising the transport of liquid water from the catalyst layer to the flow field structure. To this purpose, we are investigating the effect of structuring the gas diffusion layer (GDL) and the microporous layer (MPL) on the removal of water. For example, to visualise the effect of GDL perforation on water transport with high spatial resolution, we have developed an innovative imaging method with an environmental scanning electron microscope (ESEM).

By applying a defined temperature gradient within the GDL sample, we were able to visualise the accumulation over time and the capillary transport of liquid water resulting from the pressure increase, the first time that this had been done with high spatial resolution.

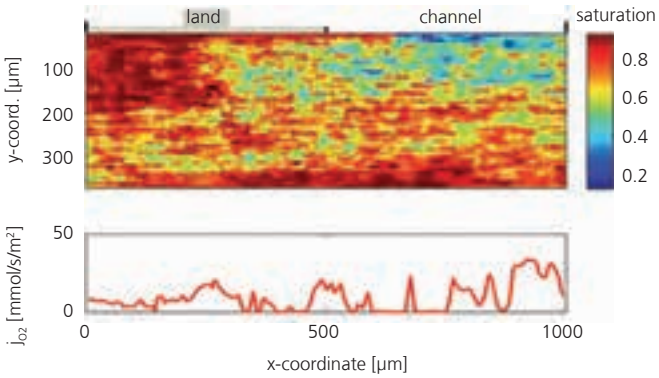


To simulate the transport of liquid water in porous structures such as the gas diffusion layer, we have developed a new fibre-based percolation network model. The model is based on an algorithm which searches for stable, spherical water menisci between the GDL fibres with variable contact angles, so that percolation can be simulated when water pressure is present. This computer-intensive pre-processing to generate the water path network pays itself off with short computing times for coupling to a continuum-based fuel cell model. With the water distribution in the GDL determined, the current generation can be simulated by the fuel cell model and applied for material optimisation.

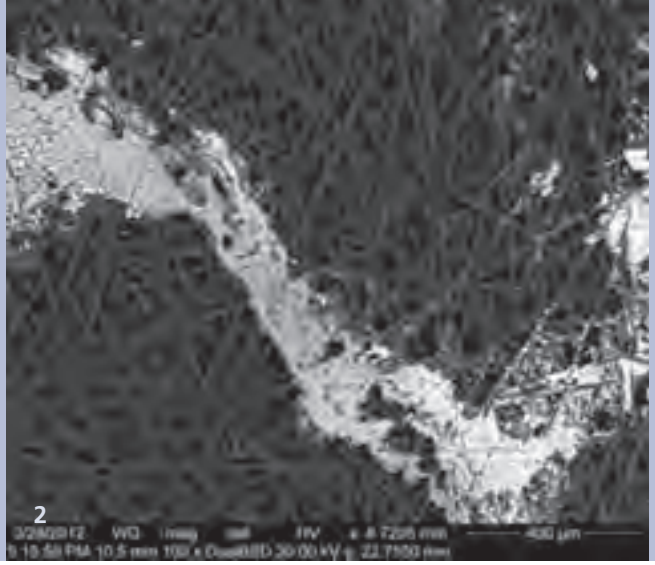
On the one hand, the simulations reveal a major hindrance to mass transport caused by the accumulation of water at the interface to the catalyst layer, and on the other hand, they identify possibilities for deliberately removing water from the GDL.

The project was supported by the German Federal Ministry of Education and Research (BMBF).

www.pem-ca-d.com



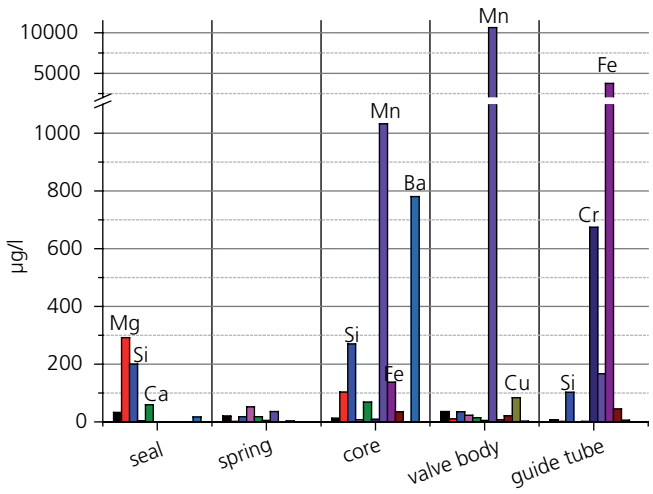
2 *(Above) Simulation of the saturation distribution of water in the GDL, assuming condensation below the land area. (Below) The molar oxygen flux at the interface to the catalyst layer (CL), which is linearly proportional to current generation according to Faraday's law, shows a strong impact due to water accumulation near the GDL/CL interface (lower edge zone in simulation).*



CHEMICAL STABILITY OF FUEL CELL SYSTEM COMPONENTS

Components of fuel cell systems must withstand harsh conditions in long-term operation. They are in contact with product water and the acids produced by side reactions, at temperatures between -40 °C and +80°C. Many components corrode under these conditions. This can cause the components themselves to fail, but may also damage the fuel cell by the introduction of dissolved materials. Manufacturers' data sheets do not provide sufficient information to assess suitability for use in fuel cell systems. Thus, realistic durability tests were developed, which provide important criteria for component selection.

Anneke Georg, Ulf Groos, Wolfgang Koch, Lisabeth Wagner, Christopher Hebling



3 *ICP-MS analysis of valve components after 8 weeks in DI water. The manganese concentration is very high. The dissolved iron is of particular concern, due to its damaging effect on the membrane. Although the data sheets specify the same materials, different elements are dissolved from the different components.*

1 *Corroded valve components in de-ionised water.*

2 *SEM-EDX measurement: Cr, Mn, Fe, Ni, Ca precipitates on a gas diffusion layer after long-term operation.*

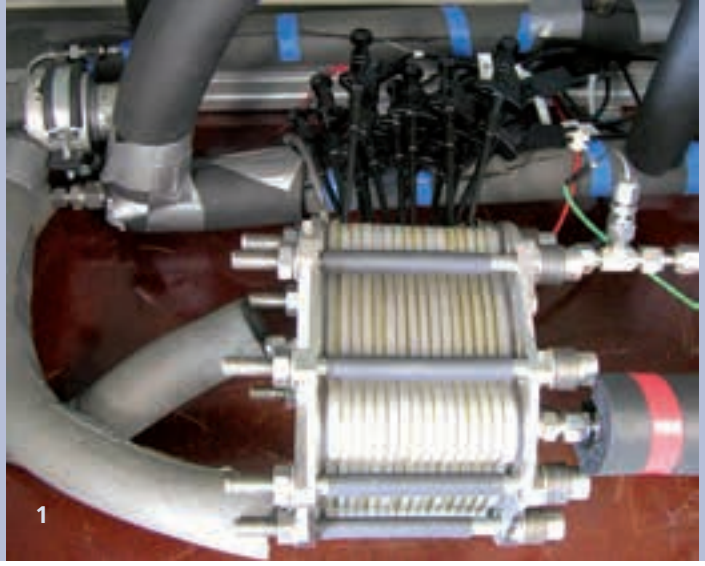
Components (e.g. piping, connectors, pumps) were subjected to the following durability test:

- freeze-thaw cycles (-20 – +50°C, 5 times, each cycle lasting 10 h)
- heating in de-ionised (DI) water (100 °C, 5 times 24 h)
- storage of the components intended to contact system fluids in DI water and in H_2O_2 (8 weeks)

The solutions from the third test were subjected to elemental analysis by ICP-MS (inductively coupled plasma mass spectroscopy) (Fig. 3). The component surfaces were examined under light and electron microscopes (SEM), and their elemental composition was determined by energy-dispersive X-ray spectroscopy (EDX) (Fig. 2).

It became evident that stainless steel components in fuel cell systems can suffer heavy corrosion (Fig. 1). The susceptibility to corrosion can be exacerbated by further treatment or contact with more noble metals. Elements dissolved out of the components can also be detected in the product water. They can form precipitates in the fuel cell (see Fig. 2) or reduce the chemical stability or the conductivity of the membrane. Altogether, the reliability tests, combined with elemental analysis, proved to be important guides for selecting components for fuel cell systems.

The project was supported by the German Federal Ministry of Economics and Technology (BMWi) within the Programme for Small Fuel Cell Devices in co-operation with our partner, DMT Produktentwicklung AG.



DYNAMIC MODELLING OF A POWER-TO-GAS ENERGY STORAGE SYSTEM

Electricity generated from renewable sources fluctuates, whereas consumers draw electricity from the grid according to demand. It is thus becoming increasingly necessary to store large amounts of electricity flexibly for some period of time. One option is chemical storage of the electrical energy in the form of substitute natural gas (SNG) in the natural gas network. To achieve this, a PEM electrolyser generates hydrogen, which is subsequently converted into methane. Whereas the PEM electrolyser can respond to the fluctuating electricity supply over a wide range, a methanisation reactor is ideally operated with a constant load. The hydrogen generated by electrolysis thus needs to be buffered in the system. A dynamic system model was constructed to design the complete system.

Thomas Aicher, Christopher Hebling

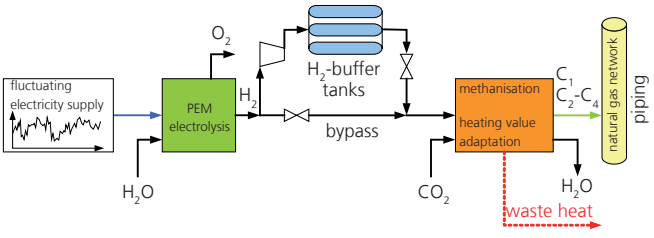
As an alternative to feeding hydrogen directly into the natural gas network, the introduction of SNG is being considered as a method to store electrical energy. To implement this, the hydrogen must be converted to methane, and small amounts of light hydrocarbons must be synthesised out of hydrogen and carbon dioxide by the Fischer-Tropsch process and added to the methane (heating value adaptation).

The configuration of such a system can be seen in Fig. 1. It includes a hydrogen tank after the PEM electrolyser, because the system must contain a buffer. This protects the subsequent methanisation and heating value adaptation processes against unacceptably large load fluctuations, because chemical systems can be operated only to a limited extent in a modulating mode.

1 *Pressurized electrolysis stack to characterise dynamic behaviour under fluctuating operating conditions.*

Based on this flow diagram, the Fraunhofer researchers prepared a Matlab/Simulink model to describe the dynamic behaviour of the individual system components. One special feature of energy storage systems which feed into the natural gas network is that they are limited from both ends. Above all, the profile of the fed-in electricity, but also possible limitations in feeding in the generated SNG into the natural gas network, play an important role in determining the optimal dimensions of the electrolyser, the hydrogen buffer tanks and the syntheses. In addition, recovery of waste heat, usage of oxygen from electrolysis and the sources of carbon dioxide must be taken into account.

The joint project was supported by the German Federal Ministry of Education and Research (BMBF). The other project partners are KIT, DVGW-EBI and the companies EnBW, h-tec , IoLiTec and Outotec.



2 *Block flow diagram of a power-to-gas energy storage system, which converts fluctuating electricity e.g. from renewable sources, into so-called substitute natural gas (SNG), in order to feed it into the natural gas network. The electricity is initially converted to hydrogen, which is then stored in buffer tanks. From the tanks, an almost constant flow of hydrogen enters the following synthesis reactors (for methanisation and heating value adaptation).*

RECYCLING OF H_2, CHLOROSILANES AND HYDROGEN CHLORIDE IN SI CVD PROCESSES

To manufacture polycrystalline silicon, trichlorosilane ($SiHCl_3$) is reduced with hydrogen (H_2). The silicon precipitates as a solid and a waste gas, consisting of silicon tetrachloride ($SiCl_4$), hydrogen chloride (HCl), unreacted trichlorosilane and about 95 % hydrogen is created. In order to operate this process economically, the hydrogen, hydrogen chloride and chlorosilanes must be separated and fed back into the reactor. As existing solutions are economically viable only for annual capacities of 10,000 tonnes or more, an alternative is desirable. One application at Fraunhofer ISE is a CVD system.

Thomas Aicher, Stefan Reber, **Alexander Susdorf**, Christopher Hebling

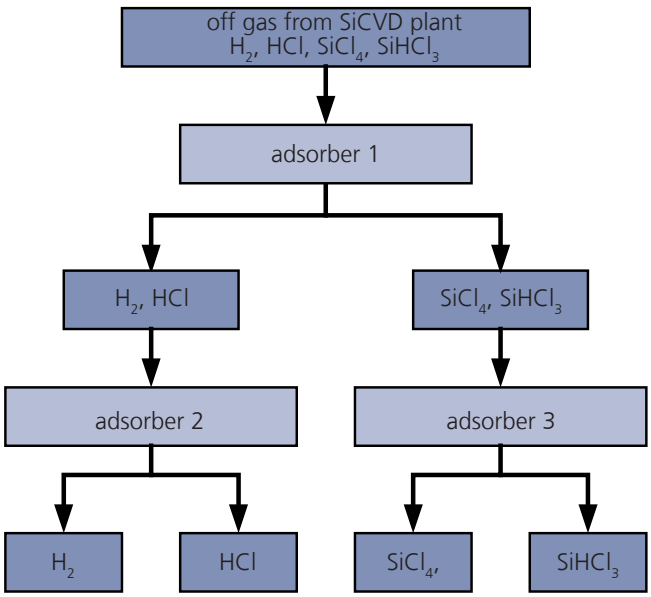
1 *Four of the six adsorbers, showing the reactors with heating strips and thermocouples (green) but without thermal insulation.*

Fraunhofer ISE has developed a new process for recycling chlorosilanes, hydrogen and hydrogen chloride in the laboratory. In this process, the gases are separated on different, commercially available adsorption materials.

The waste gas initially flows across adsorber 1, which adsorbs trichlorosilane and silicon tetrachloride. The remaining gas, then containing only hydrogen and hydrogen chloride, passes over adsorber 2, which selectively adsorbs hydrogen chloride. Thus, the product gas after adsorber 2 is pure hydrogen, which can then be reintroduced into the CVD process. When adsorber 1 is regenerated, the previously adsorbed trichlorosilane and silicon tetrachloride are thermally desorbed into a carrier gas. These materials are exposed to adsorber 3, which selectively adsorbs trichlorosilane and separates it from silicon tetrachloride. Pure hydrogen chloride and pure trichlorosilane can be obtained from the regeneration of adsorbers 2 and 3, respectively. Both materials can be added again to the CVD system.

This process to continually separate the chlorosilanes and hydrogen chloride from hydrogen is currently being tested in a pilot plant.

This work was funded within an internal project by Fraunhofer ISE.



2 *Processing diagram for separating hydrogen, chlorosilanes and hydrogen chloride from the waste gas of a Si CVD plant.*

COMMISSIONING OF A SOLAR-ASSISTED 700 BAR HYDROGEN STATION

Since March 2012, Fraunhofer ISE has operated a publicly accessible 700 bar hydrogen station with hydrogen generated on site by advanced PEM electrolysis. Two PV systems generate some of the electricity needed for the filling station and thus demonstrate the possibility for sustainable generation of hydrogen by renewable energy. The station allows a 700 bar pressurised tank to be filled rapidly within three to five minutes in compliance with standards, and thus can be used by all hydrogen vehicles of the most recent generation. 350 bar pressurised tanks can also be filled. Two fuel-cell vehicles are available at the Institute and can prove the everyday utility of the technology in daily application.

Tom Smolinka, **Christopher Voglstätter**, Christopher Hebling

The hydrogen station was constructed in two containers. In the electrolysis container, hydrogen is generated at 30 bar by a modern, membrane-based process and purified. The second container houses two compressors, the hydrogen pre-cooling unit and process control. The hydrogen is compressed in the first stage to 450 bar and stored in a buffer tank. For rapid filling, the gas is then compressed to up to 950 bar and stored in a high-pressure tank. In addition to the two dispenser units for automatic filling at 350 and 700 bar filling pressure, an additional 200 bar / 300 bar outlet for special applications was also installed.

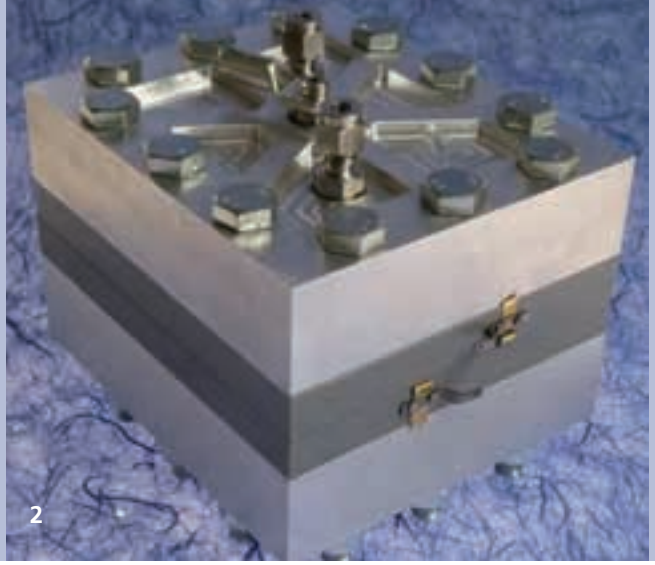
1 *700 bar hydrogen filling station at Fraunhofer ISE with one of the two fuel-cell vehicles available to the Institute.*

2 *700 bar coupling to rapidly fill the tanks of fuel-cell vehicles.*

In addition to its primary task of providing fuel for hydrogen-based vehicles, the filling station also offers further possibilities as a research and technological platform. It is equipped with extensive measurement technology to monitor the complete system. The control unit allows flexible operation management. Some components are designed such that apart from hydrogen-based mobility, further R&D projects to test filling station components, investigate demand-side management or explore the power-to-gas sector are possible.

Due to Freiburg's favourable location, the filling station is ideally integrated into the network of hydrogen stations which is being established throughout the country, and represents an important contribution to sustainable mobility in Freiburg.

The investment was partly funded by the State Ministry for the Environment, Climate and Energy Economy of Baden-Württemberg from the State infrastructure programme. Operation of the hydrogen station is partly funded by the National Innovation Programme for Hydrogen and Fuel Cell Technology.



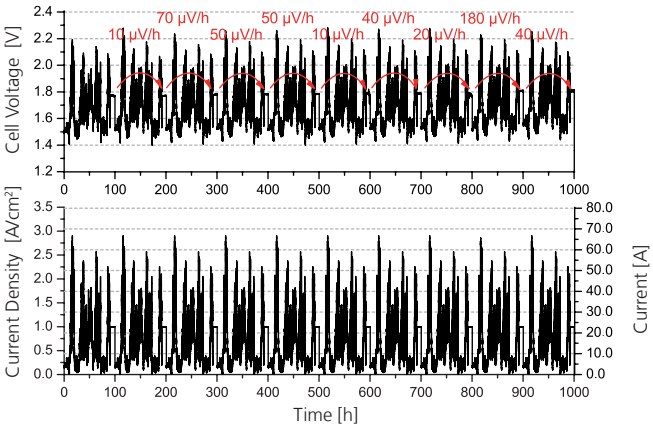
NANOSTRUCTURED ELECTRODES FOR EFFICIENT HYDROGEN PRODUCTION

The generation of hydrogen with renewable energy resources is an important key technology for storing large amounts of energy. PEM electrolysers, which operate with an acidic solid electrolyte, are particularly suitable for combination with renewable energy. They feature a very rapid dynamic response, tolerate very large partial and overload ranges and have a simple system configuration. However, noble metals must be used as catalysts within the acidic medium. By using nanostructured electrodes, kinetic losses and the loading with noble metal catalysts can be minimised. One main aspect of our work is investigating the long-term behaviour and identifying important degradation effects of newly developed electrodes.

Sebastian Rau, **Tom Smolinka**, Christopher Hebling

1 *50 bar pressure electrolysis test stand for PEM electrolysis laboratory cells.*

2 *25 cm² laboratory cell with integrated reference electrodes to measure anodic and cathodic overpotentials.*



3 *Galvanostatic measurement of a PEM electrolysis cell with nanostructured electrodes over a period of 1000 h (simulation of the power profile of a wind energy converter). The values in red specify the degradation of the cell in microvolts per hour.*

One main goal in the present development of electrodes is to reduce the loading with noble metal catalysts while ensuring that the electrodes remain very robust. One approach is offered by substrate-based catalyst systems, on which nanoparticles of noble metals are selectively deposited. Above all, niobium-doped titanium dioxide is a suitable catalyst substrate for PEM electrolysis. Together with our partner, the University of South Carolina (working group of Prof John Weidner), we have developed various electrodes based on iridium-ruthenium and their oxides. We are investigating their stability in long-term measurements with dynamic power profiles (see Fig. 3). For this purpose, we have developed a new laboratory test cell, which allows us to measure overpotentials at the anode and cathode separately.

The work was funded by the E.ON International Research Initiative.

1

OPERATING EXPERIENCE WITH FUEL CELL VEHICLES

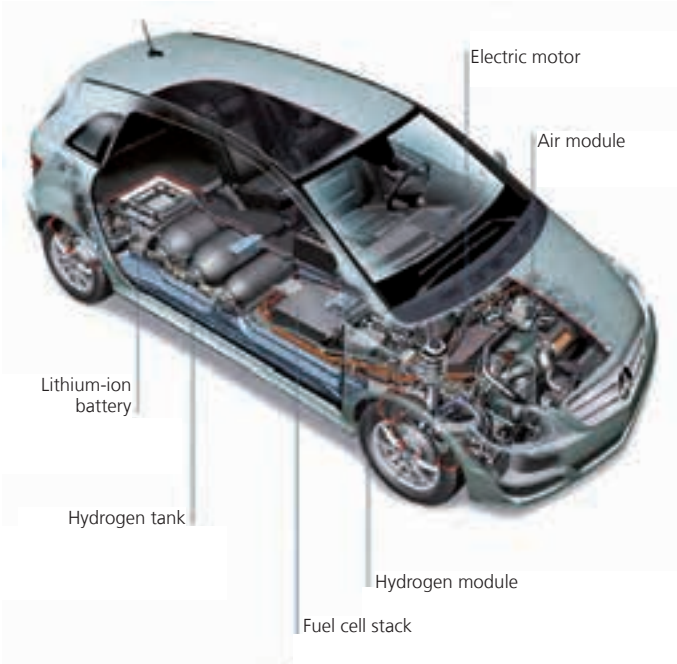
To accompany the opening of the solar hydrogen station, Fraunhofer ISE has been operating two electric vehicles powered by fuel cells since March 2012. To date, they have already been driven a total distance of more than 10,000 km. The so-called "F-Cell" prototype vehicles are based on a B Class car, Model T 245 from Daimler. Essential driving data are documented in a special log book and allow the achievable range to be analysed. For the two vehicles, the average consumption was determined to be 1.3 and 1.24 kgH_2 / 100 km, corresponding to a driving range of about 280 km. A drive from Freiburg to Stuttgart with an F-Cell car proceeds just as quickly and comfortably as usual.

Thomas Jungmann, Stefan Keller, Christopher Hebling

Electric vehicles which draw their electricity from a fuel cell attain a longer driving range than purely battery-powered electric vehicles and their tanks can be refilled within three minutes. Modern fuel-cell vehicles can start from cold at temperatures down to -20 °C and do not suffer any restriction in driving range at these temperatures. The F-Cell accelerates with the help of a 100 kW electric motor to a maximum speed of 170 km / h. The F-Cell is a hybrid vehicle with a 1.4 kWh lithium-ion battery.

With the new European driving cycle, the hydrogen consumption of the F-Cell is about 0.97 kgH_2 / 100 km. Together with the tank capacity for 3.7 kg of hydrogen, a driving range of 385 km can be calculated. The car driver and passengers experience the same comfort as in similar vehicles with combustion engines, as the interior space and fittings are comparable.

1 *The B Class car accelerates to 100 km/h in 11.4 seconds.*



2 *Cutaway drawing of an F-Cell car. © Daimler*

During drives through the countryside and particularly along motorways, the consumption is often higher than the manufacturer's specifications. When the average consumption of all trips is calculated, a consumption range of 0.93 – 2.01 kgH_2 / 100 km is determined. The longest trip with a single tank filling extended 291 km; at the end of the trip, there was still 300 g of hydrogen in the tank. For fundamental reasons, the increase in consumption at higher speeds is greater than for conventional vehicles. However, as fuel cells are also very efficient in the partial load range, the equivalent consumption is well below that for conventional vehicles.

QUALITY CONVINCES

SERVICE UNITS

As a complement to our research and development work, we offer testing and certification services to clients. At present, Fraunhofer ISE has four accredited testing laboratories: TestLab Solar Thermal Systems, TestLab Solar Façades, TestLab PV Modules and the calibration laboratory with CalLab PV Cells and CalLab PV Modules. Our further service units include a battery test laboratory, an inverter laboratory, a lighting laboratory, a test facility for heat pumps and evaporators, a laboratory for characterising phase change materials (PCM), a test laboratory for adsorbent and porous materials and a test centre for fuel cells. Furthermore, in 2012 we began to establish a development and testing centre for heat transformation at Fraunhofer ISE. In future, electrically and thermally driven heat pumps will be measured and further developed there.

Beyond the service aspect, these units also have a research function. The insights gained during characterisation, certification or testing can become the kernel for new research topics, be it in product development or improvement, further development of testing methods and standards, or theoretical development, e.g. in model-based prediction of aging.

TestLab Solar Thermal Systems has been accredited according to DIN EN ISO/IEC 17025 since May 2005. The testing facilities include:

- test stand for solar air collectors
- hail test stand
- system and storage tank test stand
- outdoor test stand with trackers and a dynamic rack
- indoor test stand with a solar simulator (max. aperture area 3 x 3.5 m^2)
- collector test stand up to 200 °C
- mechanical test unit over an area of 5 x 3 m^2 in a climatic chamber

The main work of TestLab Solar Thermal Systems is based on commissions from the industry to test collectors, systems and tanks according to European and international standards or quality labels such as the "Solar Keymark" of CEN. A unique feature is the possibility to test collectors mechanically at temperatures between -40 °C and +90 °C (see page 141).

TestLab Solar Façades was accredited according to DIN EN ISO/IEC 17025 in 2006. It offers a comprehensive range of characterisation for innovative building components and materials to developers and planners of façades, façade components and windows, including shading devices. In particular, the range of services encompasses the characterisation of components which also serve as active solar energy converters (e.g. transparent façade collectors and BIPV). In addition to accredited tests, comprehensive services concerning glare protection and daylighting are offered (see page 142).

Testing of the following properties is included in the accreditation: g value (also calorimetric measurement), transmittance (spectral and broadband), reflectance (spectral and broadband) and U value.

TestLab PV Modules has been accredited since 2006 for type authorisation of PV modules according to IEC 61215 and IEC 61646 and since 2011 for the safety standard, IEC 61730. The goal of the test facility is quality control of PV module reliability. Within the framework of its co-operation with the VDE Institute, Fraunhofer ISE is responsible for all performance tests, while the VDE Institute carries out the safety tests and issues certificates after successful testing. In addition to the tests for product type approval, tests according to the manufacturers' specifications are also carried out to accompany the development of PV modules and module components. TestLab PV Modules cooperates closely with the calibration laboratory at Fraunhofer ISE, comprising CalLab PV Cells and CalLab PV Modules (see page 138/139).

The fourth accredited laboratory, having gained this status in November 2006, is our calibration laboratory with CalLab PV Cells and CalLab PV Modules, which is one of the international leaders in this field. The calibration of photovoltaic modules plays an important role in product comparisons and for quality assurance of PV power plants. The cell calibration in CalLab PV Cells, which has been accredited as a calibration laboratory with the Deutscher Kalibrierdienst (DKD – German Calibration Service) since the end of 2008, serves as a reference for industry and research. The module calibration in CalLab PV Modules is part of the module certification process, on the one hand. On the other hand, it serves to control the quality of systems and to support development.

CONTACTS

CalLab PV Cells	Dr Wilhelm Warta	Phone +49 761 4588-5192 wilhelm.warta@ise.fraunhofer.de
	Jutta Zielonka	Phone +49 761 4588-5146 cells@callab.de
	Dr Gerald Siefer Multi-junction and concentrator cells	Phone +49 761 4588-5433 gerald.siefer@ise.fraunhofer.de
CalLab PV Modules	Frank Neuberger	Phone +49 761 4588-5280 frank.neuberger@ise.fraunhofer.de
	Dr Gerald Siefer Concentrator modules	Phone +49 761 4588-5433 gerald.siefer@ise.fraunhofer.de
TestLab PV Modules	Claudio Ferrara	Phone +49 761 4588-5650 claudio.ferrara@ise.fraunhofer.de
	Daniel Philipp	Phone +49 761 4588-5414 daniel.philipp@ise.fraunhofer.de
TestLab Solar Thermal Systems	Korbinian Kramer Stefan Mehnert	Phone +49 761 4588-5354 testlab-sts@ise.fraunhofer.de
TestLab Solar Façades	Tilmann Kuhn Passive and active thermal solar applications, solar control	Phone +49 761 4588-5297 tilmann.kuhn@ise.fraunhofer.de
	Dr Helen Rose Wilson Spectrometry and BIPV	Phone +49 761 4588-5149 helen.rose.wilson@ise.fraunhofer.de
	Ulrich Amann g-value testing (SHGC, TSET)	Phone +49 761 4588-5142 ulrich.amann@ise.fraunhofer.de
	Dr Jan Wienold Daylighting measurement rooms	Phone +49 761 4588-5133 jan.wienold@ise.fraunhofer.de

Fraunhofer ISE took a new test stand for solar thermal collectors into operation in 2012 (see page 51). It allows scientists to simulate mechanical loads, e.g. wind effects or snow loads, under extreme climatic conditions and investigate their effect on collectors. The test stand is installed inside a climatic chamber, so that the stability and safety of solar thermal collectors can be tested under wind and snow loads.

Quality assurance of PV power plants	Dr Christian Reise	Phone +49 761 4588-5282 christian.reise@ise.fraunhofer.de
Photovoltaic power electronics	Prof Bruno Burger Inverter characterisation	Phone +49 761 4588-5237 bruno.burger@ise.fraunhofer.de
Inverter laboratory	Sönke Rogalla	Phone +49 761 4588-5454 soenke.rogalla@ise.fraunhofer.de
Battery testing laboratory	Stephan Lux	Phone +49 761 4588-5419 stephan.lux@ise.fraunhofer.de
Lighting laboratory	Norbert Pfanner	Phone +49 761 4588-5224 norbert.pfanner@ise.fraunhofer.de
Laboratory for vapour compression heat pumps	Thore Oltersdorf Test stand	Phone +49 761 4588-5239 thore.oltersdorf@ise.fraunhofer.de
Testing centre for heat transformation	Dr Lena Schnabel	Phone +49 761 4588-5412 lena.schnabel@ise.fraunhofer.de
PCM laboratory	Thomas Haussmann	Phone +49 761 4588-5351 thomas.haussmann@ise.fraunhofer.de
Test laboratory for adsorption materials and porous materials	Dr Stefan Henninger	Phone +49 761 4588-5104 stefan.henninger@ise.fraunhofer.de
TestLab Fuel Cells	Ulf Groos	Phone +49 761 4588-5202 ulf.groos@ise.fraunhofer.de

CALIBRATION OF SOLAR CELLS ACCORDING TO INTERNATIONAL STANDARDS

CalLab PV Cells offers the measurement and calibration of solar cells from a wide range of PV technology and works with companies and institutes at national and international levels to develop accurate measurement methods for new types of technology. CalLab PV Cells is one of the internationally leading photovoltaic calibration laboratories. It serves as a reference for research and industry. Solar cell manufacturers commission us to calibrate their reference solar cells for production lines according to international standards.

Tobias Gandy, Jochen Hohl-Ebinger, Thomas Hultzsch, Robert Köhn, Katinka Kordelos, Markus Mundus, Simone Petermann, Michael Schachtner, Wendy Schneider, Holger Seifert, Astrid Semeraro, Karin Siebert, Gerald Siefer, **Wilhelm Warta**, Jan Weiß, Jutta Zielonka

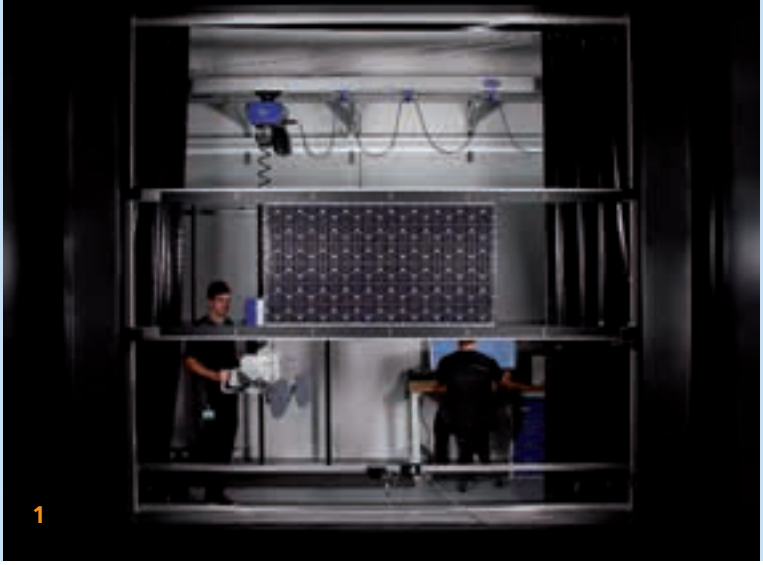
CalLab PV Cells is accredited according to ISO/IEC 17025 as a calibration laboratory for solar cell calibration with the Deutscher Kalibrierdienst (DKD). In the course of harmonising calibration in Europe, the accreditation is currently being transferred to the Deutsche Akkreditierungsstelle (DAkkS), the German signatory organisation to the ILAC Mutual Recognition Arrangement (MRA). With the support of the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU), and in co-operation with PV manufacturers, we work continuously on improving tolerances and developing new measurement procedures. For example, the change in solar cell parameters at higher temperatures plays a decisive role for their yield in practical application. A new procedure, with which temperature coefficients can be determined with a previously unattainable accuracy, has proven to be very attractive for manufacturers of solar cells. The special feature of our method is measurement of the temperature-dependent spectral response. Since 2012, we have been applying this and other special measurements

1 *The spectral response is also measured for large-area solar cells with high accuracy and exact specification of the measurement uncertainty.*

in a project to optimise the maximum annual yield of high-efficiency solar cells. The project is funded by the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU).

In order to guarantee the comparability of measurements for solar cells from different types of PV technology, we are continuing to develop measurement procedures for novel solar cells. Cells with back-surface contacts or bifacial structures are particularly important. Organic solar cells and thin-film cells, especially those with multi-junction cell structures, also present a particular challenge. To meet it, we have taken advantage of our experience with the calibration of multi-junction solar cells for space and terrestrial concentrator applications. By extending our facilities for calibrating multi-junction cells of thin-film materials, we were able to support the rapid development of this technology still better with accurate measurements. The spectral response or the external quantum efficiency of multi-junction solar cells is determined using our grating monochromator in a set-up that was specifically extended for the measurement of multi-junction solar cells. We measure the current/voltage characteristics of dual and triple cells with our triple-source simulator under almost any standard conditions, such as AM0 (ISO 15387) for space applications and AM1.5d (ASTM G173-03) for concentrator applications. Concentrator cells can be measured with our flash lamp simulator at concentration ratios of up to 5000. In addition, we have taken a solar simulator with six independent light sources into operation for calibrated measurement of solar cells with up to six pn junctions.

www.callab.de



CALIBRATION OF PV AND CONCENTRATOR MODULES

The accredited calibration laboratory, CalLab PV Modules, has been one of the internationally leading laboratories for more than 25 years. This leading position has been further reinforced by achieving a measurement uncertainty of 1.8 % for solar modules of crystalline cells.

Daniela Dirnberger, Boris Farnung, Martin Jantsch, Klaus Kiefer, Ulli Kräling, **Frank Neuberger**, Michael Schachtner, **Gerald Siefer**

CalLab PV Modules has again improved its accuracy in precision measurements of solar modules. The measurement uncertainty of 1.8 percent, which is not achieved anywhere else at present, primarily benefits the manufacturers. The very low measurement tolerances in calibrating reference modules for production lines guarantee great reliability in specifying the rated power and tolerances.

To evaluate the energy yield from PV modules, not only the rated power but also further properties such as initial degradation, low-light behaviour and temperature dependence are important. Accurate measurement of these effects makes exact yield simulation feasible for different climatic zones and provides a benchmark for investors as an aid to selecting the module manufacturer.

To check the module power for large PV power plants, we have developed a procedure for drawing representative random samples. This offers the investor reliable information on the real module power already on the basis of 10 to 50 measured modules.

1 *Precise calibration of a PV module in CalLab PV Modules.*

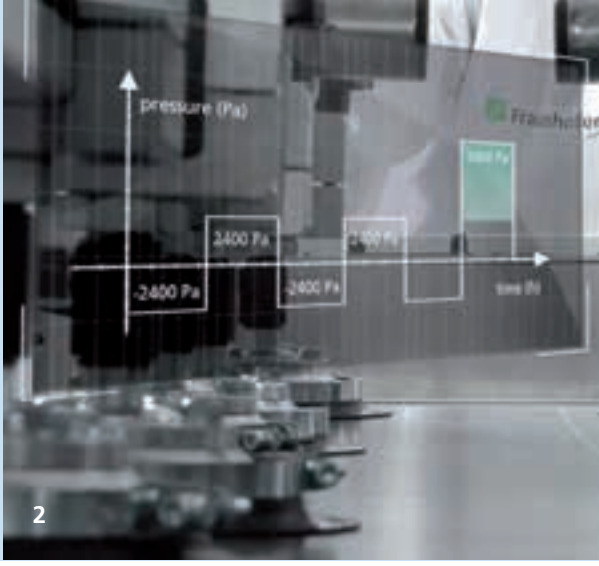
2 *Alignment of a CPV module in the laboratory measurement stand for concentrator modules.*

Measurement of concentrator modules

Measurements of concentrator modules are generally made outdoors. To do this, we operate several tracking units equipped with measurement data acquisition, so that all relevant irradiation and meteorological data are recorded in addition to the current-voltage characteristics. In addition, we operate a laboratory test stand to measure concentrator modules. This is based on the provision of parallel light using a parabolic reflector with a diameter of 2 m.

www.callab.de

1



2

TESTLAB PV MODULES

TestLab PV Modules offers a broad spectrum of services centred on quality and reliability testing. Our laboratory, which is accredited according to ISO 17025, is equipped with modern and innovative testing facilities. Many years of scientific experience in lifetime analysis mean that we can advise our clients competently and independently.

Stefan Ali, Holger Ambrosi, Heinrich Berg, Ilie Cretu, **Claudio Ferrara**, Philipp Hog, Georg Mülhöfer, **Daniel Philipp**, Sandor Stecklum, Carola Völker, Jeanette Wolf

1 *In the combined UV and damp-heat climate chamber, PV modules can be subjected to a maximal UV dose of 200 W/m² under maximum conditions of 60 % relative humidity and 90 °C temperature for accelerated aging. Thus, not only standard test conditions but also the simultaneous effects of several degradation factors can be simulated.*

2 *Mechanical-load test facility. With it, tests conforming to IEC standards and tests which go beyond these can be carried out automatically (maximum pressure and suction of 10 kPa, maximum frequency 0.2 Hz).*

TestLab PV Modules was founded in 2006 as a service unit of Fraunhofer ISE. In cooperation with the Group Service Life Analysis, we develop tests and procedures to ensure the quality and reliability of PV modules. To do this, we use innovative facilities which can be applied for purposes extending well beyond the standard tests. This allows us to simulate degradation factors very realistically. We focus on offering the following services:

Consultancy and testing specific to clients' requirements and applications
Individual questions require individual answers. Accordingly, we offer our clients target-oriented services. Regardless of whether it concerns comparative module testing (benchmarking) or assessing the suitability of a specific type of module for particular application conditions, the provision of individual and cost-effective solutions for each client always has the highest priority for TestLab PV Modules.

Assessment and analysis of defects, risk minimisation
Potential induced degradation (PID), so called snail trails and yellowing are only a few of the typical defects which clients often present to us. We offer the option of analysing these and other defects systematically and identifying causes and effects. Our goal is to reduce the occurrence of such defects. Thus, TestLab PV Modules offers specific tests and test sequences for many typical defects.

Quality control according to international standards
In close co-operation with our partner, the well known certification institute VDE, we certify modules according to international quality and safety standards (IEC 61215, IEC 61646, IEC 61730). We contribute to further development of these standards by participating in international working groups.

TESTING AND DESIGN SUPPORT IN TESTLAB SOLAR THERMAL SYSTEMS

TestLab Solar Thermal Systems is authorised by DIN CERTCO, CERTIF and SRCC, and is fully accredited according to ISO 17025 by DAkkS (Deutsche Akkreditierungsstelle). We test solar collectors, storage tanks and complete systems, thereby supporting our clients around the world in developing solar thermal system components.

1 Large test stand for mechanical loads integrated into a climatic chamber for extensive testing at temperatures between -40 °C and 90 °C.

2 Scientists of Fraunhofer ISE setting up a storage tank test, in which the performance is determined for evaluation according to the Energy Label of the EU.

Sven Fahr, **Korbinian Kramer**, Stefan Mehnert, Arim Schäfer, Christian Schmidt, Christoph Thoma, Jasmin Veser

We accompany our clients in the product certification process, e.g. for the European quality label Solar Keymark or the American quality label of the Solar Rating and Certification Corporation SRCC. We also offer on-site inspection of production as part of a contract to prepare such certification. In 2012, we completed construction of our large test stand for mechanical loads. It is integrated into a climatic chamber, so very diverse mechanical load constellations can be tested at specific ambient temperatures (from -40 °C to +90 °C) (see article on p. 51). Its special features include the large testing area of 3 x 5 m², the possibility for applying heavy loads of up to 10 tonnes and reproduction of different load scenarios, e.g. cyclic loads, load gradients, dynamic loads.

Comparative investigations of PVT hybrid collectors were continued. A methodology to characterise many variants of this technology is thus available at TestLab Solar Thermal Systems.

Long and intensive work on our solar air-collector test stand was completed. With it, it is now possible to offer similar technical characterisation to that for collectors with liquid heat-transfer media. In addition, the testing facilities for air collectors were extended to accommodate models without covers.

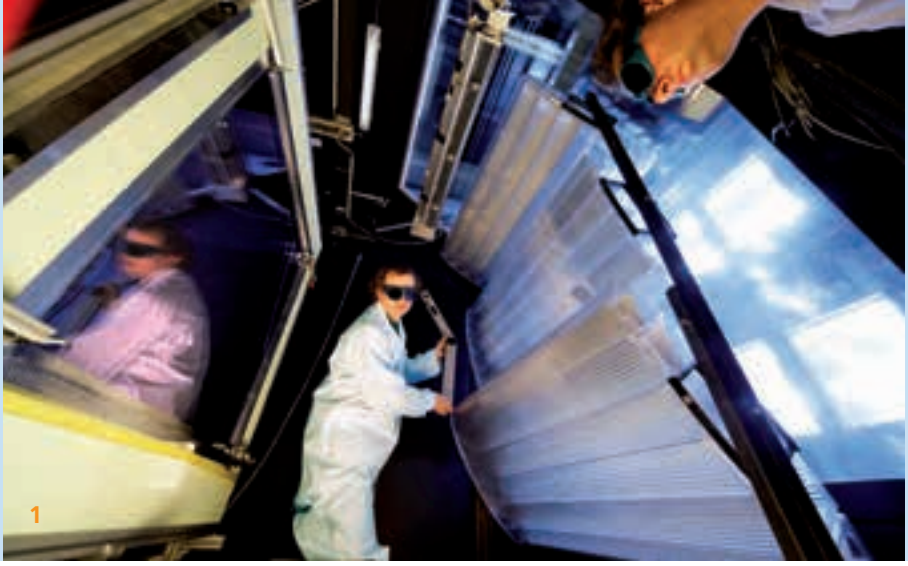
System investigations, particularly tank measurements according to DIN EN 12977, Parts 3 and 4, can be carried out in our systems and storage tank laboratory. This is where the coefficients are determined to evaluate tanks according to the Energy Label of the EU, which will be introduced in 2013.

We have operated an indoor test stand with a solar simulator in TestLab Solar Thermal Systems since 2002. In 2012, we automated many aspects of laboratory operation, making it simpler for us to achieve our accustomed high reproducibility.

In combination with our precision tracker, we applied our medium-temperature test stand to measure efficiency characteristic curves for operating points up to 200 °C. This means that experimental development work on concentrating process-heat collectors (e.g. for solar-thermally driven air-conditioning) is feasible in TestLab Solar Thermal Systems.

In 2012, many further methodological developments were introduced by our staff members to standardisation committees and will be implemented in new standards.

www.kollektortest.de



MEASUREMENT OF BUILDING FAÇADES AND TRANSPARENT COMPONENTS

TestLab Solar Façades offers a comprehensive range of characterisation for innovative building components and materials to developers, manufacturers and planners of façades, façade components and solar components. Special laboratories are available to determine the optical and thermal properties of transparent components and sun-shading systems. For façades for active use of solar energy (with photovoltaic and/or solar-thermal components), we offer comprehensive characterisation, which also includes the interaction between yield, comfort and passive solar gains. Further facilities include a daylighting measurement container and an outdoor test unit.

Ulrich Amann, Johannes Hanek, Angelika Helde, **Tilmann Kuhn**, Jan Wienold, Helen Rose Wilson

We characterise transparent and translucent materials. We test building components, e.g. glazing units, and evaluate the energy-relevant, thermal and optical properties of complete façades.

The following measurement facilities are available:
- solar calorimeter to determine the total solar energy transmittance, also for active-solar façades
- efficiency measurement
- thermal transmittance measurements (U value) of glazing units
- angle-dependent transmittance and reflectance measurements with large integrating spheres, both broadband and spectral
- UV-vis-NIR spectrometers to determine the spectral properties of glass, films and surfaces

1 *Solar calorimeter at Fraunhofer ISE to determine the total solar energy transmittance (g value).*

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

Daylighting measurement rooms

The daylighting measurement rooms consist of two identical office rooms, located side-by-side in a container. They can be rotated, so that any desired façade orientation can be chosen.
- glare protection tests
- user acceptance studies
- comparison of the lighting situation behind two façade systems

Façade testing facility

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

Quality Assurance of PV Power Plants

With the four phases of the Fraunhofer ISE quality cycle – yield assessment, module characterisation, system testing and monitoring – we offer comprehensive quality assurance of PV power plants from the planning phase to on-going operation.

- Our quality assurance services start already in the planning phase of a PV system. Our independent yield assessments provide exact information about all of the parameters which affect the yield and their uncertainty
- We offer complete and comprehensive testing of the whole PV system, so that our clients can be sure that their plant really corresponds to the state of the art and delivers the promised power. Once a PV system has started operation, its quality can be controlled with on-site analysis that includes visual inspection, thermography and determination of the actual power generated.
- Our customised PV monitoring offers accurate analysis of the component and system efficiency over the complete service lifetime of a PV power plant.

Laura Hardt, Klaus Kiefer, Anselm Kröger-Vodde, **Christian Reise**, Andreas Steinhüser

1 *10 MWp solar power station in Masdar, Abu Dhabi.*

Battery Test Laboratory

We test batteries and battery systems based on lead-acid, NiCd, NiMH and Li ion cells, as well as redox-flow and high-temperature batteries and double-layer capacitors. Battery testing systems and impedance spectrometers are available for use either according to the procedures specified by the relevant standards or in a climatic chamber or a water bath according to clients' specifications.

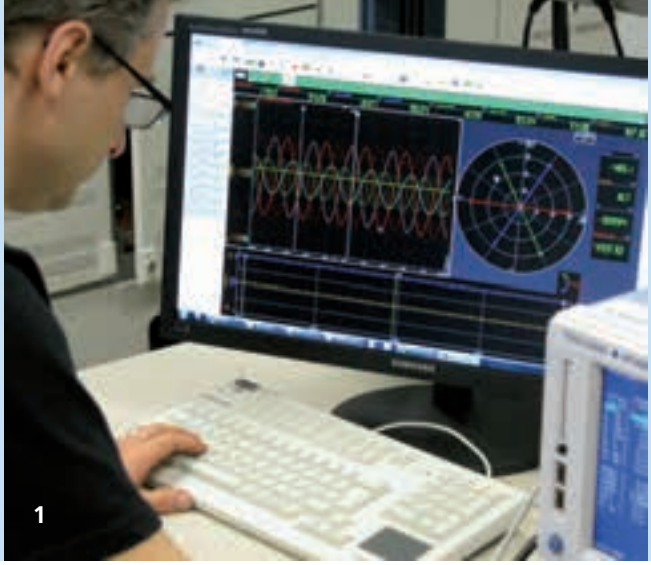
Long-term tests
We also offer long-term tests lasting several months as lifetime tests for batteries and battery systems.

Automotive sector
We test systems up to a power of 250 kW with currents up to 600 A and voltages up to 1000 V and can control the test systems via a CAN bus.

Stationary sector
Distributed storage of electricity in battery systems is becoming increasingly important. We test electric storage systems in a realistic environment, making use of solar simulators, diesel generators and our modern range of inverters and charge controllers.

Georg Bopp, Nikolaus Lang, **Stephan Lux**, Stefan Rinne, Simon Schwunk, Matthias Vetter

2 *Storage batteries, e.g. for the automotive sectors, can be tested for power of up to 250 kW.*



Inverter Laboratory

Our so-called megawatt laboratory is equipped with all of the facilities which are needed to test central inverters up to a power rating of 1 MW according to diverse grid connection guidelines. A test facility for low-voltage ride-through on the medium voltage side enables us to investigate the reaction of inverters to short-term grid defects. Our highly accurate measurement technology makes it possible to determine reliably not only the conversion efficiency of inverters but also their MPP tracking behaviour.

Thanks to international co-operation, we are able to provide support concerning guidelines of both the German association of electricity and water utilities (BDEW) and also similar bodies from other countries (China, Spain, etc.). In addition, we can offer our clients extensive simulation services in connection with certifying units and systems and addressing specific problems in PV parks.

Bruno Burger, Robin Grab, **Sönke Rogalla**

Lighting Laboratory

Characterisation

We carry out accurate measurements of photometric quantities for LED and fluorescent lamps, lights and lighting systems. These include measurement of the luminous flux, the luminous efficacy and the illuminance distribution, and investigations of the operating and long-term performance of the lighting technology under different conditions. We also determine the electrical properties of electronic controls and electronic ballasts, including the efficiency, operating behaviour and fault management.

Equipment

- software-controlled lighting measurement stand with a photometric integrating sphere of 1.50 m diameter
- software-controlled spectrometer for automated measurement of the light spectral distribution, perceived luminous colour and colour rendering
- a luminance camera, luxmeters and long-term test stands
- accurate broadband wattmeters, digital oscilloscopes
- programmable, very stable power supplies.

Georg Bopp, **Norbert Pfanner**, Matthias Vetter

1 *Our equipment and our experienced team enable detailed analysis of inverters up to a power rating of 1 MW with regard to performance and grid reaction.*

2 *Photometric integrating sphere of the lighting laboratory to determine the luminous flux, the luminous efficacy and the long-term performance of light sources and lamps.*

SmartEnergyLab – Thermal-Electrical Building Energy Systems

As their economic viability increases, distributed electricity generators are being installed in many residential buildings and provide electricity where it is consumed. Changes in the funding structure are resulting in completely new operating strategies, which are moving away from feeding all the generated electricity into the grid toward on-site consumption with local control strategies.

The SmartEngeryLab is comprehensively equipped with the types of distributed generators and storage units that will be found in future residential buildings. The laboratory works with a powerful simulation computer, which allows model-based "hardware-in-the-loop" operation. This means that any desired dynamic scenarios for loads and generation in the domestic context can be created.

The infrastructure of the SmartEnergyLab allows system providers to test and evaluate both their individual systems and also complete concepts in a realistic environment. These analyses include e.g. efficiency evaluation and the assessment and development of energy management gateways or local control strategies.

Bernhard Wille-Haußmann, Christof Wittwer

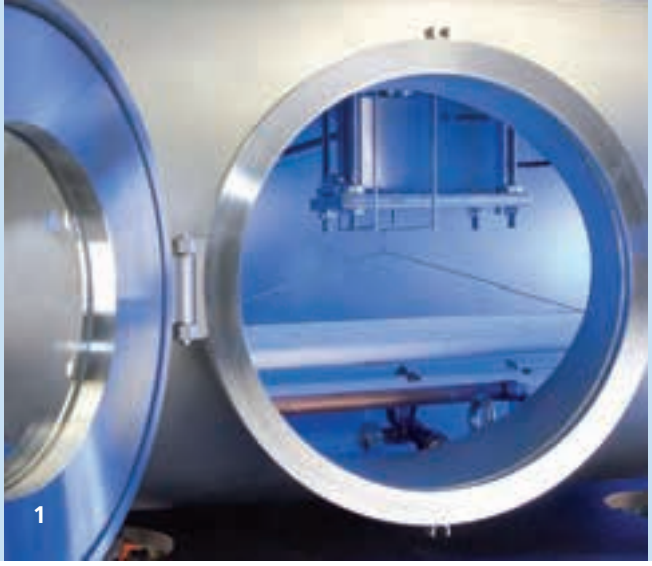
Testing Facility for Heat Pumps

To test heat pumps, we have a test stand to simulate (hardware-in-the-loop) the most important types of heat sources and sinks (ground, ground water, air). A heating power range from 4 kW up to 12 kW is covered. The measurements is made in accordance with EN 14511 and EN 14825 for space heating and according to EN 16147 for domestic hot water. At present, of the systems operating with air, only those heat pumps with duct-based configurations can be tested. The evaporator test stand is oriented toward the specifications of EN 328, but is used primarily for new development of evaporators. Extension of the power range which can be tested and expansion to include all common types of heat pumps will be completed in 2013. In this context, we intend to apply for accreditation according to ISO/IEC 17025 and registration as an official testing centre for the EHPA quality label.

Simon Braungardt, Sebastian Helmling, Thomas Kramer, Marek Miara, **Thore Oltersdorf**, Christian Sonner, Jeannette Wapler

1 *Central control desk in the SmartEnergyLab.*

2 *Measurement of a small-capacity ground-source heat pump.*



Testing and Development of Heat Exchangers

Various test stands are available to evaluate heat exchangers:

- air/water heat exchanger (air: 10–1200 m³/h for defined input humidity and temperature, water: 60–1800 l/h for defined input temperature)
- air/air heat exchanger (150–500 m³/h for defined input humidity and temperature, also suitable for open sorption)
- evaporator (for water and hydrocarbons as the working media) and adsorber (only water) (evaporation power up to 2.5 kW, adsorption capacity up to 8 kg)

The sensors installed in the measurement stands allow the heat transfer rate, the thermal transmittance and the heat transfer coefficients to be determined. The experimental expertise is complemented by simulation-based analysis. Depending on the question, tools such as COMSOL Multi-physics, OpenFoam, CoilDesigner, IMST-ART, Modelica or in-house software are used.

Further testing and simulation methods are available to investigate flow characteristics, fluid and temperature distributions and heat and mass transport dynamics, which allow the most influencing factors to be identified for characteristic components of a heat exchanger.

Gerrit Füldner, Michael Herrmann, Alexander Morgenstern, Thore Oltersdorf, **Lena Schnabel**, Peter Schossig, Ursula Wittstadt

PCM Laboratory: Characterisation of Phase-Change Materials

Phase-change materials, composites, components and systems are tested in the PCM Laboratory according to the criteria of the quality seal, RAL GZ 869. The laboratory is an authorised certification body for this quality seal.

Measurement instruments are also available to determine the following material parameters:

- thermal conductivity and thermal transmittance (U value) of building components and wall constructions
- specific and latent heat storage capacity, nucleation temperature and supercooling by Calvet and heat-flux differential scanning calorimetry (DSC)
- cycling equipment
- adiabatic test room constructed according to DIN EN 14240 for static and dynamic measurement of heat and cooling systems
- specially for characterisation of phase change slurries (PCS):
  - density
  - thermal conductivity
  - particle size
  - viscosity
  - stability analysis
- test stands to prepare, characterise and cycle emulsions
- test cells with outdoor surfaces to measure PCM systems

Stefan Gschwander, **Thomas Haussmann**, Peter Schossig

1 *Measurement stand to measure the adsorption capacity and dynamics of adsorption heat exchangers.*

2 *Calvet DSC for thermal characterisation of latent-heat storage materials.*

Test Laboratory for Porous Materials

The laboratories for thermal and structural analysis offer a broad spectrum of analytical methods to characterise porous materials. They are applied to accompany materials development and answer questions concerning surface area, pore structure, porosity, morphology and adsorption characteristics for different gases.

Our facilities include equipment for isothermal gas sorption measurements with various test gases (N_2, CO_2, EtOH, MeOH, H_2O) to determine the specific surface area, pore volume, pore size distribution and the complete adsorption characteristic with volumetric methods.

In addition, thermogravimetric methods are available for H_2O, EtOH and MeOH as the measurement gases, i.e. determination of the adsorbed mass as a function of pressure and temperature along isobars or isotherms. Our range of equipment is rounded out by instruments for macro-pore characterisation by mercury intrusion and density determination by helium pycnometry.

Various calorimeters for different size and temperature ranges, as well as two laser-flash systems, are available to determine heat capacity and thermal conductivity. The methods to investigate morphology include optical and laser-scanning microscopy to determine particle shape and size distribution, roughness and homogeneity of surfaces, as well as X-ray powder diffractometry for structural analysis.

Stefan Henninger, Peter Schossig

TestLab Fuel Cells

We characterise and test membrane fuel cells and systems with an electric power rating up to 5 kW_{el} as well as miniature fuel cells. In co-operation with the VDE Testing and Certification Institute, we offer consultancy services, tests according to standards and certification.

In the characterisation of fuel cells, we particularly emphasise the detailed investigation of local processes. With the help of electrochemical impedance spectroscopy, we can analyse the individual chemical-physical processes with regard to their dependence on material properties, construction and operation management.

Our walk-in climatic chamber allows investigations to be carried out over the temperature range from -20 °C to +60 °C. The relative humidity can be varied at temperatures above +5 °C between 10 % and 95 %. The high throughput of conditioned air, up to 2000 m^3 per hour, is notable.

Dietmar Gerteisen, **Ulf Groos**, Jürgen Wolf,

1 *Thermal balance to determine the water vapour adsorption capacity of large composite samples as a function of pressure and temperature.*

2 *Climatic chamber to characterise fuel cell stacks and systems with an electric power rating up to 5 kW_{el}.*

VISITING SCIENTISTS

Dr Hatem Bentaher
Higher Institute of Industrial Systems, Gabes, Tunisia
1.7.–31.12.2012, Research Area: Solar Cooling

Julius Denafas
Baltic Solar Energy, Vilnius, Lithuania
1.2.2012–31.1.2013, Research Area: Manufacture and Characterisation of Metal Contact Structures

Karoline Fath
Karlsruher Institut für Technologie (KIT), Karlsruhe
1.11.2010–31.10.2013, Research Area: Life Cycle Analysis of Building-integrated PV Systems

Jesús Febres Pascual
National University of Ireland, Galway, Ireland
1.9.–30.11.2012, Research Area: Energy Efficient Buildings

Simon Fey
Hochschule Offenburg, Offenburg
1.9.2011–31.7.2014, Research Area: Energy Gateway

Matteo Greppi
Università di Bologna, Bologna, Italy
3.2.–3.6.2012, Research Area: PV-Thermal Hybrid Collectors

Antti Haarahiltunen
Aalto University, School of Electrical Engineering, Aalto, Finland
1.5.–31.7.2012, Research Area: Simulation of Impurities in Silicon

Dr Henner Kampwerth
University of New South Wales, Photovoltaics Centre of Excellence, Sydney, Australia
16.–23.10.2012, Research Area: Characterisation of Silicon and Solar Cells

Antanas Katalevskis
Kaunas University of Technology, Kaunas, Lithuania
1.2.2011–31.1.2012, Research Area: Fe-Imaging with Photoluminescence

Rodrigo Lopes Sauaia
Pontifical Catholic University of Rio Grande do Sul, Porto Alegre/RS, Brazil
1.12.2011–31.1.2013, Research Area: Laser Structuring with LCP

Raymond Sterling Garay
National University of Ireland, Galway, Ireland
1.9.–30.11.2012, Research Area: Energy Efficient Buildings

Ieva Meiere
Riga Technical University, Riga, Lithuania
1.2.2012–31.1.2013, Research Area: Corrosion Investigations on Bipolar Plates for PEM Electrolysis

Daisuhe Nishi
National Institute of Advanced Industrial Science and Technology (AIST), Tsukaba, Japan
27.8.–21.9.2012, Research Area: Characterisation of III-V Multi-Junction Solar Cells

Dr Wattana Ratismith
Chulalongkorn University, Bangkok, Thailand
2.–26.10.2012, Research Area: Stationary Concentrating Solar Thermal Collectors

Salla Päivikki Repo
Aalto University, School of Electrical Engineering, Aalto, Finland
5.3.2012–28.2.2013, Research Area: Collaborative Work on the Characterisation and Technology in the Areas of Al_2O_3, Black Silicon, Material Characterisation

Seok-Jun Seo
Gwangju Institute of Science and Technology (GIFT), Gwangju, South Korea
1.3.2011–28.2.2012, Research Area: Electrochemical Properties of Porous Substrates for Dye Solar Cells

Prof Melkon Tatlier
Istanbul Technical University, Istanbul, Turkey
1.10.2012–30.9.2013, Research Area: Energy Efficient Buildings

Dr Nada Zamel
University of Waterloo, Waterloo, Canada
1.10.2011–30.9.2013, Research Area: Water Management and Fuel Cells

CONGRESSES, CONFERENCES AND SEMINARS

PV Rollout, 2nd European American Solar Deployment Conference, Boston, MA, USA, 9./10.2.2012

27th Symposium Photovoltaische Solarenergie (OTTI), Kloster Banz, Bad Staffelstein, Germany, 29.2.–2.3.2012

Workshop SiliconFOREST, Falkau, Germany, 4.–7.3.2012

Energy Storage, Düsseldorf, Germany, 13./14.3.2012

SiliconPV, 2nd International Conference on Silicon Photovoltaics, Leuven, Belgium, 3.–5.4.2012

CPV-8, 8th International Conference on Concentrating Photovoltaic Systems, Toledo, Spain, 16.–18.4.2012

Workshop "Induktive Ladesysteme", Forum ElektroMobilität e. V., Berlin, Germany, 17.4.2012

Workshop "Industriearbeitskreis zum Projekt OGEMA 2.0", Kassel, Germany, 20.4.2012

Workshop "PV-Module Reliability", Lugano, Switzerland, 3./4.5.2012

22nd Symposium Thermische Solarenergie (OTTI), Kloster Banz, Bad Staffelstein, Germany, 9.–11.5.2012

Fraunhofer-Energietage, Berlin, Germany, 10./11.5.2012

KONGRESS, Forum ElektroMobilität e. V., Berlin, Germany, 15./16.5.2012

Workshop "Chancen und Anforderungen für Kunststoffe in der Solarthermie", Berlin, Germany, 16.5.2012

Berliner Energie-Tage, Berlin, Germany, 23.–25.5.2012

38th IEEE Photovoltaic Specialist Conference, Austin, TX, USA, 3.–8.6.2012

7th Seminar Power Electronics for Photovoltaics (OTTI), Munich-Dornach, Germany, 11./12.6.2012

Fachforum "Quality of PV-Systems" (OTTI), Munich, Germany, 12.6.2012

Intersolar Europe Conference, Munich, Germany, 11.–14.6.2012

3rd VDI Conference "Wärmepumpen – Umweltwärme effizient nutzen", Düsseldorf, Germany, 19./20.6.2012

2nd Seminar Power Electronics for Photovoltaics, San Francisco, CA, USA, 9.7.2012

1st International Conference on Solar Heating and Cooling for Buildings and Industry, San Francisco, CA, USA, 9.–11.7.2012

Intersolar North America Conference, San Francisco, CA, USA, 9.–12.7.2012

Fachforum "Netzferne Stromversorgung mit Photovoltaik" (OTTI), Freiburg, 17./18.9.2012

27th European Photovoltaic Solar Energy Conference and Exhibition Frankfurt, 24.–28.9.2012

4th VDI Specialists' Symposium "Solarthermie – Heizen und Kühlen mit der Sonne", Ludwigsburg, Germany, 27./28.9.2012

FVEE Annual Meeting, Berlin, Germany, 16./17.10.2012

Solar Summit Freiburg, Freiburg, Germany, 18./19.10.2012

VDI Specialists' Conference "Thermische Energiespeicher in der Energieversorgung", Ludwigsburg, Germany, 23./24.10.2012

Workshop "ModQS – Automatisierte Fehlerdiagnose in Heizungssystemen", Freiburg, Germany, 8./9.11.2012

7th International Renewable Energy Storage Conference and Exhibition (IRES 2012), Berlin, Germany, 12.–14.11.2012

4th Workshop on MWT Solar Cell and Module Technology, Amsterdam, Netherlands, 20./21.11.2012

In 2012, Fraunhofer ISE organised or co-organised the congresses, conferences and seminars listed above.

DOCTORAL THESES

Jonathan Hampel
"HCl Gas Gettering of 3d Transition Metals for Crystalline Silicon Solar Cell Concepts"
Johannes Gutenberg-Universität Mainz
Mainz, 2012

Jonas Haunschild
"PL-Imaging – Vom Block zum Modul"
(PL-Imaging – From Block to Module)
Albert-Ludwigs-Universität Freiburg
Freiburg, 2012

Dirk Jacob
"Gebäudebetriebsoptimierung. Verbesserung von Optimierungsmethoden und Optimierung unter unsicheren Randbedingungen"
(Optimisation of Building Operation. Improving Optimisation Methods and Optimising under Uncertain Boundary Conditions)
Universität Karlsruhe
Karlsruhe, 2012

Annerose Knorz
"Entwicklung und Charakterisierung von Laserablationsverfahren für die Silizium-Solarzellenherstellung"
(Development and Characterisation of Laser Ablation Process for the Manufacture of Silicon Solar Cells)
Universität Konstanz
Konstanz, 2012

Stefan Lindekugel
"Process Optimisations for Improved Performance of Recrystallised Wafer Equivalent Solar Cells"
Universität Konstanz
Konstanz, 2012

Jochen Link
"Elektromobilität und erneuerbare Energien: Lokal optimierter Einsatz von netzgekoppelten Fahrzeugen"
(Electromobility and Renewable Energies: Local Optimised Use of Grid-Connected Vehicles)
TU Dortmund
Dortmund, 2012

Christoph Maurer
"Theoretical and Experimental Analysis and Optimization of Semi-Transparent Solar Thermal Façade Collectors"
Karlsruher Institut für Technologie (KIT)
Karlsruhe, 2012

Nilofar Moghbel
"Development of a Model of Evaluating Veiling Reflection on Monitor Screens under Daylight in Office Rooms"
Karlsruher Institut für Technologie (KIT)
Karlsruhe, 2012

Jan-Frederik Nekarda
"Laser Fired Contacts (LFC) – Charakterisierung, Optimierung und Modellierung eines Verfahrens zur lokalen Rückseitenkontaktierung dielektrisch passivierter Silizium-Solarzellen"
(Laser Fired Contacts (LFC) – Characterisation, Optimisation and Modelling of a Process for the Local Back-Side Contacting of Dielectrically Passivated Silicon Solar Cells)
Universität Konstanz
Konstanz, 2012

Dirk Reinwand
"Dynamisches Magnetron-Sputterverfahren zur Vorderseitenmetallisierung kristalliner Silicium-Solarzellen"
(Dynamic Magnetron Sputtering Process for Front-Side Metallisation of Crystalline Silicon Solar Cells)
Albert-Ludwigs-Universität Freiburg
Freiburg, 2012

Robert Woehl
"Entwicklung und Charakterisierung einer rückseitig kontaktierten und sammelnden n-Typ Silizium-Solarzelle mit Aluminium-Emitter"
(Development and Characterisation of a Back-Side Contacting and Collecting n-type Silicon Solar Cell with Aluminium Emitter)
Albert-Ludwigs-Universität Freiburg
Freiburg, 2012

PROMOTION OF YOUTH

Fraunhofer ISE is also active in recruiting youth for the scientific and engineering fields. We organise numerous on-going events in which our scientists actively partake. Through these, we strive to foster enthusiasm in today's youth for the topic of renewable energy. Further, the activities offer young people the possibility to gain insight about educational training possibilities and employment at an early stage.

Girls' Day 2012

Again in 2012, Fraunhofer opened its doors for the nation-wide "Girls' Day". Twenty students were offered the possibility to experience a closer look at the research and development work at our institute. In different laboratories at the Institute, the girls performed experiments in small groups under the direction of Fraunhofer scientists and gained insight into the daily life of a physicist working in the area of renewable energy. At the end of the day, the girls proudly presented their results to the group.

www.girls-day.de

Umwelt-Talent School 2012

From 29.–31. October 2012 the "Umwelt-Talent School" took place for the second time at Fraunhofer ISE. Experienced scientists relayed theoretical and practical know-how on the subject of solar energy. Thirty-one students in grades 9 through 13, interested in science and technology, attended. In workshops the students worked together meticulously on their inventions. The topics covered included solar power generation, solar energy concentration and the optical technology for solar applications. In addition to the practical work, Fraunhofer ISE also offered an informative and varied program around the event. The successful event carried out in cooperation with the Deutsche Bundesstiftung Umwelt (DBU) will be continued in 2013.

www.ise.fraunhofer.de/de/studium-jobs-und-karriere/talent-school

Activity in schools: "Solar researchers visit the classroom"

With this co-operative action offered to schools in the Freiburg region, Fraunhofer ISE motivates young students for jobs in solar energy. Together with the Solare Zukunft e.V., young scientists from Fraunhofer ISE prepared a class period revolving around the topic of solar energy. In addition to demonstrations and hands-on experiments, the Fraunhofer scientists describe their own educational experiences and daily job responsibilities to the students. The event offered a welcome change from the normal course work.

www.solarezukunft.org

PATENTS GRANTED

Method for Local High-Doping and Contacting of a Semiconductor Structure which Comprises a Solar Cell or Precursor of a Solar Cell
Suwito, Dominik; Benick, Jan; Jäger, Ulrich
DE 10 2010 006 315 A1

Solar Cell Assembly and also Solar Cell Arrangement
Peharz, Gerhard; Nitz, Peter; Schmidt, Thomas; Bösch, Armin; Jaus, Joachim; Bett, Andreas
2012/00101

Method for Tracking a Solar Generator to the Sun, Control for a Solar Plant
Burger, Bruno; Stalter, Olivier
EP 2 406 694 A3, ZA 2011/06576

Concentrator for Solar Radiation and Use thereof
Wirth, Harry
DE 10 2008 014 618 A1

Fluid Distribution Element for a Fluid-Conducting Device, in Particular for Multichannel-like Fluid-conducting Appliances which are Nested in each Other
Sicre, Benoit; Oltersdorf, Thore; Hermann, Michael
EP 2 220 451 A1

Solar Cell and Method for the Production of a Solar Cell
Clement, Florian; Biro, Daniel; Menkö, Michael; Kubera, Tim
DE 10 2008 033 632 A1

Measuring Method and Device for Characterising a Semiconductor Component
Warta, Wilhelm; Kasemann, Martin; Carstensen, Jürgen; Schütt, Andreas; Föll, Helmut
EP 2 245 473 B1, EP 2 245 473 A2

Semiconductor Device and the Use thereof
Dimroth, Frank; Schöne, Jan
EP 2 031 641 A1

Controllable Change-over Apparatus for a Solar Module
Burger, Bruno; Schmidt, Heribert
US 2010/0295381 A1

Thermal Plastic Collector with Pushed-in Absorber Body
Köhl, Michael; Weiß, Karl-Anders; Müller, Axel; Franke, Hannes
DE 10 2007 041 267 A1

Multi-Junction Solar Cell
Dimroth, Frank; Schöne, Jan
EP 2 012 367 A1

Method for Applying a Structure to a Semiconductor Element
Schultz-Wittmann, Oliver; Granek, Filip; Grohe, Andreas
US 2010/0301456 A1

Solar Module Serially Connected in the Front
Löckenhoff, Rüdiger
CN 101647125 A

Method for Metallising Semiconductor Elements and Use thereof
Grohe, Andreas; Nekarda, Jan; Schultz-Wittmann, Oliver
JP 5111507

Inverter with Integrated Control and Regulation for a Tracker
Burger, Bruno; Lerchenmüller, Hansjörg
KR 10-1159253 , US 2010/0126553 A1

Partially Transparent Static Sun Protection Device
Kuhn, Tilmann; Hermann, Michael
EP 2 047 055 A1

Method for Operating a Direct Oxidation Fuel Cell and Corresponding Arrangement
Eccarius, Steffen; Litterst, Christian; Koltay, Peter
US 2008/0318090 A1

Process and Device for the Precision Processing of Substrates by Means of a Laser Coupled into a Liquid Stream, and Use of the same
Kray, Daniel; Reber, Stefan; Mayer, Kuno; Hopman, Sybille; Biro, Daniel; Mette, Ansgar
EP 1 979 125 A1

Circuit Arrangement Having a Dual Coil for Producing an Alternating Voltage or an Alternating Current
Schmidt, Heribert; Burger, Bruno
US 2009/0168467 A1

Method for Dry Chemical Treatment of Substrates and also Use thereof
Reber, Stefan; Willeke, Gerhard
JP 5133257

System Comprising a Glazing Element and a Gas Supply Device
Graf, Wolfgang; Rox, Rainer
2,456,111 C

Circuit Breaker for a Solar Module
Burger, Bruno; Schmidt, Heribert
JP 4999839

Device and Method for Continuous Chemical Vapour Deposition under Atmospheric Pressure and Use thereof
Reber, Stefan; Hurrle, Albert; Schillinger, Norbert
5138594

Heat Exchanger Plate Arrangement which is in Thermal Contact with an Absorbent
Schmidt, Ferdinand; Schnabel, Lena; Henning, Hans-Martin; Nunez, Tomas; Henninger, Stefan
EP 1 920 202 A1

Solar Cell Module and Method for its Production
Jaus, Joachim; Bett, Andreas; Bösch, Armin; Dimroth, Frank; Lerchenmüller, Hansjörg
CN 101238587A, EP 1 913 643 A1, KR 10-1183743, US 2008/0230109 A1

Passenger Car Air-Conditioning Systems with Adsorption Heat Pumps
Henning, Hans-Martin; Mittelbach, Walter
CN 101098794, JP 2008-518835, US 2008/0066473 A1

Device with a Channel Conducting a Flowable Medium and a Method for Removing Inclusions
Koltay, Peter; Litterst, Christian; Eccarius, Steffen
DE 10 2005 005 231 A1

Method for Simultaneous Recrystallisation and Doping of Semiconductor Layers and Semiconductor Layer Systems Produced According to this Method
Reber, Stefan
US 2011/0018102 A1

Solar Cell with Organic Material in the Photovoltaic Layer and Method for the Production thereof
Hinsch, Andreas; Georg, Andreas; Niggemann, Michael
US 2005/0098203 A1

LECTURE COURSES AND SEMINARS

University of Freiburg

Dr Peter Fuß-Kailuweit
"Selected Semiconducter Devices", Seminar WS 11/12 and WS 12/13, Master Online Photovoltaics (MOPV)

Dr Stefan Glunz
"Photovoltaische Energiekonversion", Lectures SS 12, Faculty of Engineering

Dr Stefan Glunz, Dr Martin Schubert, Dr Harry Wirth
"Crystalline Silicon Photovoltaics", Lectures SS 12, Master Online Photovoltaics (MOPV)

Dr Stefan Glunz, Dr Uli Würfel
"Fundamentals of Solar Cells", Lectures WS 11/12 and WS 12/13, Master Online Photovoltaics (MOPV)

Prof Elisabeth von Hauff
"Physik organischer Halbleiter", Lectures SS 12, Faculty of Physics and Mathematics

Dr Doreen Kalz
"Case Study: Energy Efficiency in Building", Seminar SS 12, Zentrum für Erneuerbare Energien (ZEE), Renewable Energy Management (REM)

Dr Gerald Siefer
"III-V Solar Cells and Concentrator Systems", Lectures WS 11/12 und WS 12/13, Master Online Photovoltaics (MOPV)

Dr Werner Platzer, Dr Ralf Preu, Dr Christof Wittwer
"Technology I", Lectures WS 11/12 Zentrum für Erneuerbare Energien (ZEE), Renewable Energy Management (REM)

Dr Werner Platzer, Dr Christof Wittwer,
Dr Bernhard Wille-Haussmann, Raphael Hollinger,
Dr Jochen Link, Dr Olivier Stalter, Gregor Dötter
"Elective II – Energy Efficiency and Solar Thermal Energy", Lectures SS 12, Zentrum für Erneuerbare Energien (ZEE), Renewable Energy Management (REM)

Dr Ralf Preu
"Solar Cell Production Technology", Lectures SS 12, Master Online Photovoltaics (MOPV)

Dr Ralf Preu, Dr Christof Wittwer
"Photovoltaics", Lectures SS 12, Zentrum für Erneuerbare Energien (ZEE), Renewable Energy Management (REM)

Stefan Reichert
"Grid Integration and Control of PV Systems", Lectures WS 11/12, Master Online Photovoltaics (MOPV)

Dr Olivier Stalter
"Fundamentals of PV Systems", WS 11/12, Master Online Photovoltaics (MOPV)

Dr Olivier Stalter
"Electrical Engineering and PV Power Electronics", Lectures WS 11/12, Master Online Photovoltaics (MOPV)

Prof Eicke R. Weber, Dr Werner Platzer, Korbinian Kramer
"Solarthermie", Lectures WS 11/12, Faculty of Physics and Mathematics

Prof Eicke R. Weber, Dr Uli Würfel
"Photovoltaische Energiekonversion", Lectures SS 12, Faculty of Physics and Mathematics

Prof Eicke R. Weber, Dr Uli Würfel,
"Photovoltaik", Seminar SS 12 and WS 12/132, Faculty of Physics and Mathematics

Dr Christof Wittwer
"Smart Grid and Autonomous Communities", Lectures WS 11/12, Master Online Photovoltaics (MOPV)

Dr Uli Würfel
"New Concepts for Photovoltaic Energy Conversion", Lectures SS 12, Master Online Photovoltaics (MOPV)

Baden-Wuerttemberg Cooperative State University (DHBW), Ravensburg
Prof Bruno Burger
"Solar-Technologien", Lectures SS 12, Electrical Engineering – Automation

Dirk Kranzer
"Leistungselektronik", Lectures WS11/12, Electrical Engineering – Automation

Hector School, Karlsruhe
Prof Bruno Burger
"Green Mobility Engineering – Power Electronics", Lectures WS 11/12

Prof Bruno Burger
"Energy Engineering and Management – Power Electronics", Lectures SS 12

Dr Christof Wittwer
"Smart Grid Technology", Lectures WS 12

University of Applied Sciences, Offenburg
Norbert Pfanner
"Solartechnologie", Lectures SS 12, Electrical Engineering/Information Technology^{Plus}

KIT Karlsruhe Institute of Technology
Prof Bruno Burger
"Leistungselektronische Systeme für regenerative Energiequellen", Lectures WS 12/13, Electrical Engineering/Information Technology

Dr Heribert Schmidt
"Photovoltaische Systemtechnik", Lectures SS 12, Electrical Engineering/Information Technology

Ruhr-University Bochum
Dr Dietmar Borchert
"Photovoltaics", Lectures WS 12/13, Electrical Engineering/Information Technology

Stuttgart State Academy of Art and Design, Stuttgart
Florian Kagerer
"Bauökologie/Energieeffizientes Bauen", Lectures SS 12, Architecture

College of Applied Science, Georg Agricola zu Bochum
Dr Dietmar Borchert
"Photovoltaik", Lectures SS 12, Machine Technology

Technical University Berlin
Anton Neuhäuser
"CSP – Concentrating Solar Power", WS 11/12 TU Berlin, Masters Course of Studies: Global Production Engineering for Solar Technology

University of Kassel
Brisa Ortiz
"PV Hybrid System Simulation Tools", Seminar SS 12, European Master of Renewable Energy, EUREC

Brisa Ortiz
"Funding of R&D Projects", SS 12, European Master of Renewable Energy, EUREC

University of Koblenz-Landau
Dr Doreen Kalz
"Solares Bauen", Presence seminars WS 12/13, Distance Learning Course: Energy Management

In addition to the teaching activities at colleges and universities listed here, scientists at Fraunhofer ISE regularly head practical workshops and teach courses of further study for people from the finance sector and industry. For example, in the series „PV Training" we offer seminars and workshops on silicon technology or in the OTTI seminar „Off-Grid Power Supply" we supply knowledge on the products, planning and construction of remote electrical power systems.

BOOKS

Glunz, S. W.; Preu, R.; Biro, D.
»Crystalline Silicon Solar Cells: State-of-the-Art and Future Developments«, in: Comprehensive Renewable Energy, Chapter 1.16, Sayigh, A., Elsevier, Oxford, 2012, pp. 353-387, ISBN 9780080878737

Groos, U.; Gerteisen, D.
»Micro Fuel Cells«, in: Fuel Cell Science and Engineering: Materials, Processes, Systems and Technology, Chapter Micro Fuel Cells, Stolten, D.; Emonts, B., Wiley-VCH Verlag, Weinheim, Germany, 2012, pp. 131-145, ISBN 9783527330126

Lang-Koetz, C.[2]; Hinsch, A.; Beucker, S.[1]
»Dye Solar Cells«, in: Nanotechnology and Energy: Science, Promises, and Limits, Chapter 3.2, Lambauer, J.; Voss, A.; Fahl, U., Pan Stanford Publishing, Singapore, Singapore, 2012, pp. 114-128, ISBN 9789814310819

Mack, S.; Wolf, A.
»Bericht PTJ Forschungsjahrbuch Erneuerbare Energien 2011/MASSE-Projekt«, in: Forschungsjahrbuch Erneuerbare Energien 2011, Chapter MASSE – Massenfertigungstaugliche Verfahren für die Herstellung von monokristallinen Solarzellen mit 20 % Wirkungsgrad, PTJ, Germany, 2012

Philipps, S.; Dimroth, F.; Bett, A.
»High Efficiency III-V Multi-Junction Solar Cells«, in: Practical Handbook of Photovoltaics, Chapter ID-2 – High-Efficiency III-V Multijunction Solar Cells , McEvoy, A.; Markvart, T.; Castaner, L., Elsevier Academic Press, Maryland Heights, MO, USA, 2012, pp. 417-448, ISBN 9780123859341

Philipps, S.; Guter, W.; Welser, E.; Schöne, J.; Steiner, M.; Dimroth, F.; Bett, A. W.
»Present Status in the Development of III-V Multi-Junction Solar Cells«, in: Next Generation of Photovoltaics: New Concepts, Chapter 1, Ana Belén Cristóbal López, Antonio Martí Vega, Antonio L. Luque López, Springer, Berlin, Germany, 2012, pp. 1-22, ISBN 978-3-642-23368-5

Schmidt, D.[3]; Kalz, D.
»LowEx Technologien – Analyse und Bewertung von LowEx-Technologien in Heiz- und Kühlkonzepten in Nichtwohngebäuden«, in: Allianz Bau: Innovationen für die Baubranche, Sedlbauer, K., Fraunhofer-Verlag, Stuttgart, Germany, 2012, pp. 143-151, ISBN 9783839603451

Willeke, G. P.; Weber, E. R.
»Introduction«, in: Advances in Photovoltaics, Willeke, G.; Weber, E. R., Vol. 1, Academic Press, Waltham, MA, USA, 2012

Willeke, G. P.; Räuber A.[4]
»On the History of Terrestrial PV Development – with a Focus on Germany«, in: Advances in Photovoltaics, Willeke, G.; Weber, E. R., Vol. 1, Academic Press, Waltham, MA, USA, 2012

Winter, D.
»Permeate Gap Membrane Distillation (PGMD)«, in: Encyclopedia of Membranes, Drioli, E.; Giorno, L., SpringerReference, Heidelberg, Germany, 2012

1 *Borderstep Institut für Innovation und Nachhaltigkeit gGmbH, Berlin, Germany*
2 *Eisenmann AG, Böblingen, Germany (formerly with Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO, Stuttgart, Germany)*
3 *Fraunhofer-Institut für Bauphysik IBP, Stuttgart, Germany*
4 *PSE AG, Freiburg, Germany*

PUBLICATIONS IN REVIEWED JOURNALS

Angermann, H.[20]; Wolke, K.[55]; Gottschalk, C.[42]; Moldovan, A.; Zimmer, M.; Fittkau, J.[42]; Roczen, M.[20]; Rentsch, J.
»Electronic Interface Properties of Silicon Substrates after Ozone Based Wet-Chemical Oxidation Studied by SPV Measurements«, in: Applied Surface Science, 258 (2012), No. 21, pp. 8387-8396 (online available: http://dx.doi.org/10.1016/j.apsusc.2012.03.170)

Aßmus, M.; Köhl, M.
»Experimental Investigation of the Mechanical Behavior of Photovoltaic-Modules as Defined Inflow Conditions«, in: Journal of Photonics for Energy, 2 (2012), No. 1, pp. 022002-1 - 022002-11 (online available: http://dx.doi.org/10.1117/1.jpe.2.022002)

Bauer, J.[41]; Kwapil, W.[17]; Lausch, D.[14]; Schubert, M.; Bothe, K.[28]; Breitenstein, O.[41]
»Comments on the Paper ›Detection and Analysis of Hot-Spot Formation in Solar Cells‹ Published by M. Simon and E. L. Meyer in Solar Energy Materials & Solar Cells 94 (2010) 106-113«, in: Solar Energy Materials and Solar Cells, 99 (2012), pp. 362-364 (online available: http://dx.doi.org/10.1016/j.solmat.2011.12.014)

Beaucarne, G.[10]; Schubert, G.[52]; Hoornstra, J.[11]; Horzel, J.[22]; Glunz, S. W.
»Summary of the Third Workshop on Metallization for Crystalline Silicon Solar Cells«, in: Energy Procedia, 21 (2012), No. 12, pp. 2-13 (online available: http://dx.doi.org/10.1016/j.egypro.2012.05.002)

Bivour, M.; Reichel, C.; Hermle, M.; Glunz, S.
»Improving the a-Si:H(p) Rear Emitter Contact of n-Type Silicon Solar Cells«, in: Solar Energy Materials and Solar Cells, 106 (2012), pp. 11-16 (online available: http://dx.doi.org/10.1016/j.solmat.2012.06.036)

De Sio, A.[33]; Chakanga, K.[44]; Sergeev, O.[44]; von Maydell, K.[44]; Parisi, J.[33]; von Hauff, E.
»ITO-Free Inverted Polymer Solar Cells with ZnO:Al Cathodes and Stable Top Anodes«, in: Solar Energy Materials and Solar Cells, 98 (2012), pp. 52-56 (online available: http://dx.doi.org/10.1016/j.solmat.2011.10.015)

Deschler, F.[9]; De Sio, A.[33]; von Hauff, E.; Kutka, P.[39]; Sauermann, T.[39]; Egelhaaf, H.-J.[39]; Hauch, J.[39]; Da Como, E.[34]
»The Effect of Ageing on Exciton Dynamics, Charge Separation, and Recombination in P3HT/PCBM Photovoltaic Blends«, in: Advanced Functional Materials, 22 (2012), No. 7, pp. 1461-1469 (online available: http://dx.doi.org/10.1002/adfm.201101923)

Ecker, B.[33]; Engelhaaf, H.-J.[39]; Stein, R.[39]; Parisi, J.[33]; von Hauff, E.
»Understanding S-Shaped Current-Voltage Characteristics in Organic Solar Cells Containing a TiO_x Interlayer with Impedance Spectroscopy and Equivalent Circuit Analysis«, in: The Journal of Physical Chemistry C, 116 (2012), No. 31, pp. 16333-126337 (online available: http://dx.doi.org/10.1021/jp305206d)

Fell, A.
»Influence of Pulse Duration on the Doping Quality in Laser Chemical Processing (LCP) – a Simulative Approach«, in: Applied Physics A, (2012) (online available: http://dx.doi.org/10.1007/s00339-012-7144-7)

Ferrara, C.; Philipp, D.
»Why Do PV Modules Fail?«, in: Energy Procedia, 15 (2012), pp. 379-387 (online available: http://dx.doi.org/10.1016/j.egypro.2012.02.046)

Fischer, S.; Hallermann, F.[35]; Eichelkraut, T.[32]; von Plessen, G.[35]; Krämer, K.[5]; Biner, D.[5]; Steinkemper, H.; Hermle, M.; Goldschmidt, J.
»Plasmon Enhanced Upconversion Luminescence Near Gold Nanoparticles – Simulation and Analysis of the Interactions«, in: Optics Express, 20 (2012), No. 1, pp. 271-282 (online available: http://dx.doi.org/10.1364/OE.20.000271)

Fischer, S.; Steinkemper, H.; Löper, P.; Hermle, M.
»Modeling Upconversion of Erbium Doped Microcrystals Based on Experimentally Determined Einstein Coefficients«, in: Journal of Applied Physics, 111 (2012), No. 1, pp. 013109 (online available: http://dx.doi.org/10.1063/1.3674319)

Giesecke, J.; Niewelt, T.; Rüdiger, M.; Rauer, M.; Schubert, M.; Warta, W.
»Broad Range Injection-Dependent Minority Carrier Lifetime from Photoluminescence«, in: Solar Energy Materials and Solar Cells, 102 (2012), pp. 220-224 (online available: http://dx.doi.org/10.1016/j.solmat.2012.03.015)

PUBLICATIONS IN REVIEWED JOURNALS

Giesecke, J.; Schubert, M.; Warta, W.
»Measurement of Net Dopant Concentration via Dynamic Photoluminescence«, in: Journal of Applied Physics, 112 (2012), No. 6, pp. 063704-0637011
(online available: http://dx.doi.org/10.1063/1.4752722)

Giesecke, J.; Schubert, M.; Warta, W.
»Self-Sufficient Minority Carrier Lifetime in Silicon from Quasi-Steady-State Photoluminescence«, in: physica status solidi a, 209 (2012), No. 11, pp. 2286–2290
(online available: http://dx.doi.org/10.1002/pssa.201228383)

Greulich, J.; Fellmeth, T.; Glatthaar, M.; Biro, D.; Rein, S.
»Comparison of Analytical and Numerical Models for the Optimization of c-Si Solar Cells' Front Metallization«, in: IEEE Journal of Photovoltaics, 2 (2012), No. 4, pp. 588-591
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2206567)

Greulich, J.; Glatthaar, M.; Rein, S.
»Separation of Series Resistance and Space Charge Region Recombination in Crystalline Silicon Solar Cells From Dark and Illuminated Current-Voltage Characteristics«, in: IEEE Journal of Photovoltaics, 2 (2012), No. 3, pp. 241-246
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2189370)

Greulich, J.; Jäger, U.; Rein, S.; Preu, R.
»A Review and Comparison of One- and Two-Dimensional Simulations of Solar Cells Featuring Selective Emitters«, in: IEEE Journal of Photovoltaics, 2 (2012), No. 4, pp. 441-449
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2199083)

Gutmann, J.; Peters, M.; Bläsi, B.; Hermle, M.; Gombert, A.[50]; Zappe, H.[8]; Goldschmidt, J. C.
»Electromagnetic Simulations of a Photonic Luminescent Solar Concentrator«, in: Optics Express, 20 (2012), pp. A157-A167
(online available: http://dx.doi.org/10.1364/OE.20.00A157)

Hartmann, P.; Gerteisen, D.
»Local Degradation Analysis of a Real Long-Term Operated DMFC-Stack-MEA«, in: Journal of Power Sources, 219 (2012), pp. 147-154
(online available: http://dx.doi.org/10.1016/j.jpowsour.2012.07.048)

Haunschild, J.; Reis, I.; Chipei, T.; Thaidigsmann, B.; Linse, M.; Rein, S.
»Rating and Sorting of mc-Si As-Cut Wafers in Solar Cell Production Using PL Imaging«, in: Solar Energy Materials and Solar Cells, 106 (2012), pp. 71-75
(online available: http://dx.doi.org/10.1016/j.solmat.2012.05.027)

Hauser, H.; Michl, B.; Kübler, V.; Müller, C.; Hermle, M.; Bläsi, B.
»Honeycomb Texturing of Silicon via Nanoimprint Lithography for Solar Cell Applications«, in: Journal of Photovoltaics, 2 (2012), No. 2, pp. 114-122
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2184265)

Henning, H.-M.; Döll, J.
»Solar Systems for Heating and Cooling of Buildings«, in: Energy Procedia, 30 (2012), pp. 633-653
(online available: http://dx.doi.org/10.1016/j.egypro.2012.11.073)

Henninger, S. K.; Jeremias, F.; Kummer, H.; Janiak, C.[23]
»MOFs for Use in Adsorption Heat Pump Processes«, in: European Journal of Inorganic Chemistry, 2012 (2012), No. 16, pp. 2625–2634
(online available: http://dx.doi.org/10.1002/ejic.201101056)

Henninger, S.; Ristić , A.[43]; Maučec, D.[43]; Kaučič, V.[43]
»New Two-Component Water Sorbent $CaCl_2$-FeKIL$_2$ for Solar Thermal Energy Storage«, in: Microporous and Mesporous Materials, 164 (2012), pp. 266-272
(online available: http://dx.doi.org/10.1016/j.micromeso.2012.06.054)

Henninger, S.; Schicktanz, M.; Hügenell, P.; Sievers, H.[48]; Henning, H.-M.
»Evaluation of Methanol Adsorption on Activated Carbons for Thermally Driven Chillers Part I: Thermophysical Characterisation«, in: International Journal of Refrigeration, 35 (2012), No. 3, pp. 543–553
(online available: http://dx.doi.org/10.1016/j.ijrefrig.2011.10.004)

Hinsch, A.; Veurman, W.; Brandt, H.; Loayza Aguirre, R.; Bialecka, K.; Flarup Jensen, K.
»Worldwide First Fully Up-Scaled Fabrication of 60 x 100 cm² Dye Solar Module Prototypes«, in: Progress in Photovoltaics: Research and Applications, 20 (2012), No. 6, pp. 698-710
(online available: http://dx.doi.org/10.1002/pip.1213)

Hoheisel, R.; Bett, A. W.
»Experimental Analysis of Majority Carrier Transport Processes at Heterointerfaces in Photovoltaic Devices«, in: IEEE Journal of Photovoltaics, 2 (2012), No. 3, pp. 398-402
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2199080)

Hönig, R.; Kalio, A.; Sigwarth, J.; Clement, F.; Glatthaar, M.; Wilde, J.[8]; Biro, D.
»Impact of Screen Printing Silver Paste Components on the Space Charge Region Recombination Losses of Industrial Silicon Solar Cells«, in: Solar Energy Materials and Solar Cells, 106 (2012), pp. 7-10
(online available: http://dx.doi.org/10.1016/j.solmat.2012.06.040)

Hornung, T.; Steiner, M.; Nitz, P.
»Estimation of the Influence of Fresnel Lens Temperature on Energy Generation of a Concentrator Photovoltaic System«, in: Solar Energy Materials and Solar Cells, 99 (2012), pp. 333-338
(online available: http://dx.doi.org/10.1016/j.solmat.2011.12.024)

Jeremias, F.; Henninger, S. K.; Janiak, C[23]
»High Performance Metal-Organic-Framework Coatings Obtained via Thermal Gradient Synthesis«, in: Chemical Communications, 48 (2012), pp. 9708-9710
(online available: http://dx.doi.org/10.1039/c2cc34782b)

Jeremias, F.; Khuita, A.[23]; Henninger, S. K.; Janiak, C.[23]
»MIL-100 (Al, Fe) as Water Adsorbents for the Heat Transformation Purposes – a Promising Application«, in: Journal of Materials Chemistry, 22 (2012), pp. 10148-10151
(online available: http://dx.doi.org/10.1039/c2jm15615f)

Kailuweit, P.; Peters, M.; Leene, J.[51]; Mergenthaler, K.[4]; Dimroth, F.; Bett, A. W.
»Numerical Simulations of Absorption Properties of InP Nanowires for Solar Cell Applications«, in: Progress in Photovoltaics: Research and Applications, 20 (2012), No. 8, pp. 945-953
(online available: http://dx.doi.org/10.1002/pip.1169)

Kalz, D.; Pfafferott, J.[24]; Koenigsdorff, R.[25]
»Betriebserfahrungen mit Thermoaktiven Bauteilsystemen«, in: Bauphysik, 34 (2012), No. 2, pp. 66-75
(online available: http://dx.doi.org/10.1002/bapi.201200011)

Kalz, D.; Pfafferott, J.[24]
»Energieeffiziente Kühlung und Thermischer Raumkomfort: Vergleichende Analyse von 8 Europäischen Nichtwohngebäuden (Teil 1)«, in: Bauphysik, 34 (2012), No. 6, pp. 256-267
(online available: http://dx.doi.org/10.1002/bapi.201200037)

Kasemann, M.[8]; Reindl, L. M.[8]; Michl, B.; Warta, W.; Schütt, A.[30]; Carstensen, J.[30]
»Contactless Qualitative Series Resistance Imaging on Solar Cells«, in: IEEE Journal of Photovoltaics, 2 (2012) No. 2, pp. 181-183
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2184524)

Koch, L.; Steinbach, F.[29]; Hermann, M.; Witulski, J.[29]; Tekkaya, A. E.[29]
»Processing of New Solar Absorbers in Steel Design Based on Partially Cold Roll Bonded Hybrid Semi-Finished Parts«, in: Key Engineering Materials, 504-506 (2012), pp. 137-142
(online available: www.scientific.net/KEM.504-506.137)

Köhl, M.; Heck, M.; Wiesmeier, S.
»Modelling of Conditions for Accelerated Lifetime Testing of Humidity Impact on PV-Modules Based on Monitoring of Climatic Data«, in: Solar Energy Materials and Solar Cells, 99 (2012), pp. 282-291
(online available: http://dx.doi.org/10.1016/j.solmat.2011.12.011)

Kopola, P.[56]; Zimmermann, B.; Filipovic, A.; Schleiermacher, H.-F.; Greulich, J.; Rousu, S.[56]; Hast, J.[56]; Myllylä, R.[45]; Würfel, U.
»Aerosol Printed Grid for ITO-Free Inverted Organic Solar Cells«, in: Solar Energy Materials and Solar Cells, 107 (2012), pp. 252-258
(online available: http://dx.doi.org/10.1016/j.solmat.2012.06.042)

Koschikowski, J.; Ripperger, S.[7]
»Desalination Using Membrane Distillation: Flux Enhancement by Feed Water Deaeration on Spiral-Wound Modules«, in: Journal of Membrane Science, 423-424 (2012), pp. 215-224
(online available: http://dx.doi.org/10.1016/j.memsci.2012.08.018)

Kost, C.; Engelken, M.[3]; Schlegl, T.
»Value Generation of Future CSP Projects in North Africa«, in: Energy Policy, 46 (2012), pp. 88-99
(online available: http://dx.doi.org/10.1016/j.enpol.2012.03.034)

PUBLICATIONS IN REVIEWED JOURNALS

Kostka, J.; Schellenberg, R.[54]; Baitalow, F.[54]; Smolinka, T.; Mertens, F.[54]
»Concentration-Dependent Dehydrogenation of Ammonia Borane-Triglyme Mixtures«, in: European Journal of Inorganic Chemistry, 2012 (2012), No. 1, pp. 49-54
(online available: http://dx.doi.org/10.1002/ejic.201190112)

Kuhn, T.; Frontini, F.[47]
»The Influence of Various Internal Blinds on the Thermal Comfort: A New Method for Calculating the Mean Radiant Temperature in Office Spaces«, in: Energy and Buildings, 54 (2012), pp. 527-533
(online available: http://dx.doi.org/10.1016/j.enbuild.2012.02.029)

Löper, P.; Stüwe, D.; Künle, M.; Bivour, M.; Reichel, C.; Neubauer, R.; Schnabel, M.; Hermle, M.; Eibl, O.; Janz, S.; Zacharias, M.; Glunz, S. W.
»A Membrane Device for Substrate-Free Photovoltaic Characterization of Quantum Dot Based p-i-n Solar Cells«, in: Advanced Materials, 24 (2012), No. 23, pp. 3124-3129
(online available: http://dx.doi.org/10.1002/adma.201200539)

Mangold, H. S.[26]; Richter, T. V.[26]; Link, S.[27]; Würfel, U.; Ludwigs, S.[27]
»Optoelectronic Properties of Hyperbranched Polythiophenes«, in: Journal of Physical Chemistry B, 116 (2012), No. 1, pp. 154-159
(online available: http://dx.doi.org/10.1021/jp210822s)

Markötter, H.[19]; Haußmann, J.[57]; Dittmann, K.[19]; Arlt, T.[19]; Wieder, F.[19]; Tötzke, C.[19]; Klages, M.[57]; Reiter, C.[57]; Riesemeier, H.[2]; Scholta, J.[57]; Gerteisen, D.; Banhart, J.[19]; Manke, I.[19]
»Visualization of the Water Distribution in Perforated Gas Diffusion Layers by Means of Synchrotron X-Ray Radiography«, in: International Journal of Hydrogen Energy, 37 (2012), No. 9, pp. 7757–7761
(online available: http://dx.doi.org/10.1016/j.ijhydene.2012.01.141)

Maurer, C.; Kuhn, T.
»Variable g-Value of Transparent Façade Collectors«, in: Energy and Buildings, 51 (2012), pp. 177-184
(online available: http://dx.doi.org/10.1016/j.enbuild.2012.05.011)

Melke, J.; Schoekel, A.[31]; Gerteisen, D.; Dixon, D.[31]; Ettingshausen, F.[31]; Cremers, C.[15]; Roth, C.[31]; Ramaker, D. E.[6]
»The Electrooxidation of Ethanol on Pt. An In-Situ and Time-Resolved XANES Study«, in: Journal of Physical Chemistry C, 116 (2012), No. 4, pp. 2838-2849
(online available: http://dx.doi.org/10.1021/jp206295h)

Michl, B. T.; Rüdiger, M.; Giesecke, J. A.; Hermle, M.; Warta, W.; Schubert, M. C.
»Efficiency Limiting Bulk Recombination in Multicrystalline Silicon Solar Cells«, in: Solar Energy Materials and Solar Cells, 98 (2012), pp. 441-447
(online available: http://dx.doi.org/10.1016/j.solmat.2011.11.047)

Michl, B.; Giesecke, J.; Warta, W.; Schubert, M.
»Separation of Front and Backside Surface Recombination by Photoluminescence Imaging on Both Wafer Sides«, in: IEEE Journal of Photovoltaics, 2 (2012), No. 3, pp. 348-351
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2190585)

Montesdeoca-Santana, A.[4]; Jiménez-Rodríguez, E.[4]; González-Díaz, B.[4]; Borchert, D.; Guerrero-Lemus, R.[4]
»Ultra-Low Concentration Na_2CO_3/$NaHCO_3$ Solution for Texturization of Crystalline Silicon Solar Cells«, in: Progress in Photovoltaics: Research and Applications, 20 (2012), No. 2, pp. 191–196
(online available: http://dx.doi.org/10.1002/pip.1117)

Morin, G.; Dersch, J.[36]; Platzer, W.; Eck, M.[37]; Häberle, A.[46]
»Comparison of Linear Fresnel and Parabolic Through Collector Power Plants«, in: Solar Energy, 86 (2012), No. 1, pp. 1-12
(online available: http://dx.doi.org/10.1016/j.solener.2011.06.020)

Nievendick, J.; Specht, J.; Zimmer, M.; Zahner, L.; Glover, W.; Stüwe, D.; Rentsch, J.
»Formation of a Honeycomb Texture for Multicrystalline Silicon Solar Cells Using an Inkjetted Mask«, in: physica status solidi – Rapid Research Letters, 6 (2012), No. 1, pp. 7-9
(online available: http://dx.doi.org/10.1002/pssr.201105422)

Nievendick, J.; Zimmer, M.; Souren, F.[12]; Haunschild, J.; Rentsch, J.
»Relation between Solar Cell Efficiency and Crystal Defect Etching Induced by Acidic Texturization on Multicrystalline Silicon Material«, in: Solar Energy Materials and Solar Cells, 105 (2012), pp. 159-166
(online available: http://dx.doi.org/10.1016/j.solmat.2012.05.023)

Oltersdorf, A.; Moldovan, A.; Bayer, M.
»Surface Contamination of Silicon Wafer after Acid Texturization«, in: Solid State Phenomena, 187 (2012), pp. 337-340
(online available: www.scientific.net/SSP.187.337)

Peike, C.; Hülsmann, P.; Blüml, M.; Schmidl, P.; Weiß, K.-A.; Köhl, M.
»Impact of Permeation Properties and Backsheet-Encapsulant Interactions on the Reliability of PV Modules«, in: ISRN Renewable Energy, 2012 (2012), pp. 459731-1 - 459731-5
(online available: http://dx.doi.org/10.5402/2012/459731)

Peters, M.; Rüdiger, M.; Hauser, H.; Hermle, M.; Bläsi, B.
»Diffractive Gratings for Crystalline Silicon Solar Cells – Optimum Parameters and Loss Mechanisms«, in: Progress in Photovoltaics: Research and Applications, 20 (2012), No. 7, pp. 862-873
(online available: http://dx.doi.org/10.1002/pip.1151)

Reichel, C.; Granek, F.; Hermle, M.; Glunz, S. W.
»Short-Circuit Current Losses in Back-Contacted Back-Junction Si Solar Cells: Experiment and Simulation of the Charge Collection Probability«, in: IEEE Journal of Photovoltaics, 3 (2012), No. 1, pp. 217-223
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2219499)

Richter, A.; Glunz, S.; Werner, F.[28]; Schmidt, J.[28]; Cuevas, A.[49]
»Improved Quantitative Description of Auger Recombination in Crystalline Silicon«, in: Physical Review B, 86 (2012), No. 16, pp. 165202-165215
(online available: http://dx.doi.org/10.1103/PhysRevB.86.165202)

Richter, T.[27]; Braun, C.[27]; Link, S.[27]; Scheuble, J.[27]; Crossland, E.[17]; Stelzl, F.; Würfel, U.; Ludwigs, S.[27]
»Regioregular Polythiophenes with Alkylthiophene Side Chains«, in: Macromolecules, 45 (2012), No. 14, pp. 5782–5788
(online available: http://dx.doi.org/10.1021/ma2026644)

Ristić , A.[43]; Zabukovec Logar, N.[43]; Henninger, S. K.; Kaučič, V.[43]
»The Performance of Small-Pore Microporous Aluminophosphates in Low-Temperature Solar Energy Storage: The Structure-Property Relationship«, in: Advanced Functional Materials, 22 (2012), No. 9, pp. 1952-1957
(online available: http://dx.doi.org/10.1002/adfm.201102734)

Rüdiger, M.; Hermle, M.
»Numerical Analysis of Locally Contacted Rear Surface Passivated Silicon Solar Cells«, in: Japanese Journal of Applied Physics, 51 (2012), pp. 1-3
(online available: http://dx.doi.org/10.1143/JJAP.51.10NA07)

Rüdiger, M.; Schmiga, C.; Rauer, M.; Hermle, M.; Glunz, S. W.
»Efficiency Potential of n-Type Silicon Solar Cells with Aluminum-Doped Rear p+ Emitter«, in: IEEE Transactions on Electron Devices, 59 (2012), No. 5, pp. 1295-1303
(online available: http://dx.doi.org/10.1109/TED.2012.2187655)

Saint-Cast, P.; Kania, D.[1]; Heller, R.[21]; Hofmann, M.; Rentsch, J.; Preu, R.
»High-Temperature Stability of c-Si Surface Passivation by Thick PECVD Al_2O_3 with and without Hydrogenated Capping Layers«, in: Applied Surface Science, 258 (2012), pp. 8371-8376
(online available: http://dx.doi.org/10.1016/j.apsusc.2012.03.171)

Schicktanz, M.; Hügenell, P.; Henninger, S. K.
»Evaluation of Methanol/Activated Carbons for Thermally Driven Chillers, Part II: The Energy Balance Model«, in: International Journal of Refrigeration, 35 (2012), No. 3, pp. 554-561
(online available: http://dx.doi.org/10.1016/j.ijrefrig.2011.03.014)

Schindler, F.; Schubert, M. C.; Kimmerle, A.; Broisch, J.; Rein, S.; Kwapil, W.; Warta, W.
»Modeling Majority Carrier Mobility in Compensated Crystalline Silicon for Solar Cells«, in: Solar Energy Materials and Solar Cells, 106 (2012), pp. 31-36
(online available: http://dx.doi.org/10.1016/j.solmat.2012.06.018)

Schwantes, R.; Raluy, R. G.[38]; Subiela, J. V.[38]; Penate, B.[38]; Melián, G.[38]; Betancort, J. R.[38]
»Operational Experience of a Solar Membrane Distillation Demonstration Plant in Pozo Izquierdo – Gran Canaria Island (Spain)«, in: Desalination, 290 (2012), pp. 1-13
(online available: http://dx.doi.org/10.1016/j.desal.2012.01.003)

Slamova, K.; Glaser, R.; Schill, C.; Wiesmeier, S.; Köhl, M.
»Mapping Atmospheric Corrosion in Coastal Regions – Methods and Results«, in: Journal of Photonics for Energy, 2 (2012), No. 1, pp. 022003
(online available: http://dx.doi.org/10.1117/1.JPE.2.022003)

PUBLICATIONS IN REVIEWED JOURNALS

Stelzl, F. F.; Schulz-Gericke, J.; Crossland, E.[17]; Ludwigs, S.[27]; Würfel, U.
»Voltage-Induced Formation of Accumulation Layers at Electrode Interfaces in Organic Solar Cells«, in: Advanced Energy Materials, 2 (2012), No. 8, pp. 983-991
(online available: http://dx.doi.org/10.1002/aenm.201100569)

Stelzl, F. F.; Würfel, U.
»Modelling the Influence of Doping on the Performance of Bulk Heterojunction Organic Solar Cells: 1-D Effective Semiconductor vs 2-D Donor/Acceptor Model«, in: Physical Review B, 86 (2012), No. 7, pp. 075315
(online available: http://dx.doi.org/10.1103/physrevb.86.075315)

Thaidigsmann, B.; Drews, A.; Fellmeth, T.; Saint-Cast, P.; Wolf, A.; Clement, F.; Biro, D.; Preu, R.
»Synergistic Effects of Rear-Surface Passivation and the Metal Wrap Through Concept«, in: IEEE Journal of Photovoltaics, 2 (2012), No. 2, pp. 109-113
(online available: http://dx.doi.org/10.1109/JPHOTOV.2012.2183577)

Thaidigsmann, B.; Greulich, J.; Lohmüller, E.; Schmeißer, S.; Clement, F.; Wolf, A.; Biro, D.; Preu, R.
»Loss Analysis and Efficiency Potential of p-Type MWT-PERC Solar Cells«, in: Solar Energy Materials and Solar Cells, 106 (2012), pp. 89-94
(online available: http://dx.doi.org/10.1016/j.solmat.2012.04.045)

Thaidigsmann, B.; Linse, M.; Wolf, A.; Clement, F.; Biro, D.; Preu, R.
»The Path to Industrial Production of Highly Efficient Metal Wrap Through Silicon Solar Cells«, in: GREEN, 2 (2012), No. 4, pp. 171-176
(online available: http://dx.doi.org/10.1515/green-2012-0008)

Wilken, S.[33]; Hoffmann, T.[33]; von Hauff, E.; Borchert, H.[33]; Parisi, J.[33]
»ITO-Free Inverted Polymer/Fullerene Solar Cells: Interface Effects and Comparison of Different Semi-Transparent Front Contacts«, in: Solar Energy Materials and Solar Cells, 96 (2012), pp. 141-147
(online available: http://dx.doi.org/10.1016/j.solmat.2011.09.044)

Wirth, H.; Ferrara, C.
»PV Module Technology and Reliability – Status and Perspectives«, in: Green, 2 (2012), No. 4, pp. 159-169
(online available: http://dx.doi.org/10.1515/green-2012-0011)

Wolf, A.; Biro, D.; Nekarda, J.; Kimmerle, A.; Mack, S.; Preu, R.
»Erratum: ›Comprehensive Analytical Model for Locally Contacted Rear Surface Passivated Solar Cells‹ [J. Appl. Phys. 108, 124510 (2010)]«, in: Journal of Applied Physics, 111 (2012), No. 2, pp. 029905
(online available: http://dx.doi.org/10.1063/1.3676280)

Zubel, I.[13]; Granek, F.; Rola, K.[13]; Banaszczyk, K.[13]
»Texturization of Si (100) Substrates Using Tensioactive Compounds«, in: Applied Surface Science, 258 (2012), No. 22, pp. 9067-9072
(online available: http://dx.doi.org/10.1016/j.apsusc.2012.05.164)

1 Bosch Solar Energy AG, Erfurt, Germany
2 Bundesanstalt für Materialforschung und -prüfung BAM, Berlin, Germany
3 Center for Digital Technology and Management CDTM, Ludwig-Maximilians-Universität & Technische Universität München, Munich, Germany
4 Departamento de Física Básica, Universidad de La Laguna, Santa Cruz de Tenerife, Spain
5 Department of Chemistry and Biochemistry, Universität Bern, Bern, Switzerland
6 Department of Chemistry, The George Washington University, Washington, D. C., USA
7 Department of Mechanical and Process Engineering, Technische Universität Kaiserslautern, Kaiserslautern, Germany
8 Department of Microsystems Engineering, IMTEK, Albert-Ludwigs-Universität, Freiburg, Germany
9 Department of Physics and CeNS, Ludwig-Maximilians-Universität, Munich, Germany
10 Dow Corning, Seneffe, Belgium
11 ECN, Petten, The Netherlands
12 Eindhoven University of Technology, Eindhoven, The Netherlands
13 Faculty of Microsystems Electronics and Photonics, Wrocław University of Technology, Wroclaw, Poland
14 Fraunhofer-Center für Silizium-Photovoltaik CSP, Halle, Germany
15 Fraunhofer-Institute for Chemical Technology ICT, Pfinztal, Germany
17 Freiburg Institute for Advanced Studies FRIAS, Freiburg, Germany
18 Freiburger Materialforschungszentrum FMF, Albert-Ludwigs-Universität, Freiburg, Germany
19 Helmholtz-Zentrum Berlin HZB, Berlin, Germany

[20] *Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany*
[21] *Helmholtz-Zentrum Dresden-Rossendorf HZDR, Dresden, Germany*
[22] *IMEC, Leuven, Belgium*
[23] *Institut für Anorganische Chemie und Strukturchemie, Heinrich-Heine Universität, Düsseldorf, Germany*
[24] *Institut für Energiesystemtechnik INES, Hochschule für Technik, Wirtschaft und Medien, Offenburg, Germany*
[25] *Institut für Gebäude- und Energiesysteme IGE, Hochschule Biberach, Biberach, Germany*
[26] *Institut für Makromolekulare Chemie, Albert-Ludwigs-Universität, Freiburg, Germany*
[27] *Institut für Polymerchemie, Universität Stuttgart, Stuttgart, Germany*
[28] *Institut für Solarenergieforschung Hameln ISFH, Emmerthal, Germany*
[29] *Institut für Umformtechnik und Leichtbau, Technische Universität Dortmund, Dortmund, Germany*
[30] *Institute for Materials Science, Christian-Albrechts Universität, Kiel, Germany*
[31] *Institute for Materials Science, Technische Universität Darmstadt, Darmstadt, Germany*
[32] *Institute of Condensed Matter Theory and Solid State Optics, Abbe Center of Photonics, Friedrich-Schiller Universität, Jena, Germany*
[33] *Institute of Physics, Carl von Ossietzky Universität, Oldenburg, Germany*
[34] *Institute of Physics, Albert-Ludwigs-Universität, Freiburg, Germany*
[35] *Institute of Physics, RWTH Aachen, Aachen, Germany*
[36] *Institute of Technical Thermodynamics, Solar Research German Aerospace Center DLR, Cologne, Germany*
[37] *Institute of Technical Thermodynamics, Solar Research German Aerospace Center DLR, Stuttgart, Germany*
[38] *Instituto Tecnológico de Canarias ITC, Santa Lucia, Las Palmas, Spain*
[39] *Konarka Technologies GmbH, Nuremberg, Germany*
[40] *Solid State Physics, Lund University, Lund, Sweden*
[41] *Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany*
[42] *MKS Instruments, Inc., ASTex GmbH, Berlin, Germany*
[43] *National Institute of Chemistry, Ljubljana, Slovenia*
[44] *Next Energy EWE-Forschungszentrum für Energietechnologie, Oldenburg, Germany*
[45] *Optoelectronics and Measurement Techniques Laboratory University of Oulu, Oulu, Finland*
[46] *PSE AG, Freiburg, Germany*
[47] *Politecnico di Milano, Milano, Italy*
[48] *Quantachrome GmbH & Co. KG, Odelzhausen, Germany*
[49] *Research School of Engineering Australian National University, Canberra, ACT Australia*
[50] *Soitec Solar, Freiburg, Germany*
[51] *Sol Voltaics AB, Lund, Sweden*
[52] *Sunways, Constance, Germany*
[53] *Technische Universität Berlin, Berlin, Germany*
[54] *Technische Universität Bergakademie, Freiberg, Germany*
[55] *Technologie Consulting Wolke, Althengstett, Germany*
[56] *VTT Technical Research Centre of Finland, Oulu, Finland*
[57] *Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg ZSW, Ulm, Germany*

All further publications can be found in the Internet at:
www.ise.fraunhofer.de/publications

INVITED TALKS

Invited talks at international conferences and workshops

Alink, R.; Gerteisen, D.
»Fiber Based Modeling of the Liquid Water Transport in Gas Diffusion Layers«, 9th Symposium on Fuel Cell and Battery Modeling and Experimental Validation, ModVal 9 2012, Paul Scherrer Institut, Sursee, Switzerland, 2.–4.4.2012

Alink, R.; Gerteisen, D.; Haussmann, J.[11]; Markötter, H.[4]
»Water Management in Perforated Porous Transport Layers«, 19th World Hydrogen Energy Conference WHEC, Toronto, Canada, 3.–7.6.2012

Bett, A. W.
»III-V-Based Solar Cells and Their Applications«, Seminar, Heriot-Watt University, Edinburgh, Scotland, 14.3.2012

Bett, A. W.
»Concentrator Photovoltaic: A Technology Providing Highest Efficiency and Low Cost«, 22nd International Photovoltaic Science and Engineering Conference PVSEC-22 2012, Chinese Renewable Energy Society, Hangzhou, China, 5.–9.11.2012

Bett, A. W.
»Past, Present and Future of Concentrating Photovoltaics«, 2nd Workshop on CPV, Toyota Technical Institute, Nagoya, Japan, 13.11.2012

Bett, A. W.; Philipps, S. P.
»The Success Story of the Feed-in Tariff in Germany«, RETEM – Renewable Energies: Technology & Efficient Management, Al Akhawayn University, Ifrane, Morocco, 12./13.1.2012

Binder, S.
»Die Rolle von Glas in Solarzellen«, elmug4future, Elektronische Mess- und Gerätetechnik Thür eG, Suhl, Germany, 26./27.6.2012

Bromberger, K.; Dennenmoser, M.; Hebling, C.; Smolinka, T.; Vetter, M.
»Design Layout and Operational Experience of kW-Class all Vanadium Redox Flow Battery Stack«, The International Flow Battery Forum, Munich, Germany, 26./27.6.2012

Dimroth, F.; Bett, A. W.; Siefer, G.; Wiesenfarth, M.; Fuß-Kailuweit, P.; Lackner, D.; Oliva, E.
»High Efficiency Multi-Junction Solar Cell Technologies«, 2nd European Energy Conference, Maastricht, The Netherlands, 17.–20.4.2012

Dold, P.[3]
»Is There a ›Best Technology‹ in Casting?«, 6th PV Fab Managers Forum, PV Group, Berlin, Germany, 26.3.2012

Dreyer, K.; Essig, S.; Kellenbenz, R.; Klinger, V.; Oliva, E.; Roesener, T.; Siefer, G.; Wekkeli, A.; Weuffen, C.; Dimroth, F.; Bett, A. W.
»Next Generation High Efficiency III-V Solar Cells«, EXMATEC, CRHEA-CNRS, Porquerolles, France, 30.5.–1.6.2012

Glatthaar, M.
»Metalization for High Efficiency Silicon Solar Cells«, European Photovoltaics Summer School, Polish Academy of Science, Krakow, Poland, 4.–7.7.2012

Glunz, S. W.
»Overview of the High-Efficiency C-Si Solar Cell Developments in Research and Production«, 27th European Photovoltaic Solar Energy Conference and Exhibition PVSEC, Frankfurt/Main, Germany, 24.–28.9.2012

Glunz, S. W.
»High-Efficiency Silicon Solar Cells – Research and Production«, Global Photovoltaic Conference GPVC 2012, Korea-EU International Symposium on Photovoltaics, Korean Photovoltaic Society, Busan, Republic of Korea, 20./21.11.2012

Glunz, S. W.
»Siliciumsolarzellen für Indoor-Anwendungen«, Energy Harvesting – Technologien, Anforderungen, Anwendungen, IMTEK Mikroproduktion, Fellbach, Germany, 28./29.11.2012

Glunz, S. W.; Cuevas, A.[6]
»Bifacial Silicon Solar Cells – An Overview«, bifiPV Workshop, International Solar Energy Research Center, Constance, Germany, 22.–24.4.2012

Gölz, S.
»Smart Energy: Intelligente Netze und die Herausforderung für den Endkunden«, e-motion, Stadtentwicklung und IuK Technologien, Institut für Geographie, Rheinische Friedrich-Wilhelms-Universität Bonn, Friedrichshafen, Germany, 24./25.5.2012

Groos, U.; Keller, S.
»Fuel Cell Systems at Fraunhofer ISE«, GdR PACS and ACTHYF Conference and Meeting, Forschungsverband FCLAB, Belfort, France, 12.6.2012

Henning, H.-M.
»Solar Energy for Electricity, Heating and Cooling. The Technology Park Vucevia as Sustainable Energy Supply Unit«, German-Croatian Energy Conference, Split, Croatia, 21.–23.5.2012

Henning, H.-M.
»Stand der solaren Kühlung – Verfahren, Techniken, Wirtschaftlichkeit«, Workshop Solare Kühlung, PTJ, Berlin, Germany, 6.11.2012

Henning, H.-M.; Schicktanz, M.
»Potenziale und Grenzen der KWKK bei Antrieb mit BHKWS und Fernwärme«, Neue Chancen für Umwelt und Wärmewirtschaft, AGFW, Cologne, Germany, 4.12.2012

Hinsch, A.
»Nanomaterials for Energy Generation: Recent Advances«, Nanosolar, International Workshop on Nanotechnology in Solar and Energy Storage, Amrita Center for Nanosciences and Molecular Medicine, Kochi, Kerala, India, 24.2.2012

Hinsch, A.
»Dye Solar Cells: A Development for Organic Based Photovoltaics at Fraunhofer ISE«, Forum Organische Elektronik, InnovationLab, Heidelberg, Germany, 26.6.2012

Hinsch, A.
»Dye Solar Cells – A Development for Organic Based Photovoltaics«, European Photovoltaics Summer School, Polish Academy of Science, Krakow, Poland, 4.–7.7.2012

Hinsch, A.
»Farbstoffsolarmodule«, Summerschool »Gedruckte Materialien«, KIT, Karlsruhe, Germany, 26.7.2012

Hinsch, A.
»Industrielle Fertigung von Farbstoffsolarzellen«, Branchendialog: Nanotechnologie und Neue Materialen, Bundesministerium für Bildung und Forschung BMBF, Düsseldorf, Germany, 15.11.2012

Hinsch, A.
»Towards Solar Stable Dye Sensitized Electrochemical Solar Cells«, ESCI Workshop on Materials in Extreme Conditions, Aalto, Helsinki, Finland, 20.11.2012

Janz, S.; Goldschmidt, J.; Reber, S.
»PV beyond Si Wafer Technology«, Solar Summit Freiburg, Freiburg, Germany, 18./19.10.2012

Janz, S.; Löper, P.; Schnabel, M.
»Silicon Nanocrystals Produced by Solid Phase Crystallisation for PV Applications«, EMRS Spring Meeting, EMRS, Strasbourg, France, 14.–18.5.2012

Kellenbenz, R.; Klinger, V.; Wekkeli, A.
»Nichtmonotoner Tellureinbau in hochdotiertem $Ga_{0.51}In_{0.49}P$«, 27th DGKK-Workshop »Epitaxie von III-V-Halbleitern«, DGKK, Erlangen, Germany, 6./7.12.2012

Keller, S.; Ammon, G.; Koch, W.; Pistorius, G.; Sadeler, C.
»AMES – Autonomous Energy System for Electricity Supply and Battery Charging under Extended Climatic Conditions«, Fuel Cells 2012 Science & Technology, Berlin, Germany, 11./12.4.2012

Keller, S.; Bhattarai, A.; Gerteisen, D.; Alink, R.; Zamel, N.
»Empirical Methods for Fuel Cell Diagnostic«, D-Code & Genius Annual Workshop, Forschungsverband FCLAB, Belfort, France, 13./14.6.2012

Koch, W.
»Autarkes Mikroenergiesystem für die portable Notfallmedizin«, Öffentliches Statusmeeting für energieautarke Mikrosysteme, VDI/VDE/IT, Berlin, Germany, 6./7.2.2012

INVITED TALKS

Koch, W.; Keller, S.; Ammon, A.; Sadeler, C.; Groos, U.; Pistorius, G.
»AMES-Power: Portable Fuel Cell System«, f-cell and Battery Storage, Stuttgart, Germany, 9.10.2012

Kranzer, D.; Wienhausen, H.; Hensel, A.
»GaN-Leistungstransistoren in hartschaltenden und resonanten Anwendungen«, 41. Kolloquium Halbleiter-Leistungsbauelemente, AG Halbleiter-Bauelemente, Freiburg, Germany, 29./30.10.2012

Lackner, D.; Wekkeli, A.; Dimroth, F.
»Einfluss von Wachstumsbedingungen auf verspannungskompensierte GaInAs/GaAsP Quantentöpfe«, DGKK Workshop »Epitaxie von III-V Halbeleitern«, DGKK, Erlangen, Germany, 6./7.12.2012

Lim, S.[6]; Forster, M.[1]; Zhang, X.[6]; Holtkamp, J.; Schubert, M.; Cuevas, A.[6]; MacDonald, D.
»Photoluminescence Imaging for Net Doping Measurements of Surface Limited Silicon Wafers«, 22nd International Photovoltaic Science and Engineering Conference PVSEC-22 2012, Chinese Renewable Energy Society, Hangzhou, China, 5.–9.11.2012

Lohmüller, E.
»Leistungsprüfung nach erstem Förderjahr«, Stipendiatentag 2012, Reiner Lemoine Stiftung, Berlin, Germany, 27.10.2012

Moldovan, A.; Krieg, K.; Rentsch, J.; Zimmer, M.; Gitte, T.[7]; Fittkau, J.[5]
»Combined Ozone/HF/HCl/Based Cleaning and Adjusted Emitter Etch-Back for Silicon Solar Cells«, 11th UCPSS, IMEC, Ghent, Belgium, 16.–19.9.2012

Philipps, S. P.; Guter, W.
»III-V Mehrfachsolarzellen für die konzentrierende Photovoltaik«, Abschlussveranstaltung Promotionsstipendienprogramm, DBU, Osnabrück, Germany, 9.3.2012

Rau, S.; Fuentes, R.[10]; Smolinka, T.; Weidner, J.[10]
»Nano-Structured Electrodes for PEM Water Electrolysis«, Achema 2012, Dechema, Frankfurt/Main, Germany, 21.6.2012

Rau, S.; Smolinka, T.
»Bewertung aktueller Entwicklungen der Elektrolysetechnologien«, 4. Energiefachtagung, Brandenburgische Technische Universität, Cottbus, Germany, 4.6.2012

Schnabel, M.; Löper, P.; Canino, M.[2]; Allegrezza, M.[2]; Bellettato, M.[2]; Lopez-Vidrier, J.[8]; Hernandez, S.[8]; Janz, S.; Summonte, C.[2]; Garrido, B.[8]; Wilshaw, P.[9]
»Optoelectronic Characterisation of Silicon Nanocrystals Embedded in Silicon Carbide«, EMRS Spring Meeting, EMRS, Strasbourg, France, 14.–19.5.2012

Stalter, O.; Roth, W.
»Leistungselektronik für erneuerbare Energiesysteme – Aktivitäten am Fraunhofer ISE«, Job und Karriere Forum TopJob Corner, Intersolar München/F.A.Z., Munich, Germany, 13.6.2012

Weber, E.
»Forschungsziel Vorsprung: Greentech-Innovationen aus Deutschland«, Financial Times Deutschland – Greentech 2012, Frankfurt/Main, Germany, 16.2.2012

Weber, E.
»Die Herausforderungen der Energiewende an Wissenschaft, Technik und Industrie«, DECHEMA e. V. Diskussionstagung, Frankfurt/Main, Germany, 1.3.2012

Weber, E.
»New Materials and Processes for Photovoltaics Manufacturing«, Society of Vacuum Coaters SVC Tech Conference, Santa Clara, CA, USA, 30.4.2012

Weber, E.
»The Future of Crystalline Photovoltaic Technology«, Institute of Electrical and Electronics Engineers IEEE Photovoltaic Specialists Conference, Austin, TX, USA, 5.6.2012

Weber, E.
»Photovoltaics – a Technology Driver and Pillar of our Sustainable Future Energy«, Intersolar Europe 2012, Munich, Germany, 11.6.2012

Weber, E.
»Energie, Mobilität und Revitalisierung«, Rio +20-Konferenz, Rio de Janeiro, Brazil, 15.6.2012

Weber, E.
»Challenges for the Transformation to a Sustainable Energy System«, EKC2012 EU-Korea Conference on Science and Technology, Berlin, Germany, 26.7.2012

Weber, E.
»The Role of Renewable Energy in the 21st Century«, Internationale Studentenkonferenz Mikrotechnologie, Albert-Ludwigs-Universität, Freiburg, Germany, 11.10.2012

Weber, E.
»Research Policy for Transformation of our Energy System«, Solar Summit Freiburg, Freiburg, Germany, 18.10.2012

Weber, E.
»Challenges of the Global Transformation to a Sustainable Energy System for Technology and Politics«, AvH International Conference of Asian Scholars, Taipei, Taiwan, 12.11.2012

Weber, E.
»The Role of PV in the Future Sustainable Energy System«, Fraunhofer German-Japanese Solar Day, Tokyo, Japan, 13.11.2012

Weber, E.
»Vision for Photovoltaics in the Future Eco-City and Innovative Applications for Green Buildings«, Inno Asia 2012 Conference, Hong Kong, China, 14.11.2012

Weber, E.
»PV Policy and Experiences in Distributed System in Europe«, SEMI PV China 2012, Shunde, Guangdong, China, 15.11.2012

Weber, E.
»The Global Situation and Future of PV«, SEMI PV Japan 2012 – Executive Forum, Tokyo, Japan, 6.12.2012

Wiesenfarth, M.; Helmers, H.; Gamisch, S.; Bett, A. W.
»Aktiv gekühlte Receiver in der Konzentratorphotovoltaik«, 6. Tagung Kühlung in der Elektronik 2012, Haus der Technik, Essen, Germany, 22./23.5.2012

Zamel, N.
»Dependence & Through- and In-Plane Thermal Conductivity of Carbon Paper Diffusion Media on Temperature – Experimental Findings«, 9th Symposium on Fuel Cell and Battery Modeling and Experimental Validation ModVal 9 2012, Paul Scherrer Institut, Sursee, Switzerland, 2.–4.4.2012

Zamel, N.; Bhattarai, A.; Gerteisen, D.
»Effect & Local Perturbation on Electrochemical Impedance Spectroscopy & PEM Fuel Cells – Understanding the Characteristics«, 63rd Annual Meeting of the International Society of Electrochemistry, Prague, Czech Republic, 19.–24.8.2012

Zeidler, R.; Orellana, T.; Riepe, S.; Haunschild, J.; Schumann, M.; Schmid, C.; Haas, F.; Seeber, B.
»Visualisierung zur Analyse des Kristallwachstums in multikristallinem Sillicium«, DGKK-Tagung 2012, DGKK, Freiburg, Germany, 4./5.10.2012

1 *Apollon Solar, Lyon, France*
2 *CNR-Istituto per la Microelettronica e Microsistemi, Bologna, Italy*
3 *Fraunhofer-Center für Silizium-Photovoltaik CSP, Halle, Germany*
4 *Helmholtz-Zentrum Berlin HZB, Berlin, Germany*
5 *MKS Instruments, Inc, ASTex GmbH, Berlin, Germany*
6 *Research School of Engineering Australian National University, Canberra, ACT Australia*
7 *Singulus Stangl Solar GmbH, Fürstenfeldbruck, Germany*
8 *Universitat de Barcelona, Barcelona, Spain*
9 *University of Oxford, Oxford, United Kingdom*
10 *University of South Carolina, Columbia, SC, USA*
11 *Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Ulm, Germany*

IMPRINT

Editors

Marion Hopf, Christina Lotz, Karin Schneider (Head)

Press and Public Relations

External Photographers

Aeroportuali SEA Spa, Milano, Italy

Daimler

Deutsches Luft- und Raumfahrtzentrum

Michael Eckmann

Thomas Ernsting

Fraunhofer IBP

Fraunhofer ISE

Manz AG

Matthias Heyde

Peter Hinsel/Archiv DBU

Isomorph

Kramer GmbH

Novatec Solar GmbH

Ansgar Pudenz / Deutscher Zukunftspreis

Andy Ridder

Werner Rütz

Stadtmobil Südbaden AG

Visiotex

Translation from the German

Dr Helen Rose Wilson, Freiburg

Dr Anne Kovach-Hebling, Freiburg

Layout and Printing

www.netsyn.de, Joachim Würger, Freiburg

Editorial Adress

Fraunhofer Institute for
Solar Energy Systems ISE
Press and Public Relations
Heidenhofstrasse 2
79110 Freiburg
Germany
Phone +49 761 4588-5150
Fax +49 761 4588-9342
info@ise.fraunhofer.de
www.ise.fraunhofer.de

For publications orders please send an E-mail.

www.ise.fraunhofer.de/press-and-media/press-releases

CONFERENCES AND TRADE FAIRS 2013

BAU, Munich, Germany, 14.–19.1.2013

PV Rollout, 3rd European American Solar Deployment Conference, Atlanta, GA, USA, 26./27.2.2013

Battery Expo, Tokyo, Japan, 27.2.–1.3.2013

SiliconForest, Falkau, Germany, 3.–6.3.2013

28. Symposium Photovoltaische Solarenergie (OTTI), Kloster Banz, Bad Staffelstein, Germany, 6.–8.3.2013

Energy Storage, International Summit for the Storage of Renewable Energies, Düsseldorf, Germany, 18./19.3.2013

KONGRESS – Forum ElektroMobilität, Berlin, Germany, 19./20.3.2013

SiliconPV, 3rd International Conference on Silicon Photovoltaics, Hameln, Germany, 25.–27.3.2013

HANNOVER MESSE, Hanover, Germany, 8.–12.4.2013

CPV-9, 9th International Conference on Concentrating Photovoltaic Systems, Miyasaki, Japan, 15.–17.4.2013

23. Symposium Thermische Solarenergie (OTTI), Kloster Banz, Bad Staffelstein, Germany, 24.–26.4.2013

PCIM Europe, Nürnberg, 14.–16.5.2013

Workshop "PV-Module Reliability", Chambéry, France, 6./7.6.2013

3rd Symposium Small PV-Applications (OTTI), Ulm, Germany, 17./18.6.2013

39th IEEE Photovoltaic Specialist Conference, Tampa, FL, USA, 16.–21.6.2013

Intersolar Europe, Munich, Germany, 17.–21.6.2013

6. Entwicklerforum Akkutechnologien, Aschaffenburg, Germany, 25.–27.6.2013

The International Flow Battery Forum IFBF, Dublin, Ireland, 26./27.6.2013

Intersolar North America, San Francisco, CA, USA, 8.–11.7.2013

The Battery Show, Novi, Detroit, MI, USA, 17.–19.9.2013

19th SolarPACES Conference, Las Vegas, NV, USA, 17.–20.9.2013

2nd International Conference on Solar Heating and Cooling for Buildings and Industry, Freiburg, Germany, 23.–25.9.2013

Workshop "Polymeric Materials for Solar Thermal Applications", Graz, Austria, 25.9.2013

5th International Conference Solar Air-Conditioning, Bad Krozingen, Germany, 25.–27.9.2013

f-cell Forum and Battery & Storage, Stuttgart, Germany, 30.9.–2.10.2013

28th European Photovoltaic Solar Energy Conference and Exhibition PVSEC, Paris, 30.9.–4.10.2013

eCarTec Munich2012, Munich, Germany, 15.–17.10.2013

Solar Summit Freiburg, Freiburg, Germany, 23.10.2013

PARTICIPATION IN ORGANISATIONS

acatech – Deutsche Akademie der Technikwissenschaften, Member

Alliance for Rural Electrification, Member

Arbeitskreis Energie der Deutschen Physikalischen Gesellschaft, Member

Bavaria California Technology Center (BaCaTec), Board of Trustees

Brennstoffzellen- und Batterie-Allianz Baden-Württemberg (BBA-BW), Member and Executive Committee

Bundesverband Energiespeicher (BVES), Member and President

Bundesverband Kraft-Wärme-Kopplung (B.KWK), Member

Bundesverband Solarwirtschaft (BSW)
- *Arbeitskreis "Ländliche Elektrifizierung", Member*
- *Fachgruppe "Netzfragen", Member*

CAN in Automation (CiA), Member

CPV-Consortium, Board of Directors, Member

Dechema
- *Temporärer Arbeitskreis MOF, Member*
- *Temporärer Arbeitskreis Thermische Energiespeicherung, Member*

Desertec Industrial Initiative (Dii), Associate Partner

Deutsche Gesellschaft für Sonnenenergie e. V. (DGS), Member

Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN and VDE (DKE)
- *Ad-hoc-Arbeitskreis "Blitz- und Überspannungsschutz für Photovoltaik-Anlagen"*
- *Arbeitsgruppe "Portable Fuel Cell Systems"*
- *Arbeitskreis 221 "Errichtung von Photovoltaik-Anlagen nach DIN VDE 0100-712"*
- *Arbeitskreis Brandschutz VDE-AR-E 2100-712 "Anforderungen zur Freischaltung im DC-Bereich einer PV-Anlage"*
- *Komitee 373 "Photovoltaische Solarenergiesysteme"*
- *Komitee 374 "Solarthermische Anlagen zur Stromerzeugung"*
- *Komitee 384 "Brennstoffzellen"*

Deutsche Meerwasserentsalzung e. V. (DME), Member

Deutscher Kalibrierdienst DKD
- *Fachausschuss Hochfrequenz und Optik, Member*

Deutscher Kälte- und Klimatechnischer Verein e. V. (DKV), Member

Deutscher Wasserstoff- und Brennstoffzellen-Verband e. V. (DWV), Member

Deutsches Institut für Normung e. V. (DIN)
- *Fachnormenausschuss Heiz- und Raumlufttechnik (NHRS AA1.56) "Solaranlagen", Member*
- *Fachnormenausschuss Lichttechnik (FNL 6) "Innenraumbeleuchtung mit Tageslicht", Member*

Energy Efficient Building Association (EEBA), Member

Erfahrungsaustauschkreis der Prüfstellen Thermischer Solaranlagen und ihrer Bauteile EKTSuB des DIN, Vice-Chairman

EU PV Technology Platform
- *WG3 "Science, Technology & Applications", Member*
- *WG4 "Developing Countries", Member*

Europäisches Komitee für Normung (CEN)
- *TC33/WG3/TG5 "Thermal and Visual Comfort", Member*
- *TC129/WG9 "Light and Energy Transmission, Thermal Insulation", Member*
- *TC169/WG11 "Daylighting in Buildings", Member*
- *TC312/WG1/WG2/WG3 "Solar Collectors"/" Factory Made Systems"/"Thermal Solar Systems and Components; Custom Built Systems", Member*

European Academy, Institute for Renewable Energy (Bolzano/Italy), Member des Scientific Board

European Center for Power Electronics e. V. (ECPE), Member

European Committee for Electrotechnical Standardization (CENELEC)
- *TC82/WG 1 "Wafers, Cells and Modules" – NWIP "BIPV", Chair and Member*
- *Workshop 5 "Flow Batteries – Requirements and Test Methods", Member*

PARTICIPATION IN ORGANISATIONS

European H2IFC Technology Platform, Member

European Photovoltaic Industry Association (EPIA), Associate Member

European Power Electronics and Drives Association (EPE), Member

European Renewable Energy Research Centres Agency (EUREC), Member

European Solar Thermal Electricity Association (ESTELA), Member and Scientific Technical Committee, Member

European Solar Thermal Industry Federation (ESTIF), Member

European Technology Platform on Renewable Heating and Cooling (RHC-platform), President

Fachinstitut Gebäude-Klima (FGK), Member

Fachverband Transparente Wärmedämmung e. V., Member

FitLicht – Fördergemeinschaft innovative Tageslichtnutzung, Member

Fördergesellschaft Windenergie und andere Erneuerbare Energien (FGW) e. V.
- *Arbeitskreis "Photovoltaik", Co-operating member*
- *Arbeitskreis "TR3 – Elektrische Eigenschaften und Erzeugungseinheiten"*
- *Arbeitskreis "TR4 – Modellierung und Validierung von Simulationsmodellen"*

ForschungsVerbund Erneuerbare Energien (FVEE), Member

Fraunhofer Battery Alliance, Lenkungskreis, Member

Fraunhofer Building Innovation Alliance, Member

Fraunhofer Energy Alliance, Management and Spokesperson

Fraunhofer Nanotechnology Alliance, Member

Fraunhofer Optic Surfaces Alliance, Member

Fraunhofer Water Systems Alliance (SysWater), Member

Fraunhofer Network Electrochemistry, Member

Fraunhofer Network Energy Storage Systems and Networks , Member

Fraunhofer Network Intelligent Energy Grids, Co-ordination

Fraunhofer Network Sustainability, Member

Fraunhofer Network Wind Energy, Member

Fraunhofer System Research for Electromobility, Member

Fraunhofer Group for Materials and Components – MATERIALS, Member

Freiburger Verein für Arbeits- und Organisationspsychologie (FVAO), Board of Directors

Fuel Cell Europe, Member

German Scholars Organization (GSO), President

Gesellschaft für Umweltsimulation (GUS)
- *Arbeitskreis "Batterieprüfung", Member*

Global Village Energy Partnership (GVEP), Member

International Advisory Committee of EUPVSEC, Member

International Advisory Committee of SIMC, Member

International Commission on Glass
- *TC10 "Optical Properties and Characterization of Glass", Member*

International Commission on Illumination CIE
- *TC3-39 "Discomfort Glare from Daylight in Buildings", Member*
- *TC3-47 "Climate-Based Daylight Modelling", Member*

International Electrotechnical Commission IEC
- *TC82 "Solar Photovoltaic Energy Systems", WG3/WG7, Member*
- *TC105 "Fuel Cell Technologies", WG7/WG11, Member*
- *TC117 "Solar Thermal Electric Plants", Member*

International Energy Agency IEA, Mitarbeit
Energy Conservation Through Energy Storage Programme ECES
- *Annex 24 "Compact Thermal Energy Storage – Material Development for System Integration"*

Heat Pump Programme HPP
- *Annex 32 "Economical Heating and Cooling Systems for Low Energy Houses"*
- *Annex 38 "Solar and Heat Pump Systems – Systems Using Solar Thermal Energy in Combination with Heat Pumps"*

Photovoltaic Power Systems Programme (PVPS)
- *Task 9 "Development of PV Services for Regional Development"*

Solar Heating & Cooling Programme SHC
- *Task 38 "Solar Air-Conditioning and Refrigeration"*
- *Task 39 "Polymeric Materials for Solar Thermal Applications"*
- *Task 43 "Solar Rating and Certification Procedure – Advanced Solar Thermal Testing and Characterization for Certification of Collectors and Systems"*
- *Task 44 "Solar and Heat Pump Systems – Systems Using Solar Thermal Energy in Combination with Heat Pumps"*
- *Task 47 "Renovation of Non-Residential Buildings towards Sustainable Standards"*
- *Task 48 "Quality Assurance and Support Measures for Solar Cooling"*
- *Task 49 "Solar Process Heat for Production and Advanced Applications"*

International Programme Committee of GADEST, Member

International Science Panel on Renewable Energies (ISPRE), Secretariat

International Standardization Organization ISO
- *TC180 Solar Energy, WG2/WG5, Member*

Intersolar North America, Programme Commitee, Chair

Kompetenzfeld Photovoltaik NRW, Member

Kompetenznetzwerk Brennstoffzelle NRW, Member

Leibniz-Institut für Kristallzüchtung IKZ, Advisory Board

Lichttechnische Gesellschaft, Member

Mikrosystemtechnik Baden-Württemberg (MST-BW), Advisory Board

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

Photonics Baden-Württemberg, Member

Scientific Commission to the ENI Science and Technology Award, Member

Solar Keymark Network, Member

Solar Power and Chemical Energy Systems SOLARPACES
- *Task I "Solar Thermal Electric Systems"*
- *Task III "Solar Technology and Advanced Applications"*

SEMI International, Board of Directors, Member

SEMI Standards, Photovoltaic Equipment Interface Specification Task Force (PV-EIS), Member

Solar Energy Research Institute of Singapore (SERIS), Beirat

Stiftung Solarenergie, Advisory Board

Symposium Photovoltaische Solarenergie, OTTI Technologie-Kolleg, Scientific Advisory Board

Symposium PV Hybrid und Minigrid, OTTI Technologie-Kolleg, Scientific Advisory Board

Symposium Small PV Applications, OTTI Technologie-Kolleg, Scientific Advisory Board

Symposium Thermische Solarenergie, OTTI Technologie-Kolleg, Scientific Advisory Board

User Forum "ThinFilmPhotovoltaics", Scientific Advisory Board

VDE Forum Netztechnik/Netzbetrieb (VDE-FNN)
- *Projektgruppe "Blindleistung", Member*

TRADE FAIRS

VDI-Gesellschaft Energie und Umwelt (VDI-GEU)
- *Fachausschuss Regenerative Energien (FARE), Member*

VDI-Gesellschaft Technische Gebäudeausrüstung (VDI-TGA)
- *Richtlinienausschuss 4706 "Kriterien für das Innenraumklima"*
- *Richtlinienausschuss 4650, Blatt 1 und Blatt 2 "Wärmepumpen"*
- *Richtlinienausschuss 4645, "Planung und Dimensionierung von Wärmepumpen von Heizungsanlagen mit Wärmepumpen in Ein- und Mehrfamilienhäusern"*
- *Richtlinienausschuss 2164 "Latentspeichersysteme"*
- *Richtlinienausschuss 6018 "Kälteversorgung in der TGA – Planung, Bau, Abnahmeprüfung, Betrieb, energetische Bewertung"*

VDMA – The German Engineering Federation
- *Arbeitskreis 24247 "Energie-Effizienz Kälteanlagen"*
- *Productronics Association, Member*
- *Deutsches Flachdisplay-Forum (DFF), Member*
- *Organic Electronics Association (OE-A), Member*

Verein Forum Elektromobilität, Scientific Committee

Battery Expo
Tokyo, Japan, 29.2.–2.3.2012

27. Symposium Photovoltaische Solarenergie (OTTI)
Kloster Banz, Bad Staffelstein, Germany, 29.2.–2.3.2012

Energy Storage
International Summit for the Storage of Renewable Energies
Düsseldorf, Germany, 13./14.3.2012

HANNOVER MESSE
Hanover, Germany, 23.–27.4.2012

6th European Conference on PV-Hybrids and Mini-Grids
Chambéry, France, 26.–27.4.2012

22. Symposium Thermische Solarenergie (OTTI)
Kloster Banz, Bad Staffelstein, Germany, 9.–11.5.2012

SNEC – 6th International Photovoltaic Power Generation Conference & Exhibition
Shanghai, China, 16.–18.5.2012

Intersolar Europe / Special Exhibit PV Energy World
Munich, Germany, 13.–15.6.2012

Intersolar North America
San Francisco, CA, USA, 10.–12.7.2012

CLEAN TECH MEDIA AWARD
Berlin, Germany, 7.9.2012

27th European Photovoltaic Solar Energy Conference and Exhibition PVSEC
Frankfurt, Germany, 24.–28.9.2012

f-cell Forum and Trade Fair Battery & Storage
Stuttgart, Germany, 8.–10.10.2012

glasstec, special show "glass technology live"
Düsseldorf, Germany, 23.–26.10.2012

2. badenova Zukunftsforum
Konzerthaus Freiburg, Freiburg, Germany, 8.11.2012

PUBLICATIONS

Aßmus, M.; Nold, S.; Rein, S.; Hofmann, M.; Rentsch, J.; Preu, R.
"Performance Requirements of Crack Detection Systems in Silicon Solar Production", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Bartsch, J.; Mondon, A.; Kamp, M.; Kraft, A.; Wendling, M.; Wehkamp, N.; Jawaid, M.; Lorenz, A.; Clement, F.; Schetter, C.; Glatthaar, M.; Glunz, S.
"Progress with Multi-Step Metallization Processes Featuring Copper as Conducting Layer at Fraunhofer ISE", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012,

Beck, M.[83]; Bopp, G.; Goetzberger, A.; Obergfell, T.; Reise, C.; Schindele, S.
"Combining PV and Food Crops to Agrophotovoltaic - Optimization of Orientation and Harvest", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Benick, J.; Müller, R.; Bateman, N.[2]; Hermle, M.
"Fully Implanted n-Type Pert Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Benoit, P.; Fey, S.; Rohbogner, G.; Kreifels, N.
"Different Approaches for Communication Systems in Large-Scale PV and CPV Installations", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Benoit, P.; Rohbogner, G.; Fey, S.; Kohrs, R.; Wittwer, C.
"Modellierung umd Simulation von Kommunikationsnetzen für Smart Grid Anwendungen", in: Proceedings, Smart Grid – Intelligente Energieversorgung der Zukunft 2012, Stuttgart, Germany, 5./6.11.2012

Bett, A. W.
"Konzentratortechnologie und III-V-basierende Solarzellen", in: Proceedings, Physikkolloquium 2012, Ilmenau, Germany, 26.6.2012

Bett, A. W.
"Concentrator Photovoltaic: An Overview", in: Proceedings, Workshop on CPV 2012, Tianjin, China, 9.11.2012, CD-ROM

Bett, A.; Wiesenfarth, M.; Philipps, S.
"Concentrating PV: Status and Perspectives", in: Proceedings, Solar Summit 2012, Freiburg, Germany, 18./19.10.2012

Bläsi, B.; Hauser, H.; Wolf, A. J.
"Photon Management Structures for Solar Cells", in: SPIE Newsroom, 2012, (online available: 10.1117/2.1201205.004241)

Bläsi, B.; Rüdiger, M.; Mellor, A.[53]; Peters, M.[81]
"Modeling of Photonic Structures for Solar Cell Applications – Aspects from Wafer Based Technology", in: Proceedings, International Workshop of Thin Film Solar Cells 2012, Oldenburg, Germany, 7./8.2.2012

Bopp, G.; Merkle, M.; Schwunk, S.; Smolinka, T.
"Welche und wie viele Speicher braucht eine regenerative Stromversorgung", in: Proceedings, 27. Symposium Photovoltaische Solarenergie 2012, Bad Staffelstein, Germany, 29.2.-2.3.2012

Brand, A. A.; Knorz, A.; Zeidler, R.; Nekarda, J.; Preu, R.
"Nanosecond Laser Annealing to Decrease the Damage of Picosecond Laser Ablation of Anti-Reflection Layers on Textured Silicon Surfaces", in: Proceedings, SPIE Optics and Photonics 2012, San Diego, CA, USA, 12.-16.8.2012

Braungardt, S.; Schultz, N.; Langner, R.; Oltersdorf, T.
"Tree-Shaped Two-Phase Fluid Distributor for Microchannel Heat Exchangers Used as Evaporator", in: Proceedings, 3rd IIR Workshop on Refrigerant Charge Reduction 2012, Valencia, Spain, 25./26.10.2012, CD-ROM

Broisch, J.; Rein, S.; Schmidt, J.; Fertig, F.; Soiland, A.-K.[26]; Odden, J. O.[26]
"Lowly-Doped Compensated Solar-Grade CZ-Silicon for High Efficiency Solar Cell Processes", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Burhenne, L.; Rochlitz, L.; Lintner, C.; Aicher, T.
"BioSyn Biomass Gasification Process for the Production of a Tar-free Synthesis Gas", in: Proceedings, 20th European Biomass Conference & Exhibition 2012, Milano, Italy, 18.-22.6.2012

Burhenne, S.
"Toward a General Methodology for Uncertainty Quantification and Sensitivity Analysis for Building Performance Simulation", in: Proceedings, ECBS Workshop 2012, Vienna, Austria, 23.-25.4.2012

Burhenne, S.; Herkel, S.
"Methodik zur Unsicherheitsbewertung und Sensitivitätsanalyse für thermische Gebäudesimulationen", in: Proceedings, BauSIM 2012, Berlin, Germany, 26.-28.9.2012, CD-ROM

Burhenne, S.; Pazold, M.[32]; Radon, J.[96]; Herkel, S.; Antretter, F.[32]
"Integration of Modelica Models into an Existing Simulation Software Using FMI for Co-Simulation", in: Proceedings, 9th International Modelica Conference 2012, Munich, Germany, 3.-5.9.2012, CD-ROM

Cristóbal, A.[53]; Martí, A.[53]; Sala, G.[53]; Bett, A.; Ekins-Daukes, N.[41]; Roca, F.[68]; Luque-Heredia, I.[10]; Warmuth, W.[74]; Merten, J.[47]; Okada, Y.[90]; Hishikawa, Y.[69]; Hishikawa, Y.[69]; Takamoto, T.[78]; Araki, K.[15]; Fukuyama, A.[89]; Kuze, N.[3]; Kita, T.[88]; Kotagiri, A.[84]; Yamaguchi, M.[91]; Luque, A.[53]
"NGCPV: A New Generation of Concentrator Photovoltaic Cells, Modules and Systems", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Dannenberg, T.; Zimmer, M.; Rentsch, J.
"Fully Automated Concentration Control of the Acidic Texturisation Process", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Demant, M.; Greulich, J.; Rein, S.; Haunschild, J.; Glatthaar, M.
"Modelling of Physically Relevant Features in Photoluminescence Images", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Dimroth, F.
"High Efficiency Multi-Junction Solar Cell Technologies", in: Proceedings, Konkuk University, Fraunhofer ISE Project R&BD Program 2012, Seoul, Republic of Korea, 25.5.2012

Dimroth, F.; Roesener, T.; Klinger, V.; Bett, A. W.; Siefer, G.; Fuß-Kailuweit, P.; Lackner, D.; Oliva, E.
"Material Science for High-Efficiency III-V Solar Cells", in: Proceedings, EMRS Spring Meeting 2012, Strasbourg, France, 14.-18.5.2012

Dimroth, F.; Roesener, T.; Klinger, V.; Essig, S.; Siefer, G.; Fuß-Kailuweit, P.; Lackner, D.; Oliva, E.; Bett, A. W.
"Next Generation Multi-Junction Solar Cells for Concentrator Photovoltaic Applications", in: Proceedings, 16th International Conference on Metal Organic Vapor Phase Epitaxy ICMOVPE 2012, Busan, Republic of Korea, 20.-25.5.2012

Dirnberger, D.; Müller, B.; Kräling, U.; Dittmann, S.
"Uncertanities of Laboratory Measurements for Energy Rating", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012, pp. 3294-3301

Dötter, G.; Burger, B.; Rogalla, S.; Schönberger, S.
"Power Quality und dynamische Netzstützung: Entsprechen die Mittelspannungsrichtlinien den Eigenschaften?", in: Proceedings, 27. Symposium Photovoltaische Solarenergie 2012, Bad Staffelstein, Germany, 29.2-2.3.2012, CD-ROM

Drews, A.; Clement, F.; Spribille, A.; Thaidigsmann, B.; Linse, M.; Gutscher, S.; Werner, S.; Reitenbach, V.; Ould Chighali, E.; Wolf, A.; Zimmer, M.; Zimmer, M.; Nekarda, J.; Haedrich, I.; Tranitz, M.; Eitner, U.; Wirth, H.; Wilson, H. R.; Biro, D.; Preu, R.
"HIP-MWT Solar Cells – Pilot-Line Cell Processing and Module Integration", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Driesse, A.; Dirnberger, D.; Reise, C.; Reich, N.
"Spectrally Selective Sensors for PV System Performance Monitoring", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012, CD-ROM

Drießen, M.; Janz, S.; Reber, S.
"Epitaxial Wafer Equivalent Solar Cells with Overgrown SiO_2 Reflector", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Dupeyrat, P.[25]; Stefan, F.; Kwiatkowski, G.[25]; Baranzini, M.[25]; Schumann, M.[25]
"Performances and Yield Assessment of Glazed Photovoltaic-Thermal Collectors", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012, CD-ROM

Eitner, U.; Geipel, T.; Holtschke, S.-N.; Tranitz, M.
"Characterization of Electrically Conductive Adhesives", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Eltermann, F.; Röder, K.; Wiesenfarth, M.; Wilde, J.; Bett, A. W.
"Degradation Study on Optical Materials for Concentrator Photovoltaics", in: Proceedings, CPV-8 2012, Toledo, Spain, 14.-16.4.2012

Erban, C.
"Merely U And g Will Not Be Enough", in: Proceedings, Engineered Transparency, Düsseldorf, Germany, 25./26.10.2012, CD-ROM

Essig, S.; Derendorf, K.; Oliva, E.; Wekkeli, A.; Roesener, T.; Benick, J.; Hermele, M.; Siefer, G.; Bett, A. W.; Dimroth, F.
"Development of GaInP/GaAs/Si Solar Cells Using Surface Activated Wafer Bonding", in: Proceedings, ECS PRiME 2012, Honolulu, USA, 7.-12.10.2012

Fahr, S.; Kramer, K.; Mehnert, S.; Hess, S.
"SolarKeymark Certification for Concentrating Collectors – Comparing the Quasi-Dynamic and the Steady-State Method of EN 12975-2:206-A1:2010", in: Proceedings, 18. SolarPaces Conference 2012, Marrakesh, Morocco, 11.-14.9.2012, CD-ROM

Fath, K.[57]; Wilson, H. R.; Mende, S.; Kuhn, T.; Stengel, J.[57]; Schultmann, F.[57]
"Impact of Semitransparent Building-Integrated Photovoltaics on Building Life-Cycle Cost", in: Proceedings, 3rd International Association for Life-Cycle Civil Engineering 2012, Vienna, Austria, 3.-6.10.2012, CD-ROM

Fellmeth, T.; Greulich, J.; Clement, F.; Biro, D.
"Modelling of Silicon Solar Cells by Using an Extended Two-Diode-Modell Approach", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Fertig, F.; Krauß, K.; Geisrmeyer, I.; Broisch, J.; Höffler, H.; Odden, J. O.[26]; Soiland, A. K.[26]; Rein, S.
"Fully Solderable Large-Area Screen-Printed Al-BSF p-Type MC-SI Solar Cells from 100% Solar Grade Feedstock Yielding > 17 %: Challenges and Potential on Cell and Module Level", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Fey, S.; Benoit, P.; Rohbogner, G.; Christ, A. H.
"Device-to-Device Communication for Smart Grid Devices", in: Proceedings, PES Innovative Smart Grid Technologies (ISGT) 2012, Berlin, Germany, 14.-17.10.2012, CD-ROM

Fischer, S.; Steinkemper, H.; Krämer, K.[17]; Goldschmidt, J.
"Concepts to Enhance the Efficiency of Upconversion for Solar Application", in: Proceedings, SPIE Photonics Europe 2012, Brussels, Belgium, 16.-19.4.2012

Flarup Jensen, K.; Veurman, W.; Brandt, H.; Bialecka, K.; Sarker, S.[16]; Rahmanr, M. M.[16]; Im, C.[58]; Hinsch, A.; Lee, J.-J.[58]
"Photospectroscopy of I3-Species in Dye Solar Cells (DSC) as a Test for the Sealing and Diffusion Barrier Properties of Glass Frit", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Fleissner, D.; Gölz, S.; Winter, T.
"Modellierung der Eigennutzungsquote durch gemeinschaftliche Nutzung von PV-Strom", in: Proceedings, 27. Symposium Photovoltaische Solarenergie 2012, Bad Staffelstein, Germany, 29.2.-2.3.2012, CD-ROM

Fleissner, D.; Gölz, S.; Winter, T.
"Different Houshold Load Profiles as a Means to Increase Direct Electricity Consumption from PV-Systems", in: Proceedings, 5th International Conference on Integration of Renewable and Distributed Resources 2012, Berlin, Germany, 4.-6.12.2012, CD-ROM

Fluri, T.; Lude, S.; Lam, J.; Morin, G.[71]; Paul, C.[71]; Platzer, W.
"Optimization of Live Steam Properties for a Linear Fresnel Power Plant", in: Proceedings, Solar Paces 2012, Marrakesh, Morocco, 11.-14.9.2012, CD-ROM

Frank, J.; Rüdiger, M.; Fischer, S.; Goldschmidt, J. C.; Hermle, M.
"Optical Simulation of Bifacial Solar Cells", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, pp. 300-35
(online available: http://dx.doi.org/10.1016/j.egypro.2012.7.67)

Füldner, G.; Frazzica, A.[14]; Sapienza, A.[14]; Freni, A.[14]; Schnabel, L.
"Adsorption Kinetics Measurements of Adsorbent Coatings for the Use in Adsorption Chillers and Heat Pumps", in: Proceedings, Heat Powered Cycles 2012, Alkmaar, The Netherlands, 10.-12.9.2012, CD-ROM

Füldner, G.; Laurenz, E.; Schwamberger, V.[57]; Schmidt, F. P.[57]; Schnabel, L.
"Simulation of Adsorption Cycles in Adsorption Heat Pumps: Detailed Heat and Mass Transfer Compared to Lumped Parameter Modelling", in: Proceedings, Heat Powered Cycles Conference 2012, Alkmaar, The Netherlands, 10.-12.9.2012, CD-ROM

Geimer, K.; Kramer, K.; Rehfeldt, M.
"Mechanical Load Tests For Solar Thermal Collectors", in: Proceedings, Eurosun 2012, Rijeka, Croatia, 18.-20.9.2012

Geisemeyer, I.; Fertig, F.; Warta, W.; Rein, S.; Schubert, M. C.
"Impact of Reverse Breakdown in Shaded Silicon Solar Cells on Module Level: Simulation and Experiment", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Gerstmaier, T.[80]; van Riesen, S.[80]; Schulz-Gericke, J.[80]; Gombert, A.[80]; Behrendt, T.[12]; Lorenz, E.[12]; Steiner, M.; Schachtner, M.; Siefer, G.; Bett, A. W.
"Spectrally Resolved DNI Measurements: Results of a Field Comparison of Spectrometers, Isotype Cells and the SOLIS Satellite Model", in: Proceedings, CPV-8 2012, Toledo, Spain, 16.-18.4.2012

Gerteisen, D.; Markötter, H.[38]; Alink, R.; Tötzke, C.[38]; Dittmann, K.[38]; Krüger, P.[99]; Haußmann, J.[99]; Klages, M.[99]; Scholta, J.[99]; Riesemeier, H.[11]; Gerteisen, D.; Banhart, J.[38]; Manke, I.[38]
"Investigation of Fuel Cell Materials and Liquid Water Transport by Means of Synchrotron Imaging", in: ECS Transactions, 221st ECS Meeting 2012, Seattle, WA, USA, 6.-10.5.2012, pp. 322

Glunz, S. W.
"High-Efficiency Cells", in: Proceedings, 22nd Workshop on Crystalline Silicon Solar Cells & Modules 2012, Vail, CO, USA, 22.-25.7.2012, pp. 1

Gölz, S.; Götz, K.[45]; Klobasa, M.[37]; Schleich, J.[37]; Sunderer, G.[45]
"Führt Verbrauchsfeedback zu Stromeinsparungen? – Schlussfolgerungen aus dem Projekt ›Intelliekon‹", in: et Energiewirtschaftliche Tagesfragen, 8 (2012), pp. 32-35

Graf, W.
"Coating for Vacuum Tubes", in: Proceedings, 3rd SMEThermal 2012, Berlin, Germany, 7.2.2012

Greulich, J.; Wöhrle, N.; Glatthaar, M.; Rein, S.
"Optical Modeling of the Rear Surface Roughness of Passivated Silicon Solar Cells", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Groß, F.; Koschikowski, J.; Düver, D.; Martin, R.; Rebecca, S.; Winter, D.
"Membrane Distillation: Basic Considerations and Pilot Applications", in: Proceedings, Aachner Membran Kolloquium 2012, Aachen, Germany, 7./8.11.2012, CD-ROM

Gschwander, S.; Schossig, P.
"Wärme- und Kältespeicher in Gebäuden – mit neuen Materialien den Energieverbrauch senken", in: Proceedings, Energie Geladen 2012, Freiburg, Germany, 31.10.2012

Gutmann, J.; Posdziech, J.; Peters, M.; Steidl, L.[50]; Zentel, R.[50]; Zappe, H.[19]; Goldschmidt, J.
"Emission of Rhodamine B in PMMA Opals für Luminescent Solar Concentrators", in: Proceedings, Photonics Europe 2012, Brussels, Belgium, 16.-19.4.2012

Hahnel, U. J.; Benoit, P.; Gölz, S.; Kohrs, R.; Spada, H.[43]
"Methoden zur Bestimmung des Nutzereinflusses auf eine intelligente Integration von Elektrofahrzeugen in das zukünftige Energienetz", in: Proceedings, Smart Grid – Intelligente Energieversorgung der Zukunft 2012, Stuttgart, Germany, 5./6.11.2012

Haunschild, J.; Broisch, J.; Reis, I.; Rein, S.
"Cz-Silicon Wafers in Solar Cell Production: Efficiency-Limiting Defects and Material Quality Control", in: PV International, 15 (2012)

Hauser, H.; Mellor, A.[93]; Guttowski, A.; Wellens, C.; Benick, J.; Müller, C.[19]; Hermle, M.; Bläsi, B.
"Diffractive Backside Structures via Nanoimprint Lithography", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Hauser, H.; Michl, B.; Walk, C.; Eisenlohr, J.; Benick, J.; Mellor, A.[93]; Müller, C.[19]; Hermle, M.; Bläsi, B.
"Full-Wafer Roller-Nil Processes for Silicon Solar Cell Texturisation", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Heinz, F.; Warta, W.; Schubert, M. C.
"Optimizing Micro Raman and PL Spectroscopy for Solar Cell Technological Assessment", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, pp. 28-213
(online available: http://dx.doi.org/10.1016/j.egypro.2012.7.53)

Henning, H.-M.
"Solar Systems for Heating and Cooling of Buildings", in: Proceedings, Sustainable Energy ISE Annual Conference 2012, Malta, 21.2.2012, CD-ROM

Henning, H.-M.
"Solar Heating and Air-Conditioning of Buildings", in: Proceedings, 1st International Solar Heating & Cooling Conference 2012, San Francisco, CA, USA, 10.-12.7.2012, CD-ROM

Henning, H.-M.
"Vom Niedrigenergiehaus zum Effizienzhaus Plus: Produktentwicklung und -integration", in: Proceedings, dena-Energieeffizienzkongress 2012, Berlin, Germany, 18./19.9.2012

Henning, H.-M.; Palzer, A.
"100% Renewables for Electricity and Heat – a Holistic Model for a Future German Energy System", in: Proceedings, 7th International Renewable Energy Storage Conference 2012, Berlin, Germany, 12.-14.3.2012, CD-ROM

Hensel, A.; Faulhaber, F.; Kranzer, D.
"Application of Gallium Nitride Transistors in Power Electronics for PV Systems", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Hensel, A.; Wilhelm, C.
"Application of a New 600 V GaN Transistor in Power Electronics for PV Systems", in: Proceedings, 15th EPE-PEMC 2012 ECCE Europe, Novi Sad, Serbia, 4.-6.9.2012

Hermann, M.
"Kollektorkonzepts jenseits des Standes der Technik – Möglichkeiten und Herausforderungen", in: Proceedings, 10. Gleisdorf Solar 2012 2012, Gleisdorf, Austria, 12.-14.9.2012, CD-ROM

Hermann, M.; Steinbach, F.[46]; Witulski, J.[46]; Tekkaya, A. E.[46]
"Erfahrungen und Ergebnisse aus der Entwicklung von Stahlabsorbern", in: Proceedings, 22. Symposium Thermische Solarenergie 2012, Bad Staffelstein, Germany, 9.-11.5.2012, CD-ROM

Herter, B.; Fischer, S.; Bläsi, B.; Goldschmidt, J.
"Effects of Photonic Structures on Upconversion", in: Proceedings, Photonics Europe 2012, Brussels, Belgium, 16.-19.4.2012

Herter, B.; Peters, M.; Janz, S.; Hermle, M.; Goldschmidt, J. C.
"Photonic Structures for a Solar Cell-Upconversion-System", in: Future Photovoltaics, 6 (2012)

Heß, S.; Oliva, A.; Helmke, A.; Stryi-Hipp, G.; Platzer, W.
"Ergebnisse des IEE-Projekts SO-PRO: Auslegung von Solaranlagen für vier ausgewählte industrielle Prozesse", in: Proceedings, 22. Symposium Thermische Solarenergie 2012, Bad Staffelstein, Germany, 9.-11.5.2012, CD-ROM

Höffler, H.; Haunschild, J.; Zeidler, R.; Rein, S.
"Statistical Evaluation of a Luminescence-Based Imaging Method", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Höhn, O.; Peters, M.; Bläsi, B.; Zilk, M.; Ulbrich, C.; Hoffmann, A.
"Combination of Angularly Selective Photonic Structures and Cencentration Solar Cell System", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Höhn, O.; Peters, M.; Hoffmann, A.[29]; Bläsi, B.; Ulbrich, C.[29]; Schwarz, U.[31]
"Optimization of Angularly Selective Photonic Filters for Concentrator Photovoltaic", in: Proceedings, Photonics Europe 2012, Brussels, Belgium, 16.-20.4.2012

Hollinger, R.; Hamperl, S.; Erge, T.; Wille-Haussmann, B.; Wittwer, C.
"Simulating the Optimized Participation of Distributed Controllable Generators at the Spot Market for Electricity Considering Prediction Errors", in: Proceedings, IEEE PES Innovative Smart Grid Technologies ISGT Europe 2012, Berlin, Germany, 14.-17.10.2012, CD-ROM

Hülsmann, P.; Weiß, K.-A.; Köhl, M.; Heck, M.
"Numerische Simulation der Feuchtebelastung von PV-Modulen für unterschiedliche Klimastandorte", in: Proceedings, Jahrestagung der GUS 2012, Stutensee-Blankenloch, Germany, 14.-16.3.2012, CD-ROM

Impera, D.; Bivour, M.; Michl, B.; Schubert, M. C.; Hermle, M.
"Characterization of Silicon Heterojunctions on Multicrystalline Absorbers Using Injection-Dependent Photoluminescence Imaging", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, pp. 280-286
(online available: http://dx.doi.org/10.1016/j.egypro.2012.7.64)

Jäger, U.; Mack, S.; Wufka, C.; Wolf, A.; Biro, D.; Nekarda, J.; Preu, R.
"Selective Emitters in Passivated Emitter and Rear Silicon Solar Cells Enabling 20% on Large Area p-Type Silicon", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Jäger, U.; Wolf, A.; Steinhauser, B.; Benick, J.; Nekarda, J.; Preu, R.
"Laser Doping for High Efficiency Silicon Solar Cells", in: Proceedings, SPIE Optics and Photonics 2012, San Diego, CA, USA, 12.-16.8.2012

Jantsch, M.; Dirnberger, D.; Neuberger, F.
"Optimized Procedures for Representative Samples from PV Module Batches", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012, pp. 3214 - 3218

Janz, S.; Lindekugel, S.; Pavlovic, R.; Schillinger, K.; Rachow, T.; Reber, S.
"High Quality Silicon Films from Halogen Lamp Melting for New Thin-Film Solar Cell and Module Concepts", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Jeurink, J.; von Morzè, N.; Kroely, L.; Hofmann, M.; Rentsch, J.; Preu, R.
"Inline Microwave-Excited Plasma Deposition of Thin Amorphous Silicon Layers", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Kafle, B.; Kühnhold, S.; Beyer, W.[29]; Lindekugel, S.; Saint-Cast, P.; Hofmann, M.; Rentsch, J.
"Thermal Stability Investigations of PECVD AL_2O_3 Films Discussing a Possibility of Improving Surface Passivation by Re-Hydrogenation after High Temperature Processes", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Kalio, A.; Olweya, S.; Leibinger, M.; Glatthaar, M.; Wilde, J.[19]
"Study of Sintering Behavior of Silver Front Side Metallization Pastes", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012

Kaltenbach, T.; Kurth, M. R.; Schmidt, C.; Meier, T.; Köhl, M.; Weiß, K.-A.
"Ageing Tests with Components for Solar Thermal Collectors", in: Proceedings, International Conference Solar Heating and Cooling for Buildings and Industry SHC 2012, San Francisco, CA, USA, 9.-11.7.2012, CD-ROM

Kaltenbach, T.; Schmidt, C.; Weiß, K.-A.; Meier, T.; Heck, M.; Köhl, M.
"Aging Tests for Solar Thermal Collectors and Components Exposed to Outdoor Weathering with Different Climatic Conditions and Accelerated Weathering Tests", in: Proceedings, Gleisdorf Solar 2012, Gleisdorf, Austria, 12.-14.9.2012

Kalz, D.; Burggraf, P.[40]; Sikorski, E.[40]
"Energetische Analyse von Nichtwohngebäuden im Bestand", in: BHKS-Almanach, (2012), pp. 70-73

Kalz, D.; Fischer, M.; Pfafferott, J.[40]; Melcher, M.[21]
"Energetische Sanierung einer Druckerei: Kühlen und Heizen mit Umweltenergie in Kombination mit thermoaktiven Bauteilsystemen", in: EnEV im Bestand, 9 (2012), pp. 14-23

Kalz, D.; May-Ostendorp, P. T.[18]; Henze, G. P.[18]; Rajagopalan, B.[18]; Fischer, M.; Mehnert, J.
"Experimental Investigation of Model Predictive Control-Based Rules for a Radiantly Cooled Office", in: Proceedings, Intelligent Buildings and Advanced Control Techniques, COBEE Conference 2012, Boulder, CO, USA, 8.3.2012, CD-ROM

Kalz, D.; Winiger, S.; Fischer, M.
"Energetische Betriebsanalyse von erdgekoppelten Wärmepumpen für die Wärme- und Kälteversorgung von Nichtwohngebäuden", in: Proceedings, Klimatechnik und Wärmepumpen 2012, Würzburg, Germany, 21.-23.11.2012, CD-ROM

Keding, R.; Rothhardt, P.; Roters, C.; Fallisch, A.; Hohage, S.; Hofmann, M.; Woehl, R.; Borchert, D.; Biro, D.
"Silicon Doping Performed by Different Diffusion Sources Aiming Co-Diffusion", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Kick, C.; Thaidigsmann, B.; Linse, M.; Clement, F.; Wolf, A.; Biro, D.
"Printed Fire-Through Contacts (FTC) – An Alternative Approach for Local Rear Contacting of Passivated Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Kimmerle, A.; Rüdiger, M.; Wolf, A.; Hermle, M.; Biro, D.
"Validation of Analytical Modelling of Locally Contacted Solar Cells by Numerial Simulations", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Koch, L.; Hermann, M.; Bauch, M.
"Investigation of New Integrated Solar Thermal Absorbers by Means of a 2-D Model", in: Proceedings, Eurosun 2012, Rijeka, Croatia, 18.-20.9.2012, CD-ROM

Köhl, M.; Weiß, K.-A.; Saile, S.
"Solarkollektoren aus Polymeren: EU FP27 Projekt SCOOP", in: Proceedings, 22. Symposium Thermische Solarenergie 2012, Bad Staffelstein, Germany, 9.-11.5.2012

Kost, C.; Flath, C.[57]; Möst, D.[85]; Fluri, T.
"CSP Storage Design and Market Value in an Export Case", in: Proceedings, SolarPACES Conference 2012, Marrakesh, Morocco, 11.-14.9.2012, pp. 38-39

Kost, C.; Thomsen, J.; Schlegl, T.
"Market Entrance of PV Industry in Emerging Markets", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012, CD-ROM

Krauß, K.; Fertig, F.; Kohn, N.; Rauer, M.; Woehl, R.; Rein, S.
"Influence of Parasitic Plasma Wrap-Around During Anti-Reflective Coating Deposition on the Formation of an Aluminium Back Surface Field", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Krugl, G.; Wolke, W.; Wagner, F.; Rentsch, J.; Preu, R.
"Sputtered Aluminium Oxide for Rear Side Passivation of p-Type Silicon Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Kühnhold, S.; Kafle, B.; Saint-Cast, P.; Hofmann, M.; Rentsch, J.; Preu, R.
"Impact of Thermal Treatment on PECVD Al_2O_3 Passivation Layers", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Kurth, M. R.; Schuldis, D.; Kaltenbach, T.; Weiß, K.-A.; Köhl, M.
"Untersuchung von Anti-Soiling Beschichtung für die Solarindustrie", in: Proceedings, 22. Symposium Thermische Solarenergie 2012, Bad Staffelstein, Germany, 9.-11.5.2012

Laukamp, H.; Bopp, G.; Grab, R.; Philipp, S.; Schmidt, H.; Reil, F.[92]; Sepanski, A.[92]; Thiem, H.[9]; Vaassen, W.[92]; Häberlin, H.[7]; von Heeckeren, B.[7]
"Sind PV-Anlagen brandgefährlich? – Mythen und Fakten", in: Proceedings, 27. Symposium Photovoltaische Solarenergie 2012, Bad Staffelstein, Germany, 29.2.-2.3.2012, CD-ROM

Lindekugel, S.; Rachow, T.; Janz, S.; Reber, S.
"Intermediate Layer and Back Surface Field Optimisations for the Recrystallised Wafer Equivalent", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Lohmüller, E.; Hendrichs, M.; Thaidigsmann, B.; Eitner, U.; Clement, F.; Wolf, A.; Biro, D.; Preu, R.
"Current Status of MWT Silicon Solar Cell and Module Technology", in: PV International, 17 (2012)

Lohmüller, E.; Thaidigsmann, B.; Werner, S.; Clement, F.; Wolf, A.; Biro, D.; Preu, R.
"Evaluation of Via Pastes for p- and n-Type Metal Wrap through (MWT) Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Löper, P.; Canino, M.[13]; López-Vidrier, J.[65]; Schnabel, M.; Witzky, A.; Belletato, M.[13]; Allegrezza, M.[13]; Hiller, D.[19]; Hartel, A.[19]; Gutsch, S.[19]; Hernández, S.[65]; Hernández, S.[65]; Guerra, R.[94]; Ossicini, S.[94]; Garrido, B.[65]; Janz, S.; Zacharias, M.[19]
"Silicon Quantum Dots in Photovoltaic Devices: Device Fabrication, Characterization and Comparison of Materials", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Löper, P.; Pysch, D.[76]; Richter, A.; Hermle, M.; Janz, S.; Zacharias, M.[19]; Glunz, S. W.
"Analysis of the Temperature Dependence of the Open-Circuit Voltage", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, pp. 135-142
(online available: http://dx.doi.org/10.1016/j.egypro.2012.7.41)

Löper, P.; Witzky, A.; Hartel, A.[19]; Gutsch, S.[19]; Hiller, D.[19] ; Goldschmidt, J. C.; Janz, S.; Glunz, S. W.; Zacharias, M.[19]
"Photovoltaic Properties of Silicon Quantum Dots in Dielectric Matrices", in: Proceedings, SPIE Photonics OPTO 2012, San Francisco, CA, USA, 21.-26.1.2012

Mack, S.; Wolf, A.; Werner, S.; Dubè, C. E.[2]; Bhosle, V.[2]; Biro, D.
"Synergistic Use of Ion Implant Annealing Processes for Thermal Oxide Rear Surface Passivation", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Martínez, M.[54]; Rubio, F.[54]; Sala, G.[53]; Pachón, D.[53]; Bett, A. W.; Siefer, G.; Vetter, M.; Schies, A.; Wachtel, J.; Gombert, A.[80]; Wüllner, J.[80]; Wüllner, J.[80]; Díaz, V.[55]; Vázquez, M. A.[55]; Abulfotuh, F.[70]; Fetyan, K.[70]; el Moussaoui, A.[72]; Mansouri, S.[72]; Loudiyi, K.[4]; Darhmaoui, H.[4], Mrabti, T.[4]
"CPV Plants Data Analysis. ISFOC and NACIR Projects Results", in: Proceedings, CPV-8 2012, Toledo, Spain, 16.-19.4.2012

Maurer, C.; Pflug, T.; Di Lauro, P.; Hafner, J.[79]; Knez, F.[79] ; Jordan, S.[79]; Hermann, M.; Kuhn, T. E.
"SHC with Transparent Façade Collectors in a Demo Building", in: Energy Procedia, International Conference Solar Heating and Cooling for Buildings and Industry SHC 2012, San Francisco, CA, USA, 9.-11.7.2012, CD-ROM

Max, J.; Philipp, S.; Schwunk, S.
"Battery Management in Hybrid Battery Systems up to 1200 V", in: Proceedings, IRES 2012, Berlin, Germany, 12.-14.11.2012, CD-ROM

Michl, B.; Schön, J.; Schindler, F.; Warta, W.; Schubert, M.
"Reducing the Impact of Iron on Carrier Lifetimes in Multicrystalline Silicon Wafers by Optimized Diffusion Temperature Profiles", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Mierau, M.; Kohrs, R.; Wittwer, C.
"A Distributed Approach to the Integration of Electric Vehicles into Future Smart Grids", in: Proceedings, Innovative Smart Grid Technology 2012, Berlin, Germany, 14.-17.10.2012

Milenkovic, N.; Rachow, T.; Heinz, F.; Reber, S.; Janz, S.
"Simulation and Characterization of Epitaxial n- and p-Type Emitters on Silicon Wafer Solar Cells", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Morgenstern, A.
"Kühlen mit der Sonne – Technik die sich bewährt hat", in: Proceedings, Energie Geladen 2012, Freiburg, Germany, 31.10.2012

Morrison, D.[67]; Devenport, S.[67]; Heasman, K.[67]; Schmiga, C.; Glatthaar, M.
"Development of Rear Passivated Laser Grooved Buried Contact (LGBC) Laser Fired Contact (LFC) Silicon Solar Cells Using Thin Wafers", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Munz, G.; Bongs, C.; Morgenstern, A.; Lehmann, S.; Kummer, H.; Henning, H.-M.; Henninger, S. K.
"A Novel Dehumidification and Cooling System Driven by an Evacuated Tube Solar Air Collector", in: Proceedings, Heat Powered Cycles 2012, Alkmaar, The Netherlands, 10.-12.9.2012, CD-ROM

Nesswetter, H.[23]; Lugli, P.[49]; Bett, A. W.; Zimmermann, C. G.[23]
"Electro- and Photoluminescence Characterization of Multi-Junction Solar Cells", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012

Nievendick, J.; Stocker, M.; Specht, J.; Glover, W.; Zimmer, M.; Rentsch, J.
"Application of the Inkjet-Honeycomb-Texture in Silicon Solar Cell Production", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Nold, S.; Voigt, N.; Friedich, L.; Weber, D.; Hädrich, I.; Mittag, M.; Wirth, H.; Thaidigsmann, B.; Hofmann, M.; Rentsch, J.; Preu, R.
"Cost Modelling of Silicon Solar Cell Production Innovation along the PV Value Chain", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Palzer, A.; Westner, G.[22]; Madlener, R.[48]
"Evaluation of Different Hedging Strategies for Commodity Price Risks of Industrial Cogeneration Plants", in: Proceedings, ENERDAY 2012, Dresden, Germany, 28.4.2012

Palzer, A.; Westner, G.[22]; Madlener, R.[48]
"Evaluation of Different Hedging Strategies for Commodity Price Risks of Industrial Cogeneration Plants", in: FCN Working Paper, 2 (2012)

Pavlovic, R.; Janz, S.; Janz, S.
"Integrated Interconnection of Crystalline Silicon Thin Film Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Peike, C.; Kaltenbach, T.; Weiß, K.-A.; Köhl, M.
"Indoor vs. Outdoor Aging-Polymer Degradation in PV Modules Investigated by Raman Spectroscopy", in: Proceedings, SPIE Optics and Photonics 2012, San Diego, CA, USA, 12.-16.8.2012

Philipps, S. P.
"III-V Mehrfachsolarzellen für die konzentrierende Photovoltaik", in: Proceedings, Woche der Umwelt 2012, Berlin, Germany, 5./6.6.2012

Philipps, S.; Bett, A.
"High-Efficiency Solar Cell Architectures Based on III-V Semiconductor Materials", in: Proceedings, Korea-EU International Symposium on Photovoltaics 2012, Busan, Republic of Korea, 21.11.2012, CD-ROM

Philipps, S.; Bett, A.; Glunz, S.
"Development of Advanced PV Technologies in Germany", in: Proceedings, 2nd German-Japanese Solar Day 2012, Tokyo, Japan, 13.11.2012

Piekarczyk, A.; Peike, C.; Kaltenbach, T.; Weiß, K.-A.
"Charakterisierung und Qualifizierung von Kunststoffmaterialien für Solarthermische Anwendungen", in: Proceedings, Gleisdorf Solar 2012, Gleisdorf, Austria, 12.-14.9.2012

Pospischil, M.; Specht, J.; Gentischer, H.; König, M.[39]; Hoerteis, M.[39]; Mohr, C.[39]; Zengerle, R.[19]; Clement, F.; Biro, D.
"Correlations between Finger Geometry and Dispensing Paste Rheology", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Rachow, T.; Ledinsky, M.; Fejfar, A.; Janz, S.; Reber, S.
"µc-Si Solar Cells by Direct Deposition with APCVD", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Rachow, T.; Milenkovic, N.
"Formation of High Efficiency Epitaxial Emitters by APCVD", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Réhault, N.; Kalz, D.
"Ongoing Commissioning of a High Efficiency Supermarket with a Ground Coupled Carbon Dioxide Refrigeration Plant", in: Proceedings, International Conference for Enhanced Building Operations, Manchester, Great Britain, 23.-26.10.2012

Reich, N.; Goebel, A.; Dirnberger, D.; Kiefer, K.
"System Performance Analysis and Estimation of Degradation Rates Based on 500 Years of Monitoring Date", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012, CD-ROM

Reitenbach, V.; Spitz, M.; Drews, A.; Weiß, M.; Ould Chighali, E.; Thaidigsmann, B.; Lohmüller, E.; Knorz, A.; Clement, F.; Wolf, A.; Biro, D.; Preu, R.
"Process Characterisation of MWT Solar Cells – a new Method to Analyse Via Contacts", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Rentsch, J.; Ackermann, R.; Kästner, G.; Schwab, C.; Zimmer, M.; Preu, R.
"Challenges for Single Chemical Processing", in: PV International, 16 (2012)

Richter, A.; Souren, F. M.[82]; Schuldis, D.; Görtzen, R. M.[82]; Benick, J.; Hermle, M.; Glunz, S. W.
"Thermal Stability of Spatial ALD Deposited Al_2O_3 Capped by PECVD SiN_x for the Passivation of Lowly- and Highly-Doped p-Type Silicon Surfaces", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Richter, A.; Werner, F.[44]; Cuevas, A.77; Schmidt, J.[44]; Glunz, S. W.
"Improved Parameterization of Auger Recombination in Silicon", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, (online available: http://dx.doi.org/10.1016/j.egypro.2012.7.34)

Rochlitz, L.; Burhenne, L.; Lintner, C.; Aicher, T.
"Das BioSyn-Verfahren – Biomassevergasung zur Erzeugung eines teerfreien Synthesegases", in: Proceedings, Fachtagung Konversion von Biomassen 2012, Rotenburg/Fulda, Germany, 19.-21.3.2012, pp. 95-100

Rogalla, S.
"Central Inverters", in: Proceedings, Power Electronics for Photovoltaics 2012, Munich, Germany, 12.6.2012, pp. 183-201

Rogalla, S.
"Three Phase String Inverters", in: Proceedings, Power Electronics for Photovoltaics 2012, Munich, Germany, 12.6.2012, pp. 127-146

Rogalla, S.; Blume, S.; Burger, B.; Reichert, S.; Siedle, C.
"Verbesserter Ansatz zur Bestimmung der Oberschwingungs-emissionen von Zentralwechselrichtern", in: Proceedings, 27. Symposium Photovoltaische Solarenergie 2012, Bad Staffelstein, Germany, 29.2.-2.3.2012, pp. 389-394

Rohbogner, G.; Fey, S.; Hahnel, U.; Benoit, P.; Wille-Haussmann, B.
"What the Term Agent Stands for in the Smart Grid", in: Proceedings, IEEE Federated Conference on Computer Science and Information, Breslau, Poland, 9.-12.9.2012, CD-ROM

Roth, W.; Placha, H.; Reichert, S.; Reiners, F.; Schwunk, S.; Wittwer, C.
"Firmendarstellung für das 27. Symposium Photovoltaische Solar-energie", in: Proceedings, 27. Symposium Photovoltaische Solar-energie 2012, Bad Staffelstein, Germany, 29.2-2.3.2012, CD-ROM

Rothhardt, P.; Stoffels, T.; Keding, R.; Belledin, U.; Wolf, A.; Biro, D.
"Control of Phosphorus Doping Profiles for Co-Diffusion Processes", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Rühle, K.; Glunz, S.; Kasemann, M.[19]
"Towards New Design Rules for Indoor Photovoltaic Cells", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012, pp. 02588-02591

Rühle, K.; Rauer, M.; Kasemann, M.[19]
"Passivation Layers for Indoor Solar Cells", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, pp. 46-411

Ruschenburg, J.; Herkel, S.
"A Comparative Analysis of Market Available Solar Thermal Heat Pump Systems", in: Proceedings, EuroSun 2012, Rijeka, Croatia, 18.-20.9.2012, CD-ROM

Ruschenburg, J.; Palzer, A.; Günther, D.; Miara, M.
"Solare Wärmepumpensysteme in Einfamilienhäusern – Eine modellbasierte Analyse von Feldtestdaten", in: Proceedings, 22. Symposium Thermische Solarenergie 2012, Bad Staffelstein, Germany, 9.-11.5.2012

Sabo, A.; Wille-Haussmann, B.; Wittwer, C.
"Betriebsstrategien für PV-Batteriesysteme im Stromnetz/Operation Strategies for PV Battery Systems in the Electricity Grid", in: Proceedings, Smart Grid – Intelligente Energieversorgung 2012, Stuttgart, Germany, 5./6.11.2012

Saint-Cast, P.; Hofmann, M.; Kühnhold, S.; Kania, D.[8]; Weiss, L.[98]; Heo, Y.-H.[60]; Billot, E.; Olwal, P.[8]; Trogus, D.; Rentsch, J.; Preu, R.
"A Review of PECVD Aluminium Oxide for Surface Passivation", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Saint-Cast, P.; Hofmann, M.; Kühnhold, S.; Nekarda, J.; Preu, R.
"Recombination on Locally Processed Wafer Surfaces", in: Proceedings, 2nd International Conference on Silicon Photo-voltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Scherff, M.[75]; Ballmann, T.[75]; Müller, J. W.[75]; Antonelli, D.[27]; Busto, C.[27]; Grasso, F.[27]; Ferrazza, F.[2]; Tonelli, E.[2]; Baert, K.[73]; Duerinckx, F.[73]; Cacciato, A.[73]; Oswald, W.[63]
"The European Project 20PlμS: 20 Percent Efficiency On Less Than 100 μM Thick Industrially Feasible Crystalline-Si Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Schicktanz, M.
"Influencia de las Fluctuaciones de Temperatura en el Comportami-ento Operativo de los Enfriadores de Adsorción", in: Frio-Calor Aire Acondicionado, 448 (2012), pp. 3-8

Schicktanz, M.; Henning, H.-M.
"Einfluss verschiedener Parameter auf die Vollkosten der thermischen Kälteerzeugung mit Fernwärme", in: Kälteerzeugung aus Wärme, AGFW-Merkblatt FW 301 (2012)

Schillinger, K.; Rachow, T.; Flatten, L.; Janz, S.; Reber, S.
"Investigations on Crystal Quality of Thin Silicon Films Prepared by Zone Melting Recrystallization on Different Intermediate Layers and Cost Effective Substrates", in: Proceedings, 6th International Workshop on c-Si for Solar Cells, Aix-les-Bains, France, 8.-13.10.2012

Schillinger, K.; Rachow, T.; Flatten, L.; Janz, S.; Reber, S.
"Thin Silicon Films Prepared by ZMR on Cost Effective Substrates-Influence of the Intermediate Layer of Crystal Quality",
in: Proceedings, 6th International Workshop on c-Si for Solar Cells 2012, Aix-les-Bains, France, 8.-13.10.2012

Schmiga, C.; Rauer, M.; Rüdiger, M.; Glatthaar, M.; Glunz, S. W.
"Status and Perspectives on n-Type Silicon Solar Cells with Aluminium-Alloyed Rear Emitter", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Schmitt, P.; Kaiser, P.; Savio, C.; Tranitz, M.; Eitner, U.
"Intermetallic Phase Growth and Reliability of Sn-Ag-Soldered Solar Cell Joints", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Schmitt, P.; Tranitz, M.; Anderson, R.20
"Effect of Durability Testing on Solder Joint Adhesion and Failure Mode of Front Side Metallizations", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012, CD-ROM

Schön, J.; Haarahiltunen, A.[1]; Fenning, D.[62]; Bounassisi, T.[62]; Savin, H.[1]; Warta, W.; Schubert, M.
"Modeling the Size Distribution of Iron Precipitates in MC Silicon", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012

Schröer, S.; Bivour, M.; Schön, J.; Hermle, M.; Glunz, S. W.
"Reduction of Absorption Losses and Efficiency Gains by Investigating Amorphous/Crystalline SHJ Rear Emitter Solar Cells",
in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Schubert, M.; Schön, J.; Michl, B.; Abdollahinia, A.; Warta, W.
"Modeling Distribution and Impact of Efficiency Limiting Metallic Impurities in Silicon Solar Cells", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA3.-8.6.2012

Schuldis, D.; Richter, A.; Benick, J.; Hermle, M.
"Influence of Different Post Deposition Treatments on the Passivation Quality and Interface Properties of Thermal ALD Al_2O_3 Capped by PECVD SiN_x", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Schumann, M.; Meyer, S.[30]; Schmid, C.; Haas, F.; Riepe, S.; Cröll, A.[59]
"Impurity Control of Quartz Crucible Coatings for Directional Solidification of Silicon", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Schwab, C.; Wolf, A.; Graf, M.; Nekarda, J.; Kästner, G.; Zimmer, M.; Kühnhold, S.; Hofmann, M.; Preu, R.
"Passivation of Inline Wet Chemically Polished Surfaces for Industrial PERC Devices", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Schwarz, F.[61]; Beckmann, R.[61]; Kohn, N.; Nölker, S.[61]; Kastl, S.[61]; Hofmann, M.; Ferrè, R.[61]; Pernau, T.[61]; Wanka, H.[61]; Rentsch, J.
"Advanced Anti-Reflection and Passivation Layer Systems Produced by High-Power Plasma in the New Manz PECVD System",
in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Schwunk, S.; Armbruster, N.; Straub, S.; Kehl, J.; Vetter, M.
"Particle Filter for State of Charge and State of Health Estimation for Lithium-Iron Phosphate Batteries", in: Proceedings, 13. Ulm Electrotechemical Talks 2012, Ulm, Germany, 3.-5.7.2012

Seiffe, J.; Nold, S.; Hofmann, M.; Rentsch, J.; Preu, R.
"Multifunctional PECVD Layers – Cost Analysis of the X-Pert Approach", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Seiffe, J.; Pillath, F.; Trogus, D.; Brand, A.; Savio, C.; Hofmann, M.; Rentsch, J.; Preu, R.
"Multifunctional PECVD Layers: Dopant Source, Passivation and Optics", in: Proceedings, 38th IEEE Photovoltaic Specialists Conference PVSC 2012, Austin, TX, USA, 3.-8.6.2012

Sierra Trillo, M.; Glatthaar, M.; Hopman, S.; Krossing, I.
"Impact of the Solvent Properties on the Morphology of the Silicon Surface Generated by Laser Ablation", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Smolinka, T.
"Water Electrolysis for Hydrogen Production from Renewable Energies", in: Proceedings, f-cell and battery storage 2012, Stuttgart, Germany, 9.10.2012

Sonner, C.; Oltersdorf, A.; Zimmer, M.; Moldovan, A.; Rentsch, J.
"Investigation of the Cleaning Effects Regarding Organic Contaminats on the Alkaline Texturisation", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Sprenger, W.; Assoa, Y. B.[47]; Zamini, S.[5]; Misara, S.[35]; Pellegrino, M.[68]; Erleaga, A. A.[86]
"Numerical Analysis of the impact of Environmental Conditions on BIPV Systems, an Overview of BIPV Modelling in the Sophia Project", Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012, CD-ROM

Sprenger, W.; Wilson, H. R.; Kuhn, T.
"Auswirkung von innerer Verschattung und Temperaturanalyse bei PVSHADE", in: Proceedings, Bauwerksintegrierte Photovoltaik 2012, Bad Staffelstein, Germany, 28.2.2012, CD-ROM

Spribille, A.; Greulich, J.; Lohmüller, E.; Clement, F.; Specht, J.; Biro, D.; Preu, R.; Koehler, I.[64]; Doll, O.[64]; Stockum, W.[64]; Tueshaus, C.[64]
"MWT Solar Cell Processing by Use of Isishape® Solar Etch® SiD for Rear Contact and Edge Isolation", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Steiner, M.; Siefer, G.; Bösch, A.; Hornung, T.; Bett, A. W.
"Realistic Power Output Modeling of CPV Modules", in: Proceedings, CPV-8 2012, Toledo, Spain, 16.-18.4.2012

Stüwe, D.; Keding, R.; Hahn, D.; Jahn, M.; Fallisch, A.; Clement, F.; Hofmann, M.; Woehl, R.; Biro, D.; Tueshaus, C.[64]; Doll, O.[64]; Doll, O.[64]; Stockum, W.[64]; Koehler, I.[64]
"Inkjet-Printed Diffusion Barrier for Structured Doping Areas from Doped PECVD Silicate Glasses", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Szolak, R.; Aicher, T.; Schlüter, M.; Kovacevic, J.[66]; Hehle, M.[66]
"Aktive Rußpartikelfilterregenerierung mit Kraftstoffdampf und Synthesegas", in: Proceedings, 7. Internationale MTZ-Fachtagung 2012, Nürnberg, Germany, 6./7.11.2012

Terheiden, B.[95]; Horbelt, R.[95]; Schiele, Y.[95]; Seren, S.[95]; Ebser, J.[95]; Hahn, G.[95]; Morrison, D.[67]; Heasman, K.[67]; Devenport, S.[67]; Holman, Z.[24]; Descoeudres, A.[24]; De Wolf, S.[24]; Baliff, C.[24]; Saint-Cast, P.; Michl, B.; Schmiga, C.; Weber, B.; Glunz, S. W.; Köntopp, M. B.[75]; Thomsen, J.; Kost, C.; Saad, N.; Schlegl, T.
"Developing Local Value Creation in an Emerging CSP Market: The Case of Morocco", in: Proceedings, SolarPACES Conference 2012 2012, Marrakesh, Morocco, 11.-14.9.2012, pp. 453-454

Vetter, M.
"Battery System Technology – From Cells to Systems", in: Proceedings, Hybrid & Electric Vehicles Forum 2012, Prague, Czech Republic, 1./2.2.2012, CD-ROM

Vetter, M.
"Battery Systems Development for the Electric Grid", in: Proceedings, Large Lithium Ion Battery Technology and Application Symposium AABC 2012, Orlando, FL, USA, 6.-10.2.2012, CD-ROM

Vetter, M.
"Batteriespeichertechnologien", in: Proceedings, PHOTOvoltaik – modernste E-Technik im Einsatz 2012, Vienna, Austria, 19.4.2012, CD-ROM

Vetter, M.
"Dezentrale netzgekoppelte PV-Batteriesysteme", in: Proceedings, Netzferne Stromversorgung und Photovoltaik 2012, Freiburg, Germany, 17./18.9.2012, CD-ROM

Vetter, M.
"Hybrides Lithium-Blei-Batteriesystem für die Anwendung in PV-Inselnetzen", in: Proceedings, 2. VDI Konferenz Elektrochemische Energiespeicher für stationäre Anwendungen 2012, Ludwigsburg, Germany, 16./17.10.2012, CD-ROM

Vetter, M.
"Solare Inselsysteme in DC", in: Proceedings, Cluster Seminar – Niederspannungs-Gleichstromnetze 2012, Erlangen, Germany, 7./8.11.2012, CD-ROM

Vetter, M.
"Advanced Battery Solutions for PV Applications", in: Proceedings, Intersolar China 2012, Beijing, China, 13.12.2012, CD-ROM

Vetter, M.; Dennenmoser, M.
"Status and Potential of Redox-Flow Batteries", in: Proceedings, Intersolar North America 2012, San Francisco, CA, USA, 9.-12.7.2012, CD-ROM

Vetter, M.; Dötsch, C.[33]; Würsig, A.[34]; Brettschneider, P.[36]
"Urban Hybrid Energy Storage – Enabling Large-Scale Integration of Renewables", in: Proceedings, Intersolar North America 2012, San Francisco, CA, USA, 9.-12.7.2012, CD-ROM

Vetter, M.; Reiners, F.; Schwunk, S.; Dietrich, V.[56]
"Next Generation of Hybrid PV Mini-Grids", in: Proceedings, Intersolar North America 2012, San Francisco, CA, USA, 9.-12.7.2012, CD-ROM

Vetter, M.; Rohbogner, G.; Dötsch, C.[33]; Würsig, A.[34]; Brettschneider, P.[36]
"Urban Hybrid Energy Storage – An Alternative for Centralized Batteries in the Distribution Grid?", in: Proceedings, Solar Summit 2012, Freiburg, Germany, 18./19.10.2012, CD-ROM

Viennahausen, A. H.; Kranzer, D.
"1 MHz Resonant DC/DC-Converter Using 600 V Gallium Nitride (GaN) Power Transistors", in: Proceedings, European Conference on Silicon Carbide & Related Materials ECSCRM 2012, St. Petersburg, Russia, 2.-6.9.2012

Vorbeck, L.; Gschwander, S.; Thiel, P.[42]; Lüdemann, B.[42]; Schossig, P.
"Pilot Application of Phase Change Slurry in a 5 m^3 Storage", in: Proceedings, Innostock 2012, Lleida, Spain, 15.-18.5.2012, CD-ROM

Walter, J.; Eberlein, D.; Haunschild, J.; Tranitz, M.; Eitner, U.
"A Method to Detect Defective Solder Joints by Rs-Electroluminescence Imaging", in: Proceedings, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012

Weber, B.; Orellana, T.; Riepe, S.
"Investigations on Breakage and Quality for Thin Slurry Sawn Wafers", in: Proceedings, 6th International Workshop on Crystalline Silicon Solar Cells CSSC 2012, Aix-les-Bains, France, 8.-11.10.2012

Weber, B.; Riepe, S.
"Challenges of the Multi Wire Sawing Process for Thin Wafers below 120µm Thickness", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Weiß, K.-A.; Peike, C.; Piekarczyk, A.
"Kunststoffanwendungen in der Photovoltaik und Niedertemperatur-Solarthermie", in: Proceedings, Polyurethan 2012, Nürtingen, Germany, 7./8.11.2012, CD-ROM

Welz, C.; Di Lauro, P.; Thoma, C.; Richter, J.; Hermann, M.; Stryi-Hipp, G.; Maurer, C.
"Physikalische Modellierung und Simulation sowie detaillierte Vermessung von Luftkollektoren", in: Proceedings, 22. Symposium Thermische Solarenergie, Bad Staffelstein, Germany, 9.-11.5.2012, CD-ROM

Wendling, M. D.; Mondon, A.; Kraft, A.; Bartsch, J.; Glatthaar, M.; Glunz, S. W.
"Analysis of Chemical Stability of Printing Pastes in Electrochemical Plating Solutions", in: Energy Procedia, 2nd International Conference on Silicon Photovoltaics SiliconPV 2012, Leuven, Belgium, 3.-5.4.2012, pp. 497-52
(online available: http://dx.doi.org/10.1016/j.egypro.2012.7.100)

Wiemken, E.; Petry Elias, A. R.; Nienborg, B.; Zachmaier, P.[6]; Safarik, M.[51] ; Schmidt, F.[57]; Glück, C.[57]
"EVASOLK - Evaluation of Solar Cooling in Comparisn to Reference Technologies", in: Proceedings, Eurosun 2012, Rijeka, Croatia, 18.-20.9.2012, CD-ROM

Wiesenfarth, M.; Helmers, H.; Philipps, S. P.; Steiner, M.; Bett, A. W.
"Advanced Concepts in Concentrating Photovoltaics (CPV)", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-29.9.2012, pp. 11-15

Wiesenfarth, M.; Steiner, M.; Helmers, H.; Siefer, G.; Oliva, E.; Dimroth, F.; Shelef, G.[87]; Polonsky, G.[87]; Flitsanov, Y.[87]; Kribus, A.[87]; Bett, A. W.
"Front-Side Interconnected Large Area Concentrator Cells for Compact Concentrator Modules", in: Proceedings, CPV-8 2012, Toledo, Spain, 16.-18.4.2012, pp. 24-27

Wieser, M.; Clement, J.; Benoit, P.; Kohrs, R.; Wittwer, C.
"A Modular Prototyping Hard- and Software Platform for Faster Development of Intelligent Charging Concepts for Electric Vehicles", in: Proceedings, International Conference on Power Engineering, Energy and Electrical Drives 2012, Istanbul, Turkey, 13.-17.5.2012, CD-ROM

Wille-Haussmann, B.; Link, J.; Sabo, A.; Wittwer, C.
"Photovoltaik Eigenstromnutzung – Fluktuation von Strahlung und Last", in: Proceedings, 27. Symposium Photovoltaische Solarenergie 2012, Bad Staffelstein, Germany, 29.2-2.3.2012, CD-ROM

Wolf, S.; Herter, B.; Fischer, S.; Höhn, O.; Martín-Rodríguez, R.[97]; Aeberhard, U.[52]; Goldschmidt, J. C.
"Exploiting Photonic Structures to Improve the Efficiency of Upconversion by Field Enhancement and a Modification of the Local Density of Photonic States", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Wystricil, D.; Kalz, D.
"Thermo-Hydraulische Modellierung eines Niedrigexergiesystems zur Gebäudeheizung und -kühlung und exergetische Bewertung von Regelungsstrategien", in: Proceedings, BauSIM 2012, Berlin, Germany, 26.-28.9.2012

Zeidler, R.; Haunschild, J.; Seeber, B.; Riepe, S.; Höffler, H.; Fertig, F.; Reis, I.; Rein, S.
"Tomographic Defect Reconstruction of Multicrystalline Silicon Ingots Using Photoluminescence Images of As-Cut Wafers and Solar Cells", in: Proceedings, 27th European Photovoltaic Solar Energy Conference and Exhibition EUPVSEC 2012, Frankfurt/Main, Germany, 24.-28.9.2012

Zeidler, R.; Riepe, S.; Seeber, B.; Haunschild, J.; Orellana, T.; Schmid, C.; Rein, S.
"Tomographic Defect Reconstruction of Multicrystalline Silicon Ingots Using Photoluminescence Images of As-Cut Wafers", in: Proceedings, 6th International Workshop on Crystalline Silicon Solar Cells CSSC 2012, Aix-les-Bains, France, 8.-11.10.2012

Zipf, V.; Neuhäuser, A.; Nitz, P.; Gschwander, S.; Platzer, W.
"High Temperature Latent Heat Storage for CSP: Testing of First Prototype with Thermal Oil", in: Proceedings, Innostock 2012, Lleida, Spain, 15.-18.5.2012, CD-ROM

1 *Aalto University, Aalto, Finland*
2 *Applied Materials, Inc., Gloucester, MA, USA*
3 *Asahei-Kasei, Shizuoka, Japan*
4 *AUI, Ifrane, Morocco*
5 *Austrian Institute of Technology AIT, Vienna, Austria*
6 *Bayerisches Zentrum für Angewandte Energieforschung Bayern ZAE, Garching, Germany*
7 *Berner Fachhochschule für Technik und Informatik, Burgdorf, Switzerland*
8 *Bosch Solar Energy AG, Erfurt, Germany*
9 *Branddirektion München, Munich, Germany*
10 *BSQ Solar S. L., Madrid, Spain*
11 *Bundesanstalt für Materialforschung und -prüfung BAM, Berlin, Germany*
12 *Carl von Ossietzky Universität, Oldenburg, Germany*
13 *CNR-Istituto per la Microelettronica e Microsistemi, Bologna, Italy*
14 *CNR-Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano", Messina, Italy*
15 *Daido Steel Co., Nagoya, Japan*
16 *Department of Advanced Technology Fusion Konkuk University, Seoul, Republic of Korea*
17 *Department of Chemistry and Biochemistry University of Bern, Bern, Switzerland*
18 *Department of Civil Environmental and Architectural*

Engineering University of Colorado, Boulder, CO, USA

[19] *Department of Microsystems Engineering IMTEK, Albert-Ludwigs-Universität, Freiburg, Germany*

[20] *DuPont Microcircuit Materials, Bristol, Great Britain*

[21] *E&B engelhardt und bauer Druck und Verlag GmbH, Karlsruhe, Germany*

[22] *E.ON Energy Projects GmbH, Munich, Germany*

[23] *EADS Astrium GmbH, Munich, Germany*

[24] *Ecole Polytechnique Fédérale de Lausanne, Neuchâtel, Switzerland*

[25] *EDF R&D ENERBAT, Moret sur Loing, France*

[26] *Elkem Solar AS, Kristiansand, Norway*

[27] *Eni S.p.A. Centro Ricerche per le Energie non Convenzionale, Novara, Italy*

[28] *Eni S.p.A. Research and Technological Innovation Department, Roma, Italy*

[29] *Forschungszentrum Jülich, Jülich, Germany*

[30] *Fraunhofer Center for Silicon-Photovoltaics CSP, Halle, Germany*

[31] *Fraunhofer Institute for Applied Solid State Physics IAF, Freiburg, Germany*

[32] *Fraunhofer Institute for Building Physics IBP, Holzkirchen, Germany*

[33] *Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Oberhausen, Germany*

[34] *Fraunhofer Institute for Silicon Technology ISIT, Itzehoe, Germany*

[35] *Fraunhofer Institute for Wind Energy and Energy System Technology IWES, Kassel, Germany*

[36] *Fraunhofer Institute for Optronics, System Technologies and Image Exploitation AST, Ilmenau, Germany*

[37] *Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany*

[38] *Helmholtz-Zentrum Berlin HZB, Berlin, Germany*

[39] *Heraeus Precious Metals GmbH & Co. KG, Hanau, Germany*

[40] *Hochschule für Technik, Wirtschaft und Medien, Offenburg, Germany*

[41] *Imperial College of Science, Technology and Medicine ICSTM, London, Great Britain*

[42] *Imtech Deutschland GmbH & Co, Hamburg, Germany*

[43] *Institut für Psychologie, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*

[44] *Institut für Solarenergieforschung Hameln ISFH, Emmerthal, Germany*

[45] *Institut für sozial-ökologische Forschung, Frankfurt, Germany*

[46] *Institut für Umformtechnik und Leichtbau, Technische Universität Dortmund, Dortmund, Germany*

[47] *Institut National de l'Energie Solaire INES, Le Bourget-du-Lac, France*

[48] *Institute for Future Energy Consumer Needs and Behavior FCN School of Business and Economics/E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany*

[49] *Institute for Nanoelectronics, Technische Universität München, Munich, Germany*

[50] *Institute for Organic Chemistry, Johannes Gutenberg Universität, Mainz, Germany*

[51] *Institute of Air Handling and Refrigeration ILK, Dresden, Germany*

[52] *Institute of Energy- and Climateresearch, Forschungszentrum Jülich, Jülich, Germany*

[53] *Instituto de Energia Solar, Universidad Politècnica, Madrid, Spain*

[54] *ISFOC, Puertollano, Spain*

[55] *Isofotón, Málaga, Spain*

[56] *KACO new energy GmbH, Neckersulm, Germany*

[57] *Karlsruhe Institute of Technology KIT, Karlsruhe, Germany*

[58] *Konkuk University – Fraunhofer Next Generation Solar Cell Research Center KFnSC, Seoul, Republic of Korea*

[59] *Kristallographisches Institut, Albert-Ludwigs-Universität, Freiburg, Germany*

[60] *LG Electronics, Seoul, Republic of Korea*

[61] *Manz AG, Reutlingen, Germany*

[62] *Massachusetts Institute of Technology MIT, Cambridge, MA, USA*

[63] *Mechatronic Systemtechnik GmbH, Villach, Austria*

[64] *Merck KGaA, Darmstadt, Germany*

[65] *MIND-IN²UB, Universitat de Barcelona, Barcelona, Spain*

[66] *MTU Friedrichshafen GmbH, Friedrichshafen, Germany*

[67] *Narec Solar Ltd., Blyth, United Kingdom*

[68] *National Agency for New Technologies Energy and Sustainable Economic Development ENEA, Portici, Italy*

[69] *National Institute of Advanced Industrial Science and Technology AIST, Ibaraki, Japan*

[70] *National Water Research Center NWRC, Cairo, Egypt*

[71] *Novatec Solar, Karlsruhe, Germany*

[72] *ONE, Casablanca, Morocco*

[73] *Photovoltech NV, Tienen, Belgium*

[74] *PSE AG, Freiburg, Germany*

[75] *Q-Cells SE, Bitterfeld-Wolfen, Germany*

[76] *RENA GmbH, Freiburg, Germany*

[77] *Research School of Engineering Australian National University, Canberra, ACT Australia*
[78] *Sharp Co., Nara, Japan*
[79] *Slovenian National Building and Civil Engineering Institute ZAG, Ljubljana, Slovenia*
[80] *Soitec Solar GmbH, Freiburg, Germany*
[81] *Solar Energy Research Institute of Singapore SERIS, Singapore*
[82] *SoLayTec, Eindhoven, The Netherlands*
[83] *Staatliche Forschungsanstalt für Gartenbau Weihenstephan, Weihenstephan-Triesdorf, Germany*
[84] *Takano Co., Nagano, Japan*
[85] *Technische Universität Dresden, Dresden, Germany*
[86] *Tecnalia Research & Innovation, Derio, Spain*
[87] *Tel Aviv University, Tel Aviv, Israel*
[88] *The University of Kobe, Kobe, Japan*
[89] *The University of Miyazaki, Miyazaki, Japan*
[90] *The University of Tokyo, Tokyo, Japan*
[91] *Toyota Technological Institute, Nagoya, Japan*
[92] *TÜV Rheinland Energie und Umwelt GmbH Regenerative Energien, Cologne, Germany*
[93] *Universidad Politécnica de Madrid, Madrid, Spain*
[94] *Università di Modena e Reggio Emilia, Reggio Emilia, Italy*
[95] *Universität Konstanz, Constance, Germany*
[96] *University of Cracow, Cracow, Poland*
[97] *Utrecht University, Utrecht, The Netherlands*
[98] *Voltec Solar, Dinsheim, France*
[99] *Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg ZSW, Ulm, Germany*