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FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

Annual Report 2015/16

Cover photo:
Hydrogen production by electrolysis of water in an electrolyser cell with a polymer electrolyte membrane.

FOREWORD

The past few years have not been easy for the solar sector in Germany. The large global production overcapacity led to unexpectedly rapid price reductions, which resulted in quickly growing markets. Unfortunately, Germany did not participate in this development, partly due to political decisions which took effect just at the time when this sector was preparing for a second growth cycle toward a 100 GW/a market in 2020.

Fraunhofer ISE responded to the difficult situation of our industrial partners with strategic modifications, organizational optimization and consolidation, which are already bearing fruit. Our central topic continues to be the development and market introduction of technology which is needed to transform the energy system toward sustainability and efficient usage of energy derived entirely from renewable sources. This will continue to be essential in the coming decades, particularly after the international agreement on climate goals achieved at the Paris Climate Change Conference COP-21.

Overall, we can look back on a solid year in 2015. Some positive signals can already be recognized. Based on the global dynamics of the photovoltaic market, renewed growth in the demand for production capacity can be anticipated – an opportunity for the equipment-manufacturing industry and thus for implementation of our newly developed technologies.

At the beginning of the year, we conducted a survey among our national and international industrial clients to learn what they valued in our work and where we could make improvements. We received very good ratings particularly for our expertise, our technical facilities and our many years of experience. These replies have confirmed us in our central goal of using successful projects and excellent research results to better assist our clients, as they compete in the market.

In order to further optimize our technical infrastructure, we officially opened a new laboratory complex, located in the Auerstrasse in Freiburg. This new center for storage and heat transformation technology provides the technological facilities needed to address several topics that are central to the energy transformation. It houses advanced laboratory and prototype facilities for research on battery systems for photovoltaics and mobility, redox-flow batteries, hydrogen generation by electrolysis, high-temperature storage units for solar thermal technology and heat pumps and chillers driven by electricity, gas or heat.

We have also extended our range of services in 2015 by the accreditation of our TestLab Power Electronics by the DAkkS. Due to the growth of the renewable energy economy, the dynamics of controlling energy supply networks have increased, and demands on the electrical properties of power electronics in the grid have risen. In order to guarantee the reliability of generator units, Fraunhofer ISE is now offering a more extensive portfolio of certified testing services, following international guidelines and standards.

Our proximity to industry is also documented well by our spin-offs. In 2015, we transferred the "kerfless wafer" technology developed at Fraunhofer ISE to produce epitaxially grown silicon wafers (EpiWafer) to our spin-off, NexWafe GmbH, where it is to be commercialized further. The EpiWafer is a cost-effective substitute for conventional n-doped or p-doped monocrystalline silicon wafers. Furthermore, NexWafe and Fraunhofer ISE have further optimized the production steps for EpiWafer, such that now the solar cell has achieved a short circuit current of 39.6 mA/cm^2 according to the most recent measurements – a world record for solar cells of epitaxially grown silicon!

Fraunhofer ISE was able to gain another world record in 2015, this one being for its solar cells produced with TopCon technology. An efficiency value of 25.1 % was measured for the first time for silicon solar cells with contacts on both surfaces. In addition, our back-surface design offers great potential for further increases in efficiency. With these results, we con-

Current lectures and publications
by Institute Director Prof. Eicke R. Weber:
www.ise.fraunhofer.de/en/publications/lectures-and-talk-prof-weber

vincingly demonstrate that the opportunities for further cost reduction and efficiency increases in photovoltaic research are far from being exhausted!

Our fundamental report by Prof. Hans-Martin Henning and Andreas Palzer, entitled "What will the energy transformation cost?", has contributed decisively to a better understanding of the systemic challenges which must be addressed to reach the goal of an 80 % reduction in greenhouse gas emission by 2050 in Germany. The model-based investigation covers all sectors and energy forms. Applying a time resolution of one hour, it analyzes how Germany can achieve its climate protection goals with efficient energy usage and renewable energy. Different cost-optimized transformation routes are analyzed in detail. Fluctuating, renewable energy sources play a key role in the future energy supply in all scenarios. The new mixture of energy generators demands that both electricity generation and electricity consumption become very much more flexible. Electricity will also be increasingly important for heating purposes. The study reveals that we have many exciting research tasks ahead of us to put the energy transformation into practice.

In order to further strengthen research for a sustainable energy supply and to intensify cooperation with the commercial world, the five Fraunhofer Institutes in Freiburg and the University of Freiburg established the "Leistungszentrum Nachhaltigkeit" (Centre of Excellence for Sustainability). In addition, the University has founded the "Institut für Nachhaltige Technische Systeme INaTECH" (Institute for Sustainable Technological Systems) in its Technical Faculty. It now forms the engineering core of the Centre of Excellence for Sustainability. We are very pleased that Dr Stefan Glunz was appointed as Chair for Photovoltaic Energy Conversion at INaTECH.

Fraunhofer ISE aims not only to deliver significant results to promote a sustainable energy supply, but also to carry out its research and development work in a sustainable manner. As a guide to further improvement, we prepared a sustainability report in 2015 for the first time. It is the basis for future regular checks on the Institute's progress in this important aspect.

Our bids in the market for international projects are encountering increasing interest. We, together with the Fraunhofer-Gesellschaft, have used the prize money from the Zayed Future Energy Award, which I received on behalf of Fraunhofer ISE in 2014, to establish a "Fraunhofer Zayed Programme" to provide seed funding for international projects. To date, 14 projects, e.g. in Egypt, Brazil, Chile, Great Britain, Haiti, India and South Africa, have been financed, in which Fraunhofer ISE is participating with a central role.

International cooperation has also been strengthened by a new solar research institute in South America. The goal of the new Fraunhofer Center for Solar Energy Technologies (FCR-CSET), which was founded by the Fraunhofer Chile Research Foundation in Santiago de Chile, is to make greater use of the solar potential in this sunny country. Primarily, solar thermal and photovoltaic technology and applications are to be further developed there, with partners from research and industry, and implemented locally. The Research Center for Solar Energy was officially opened in 2015 in the presence of the Chilean Deputy Minister for Energy, Jimena Jara.

Finally, I extend my sincere gratitude to our Board of Trustees, auditors, scholarship donors, contact persons in Federal and State Ministries and all of our industrial partners for constructive cooperation and support and funding of our Institute.
We look forward to further trustful cooperation next year.

OUR VISION

The Fraunhofer Institute for Solar Energy Systems ISE conducts applied research and development to promote a sustainable, economic, safe and socially just energy supply system for the whole world.

OUR MISSION

The Institute develops technical solutions to use renewable energy sources economically and to increase energy efficiency. With its systems-oriented and technological innovations, it contributes to the competitive strength of its clients and to social acceptance of sustainable energy systems. Fraunhofer ISE aims to occupy and further expand an internationally leading position as a research institute dedicated to efficient and solar energy systems by generating excellent research results, carrying out successful projects, cooperating with partners and founding spin-off companies. In this way, it intends to contribute to the transformation of the energy supply system. The Institute cooperates with renowned partners from around the world to achieve optimal results. Our goal is to combine excellent scientific research and development with economic success, industrial implementation and technical progress.

OUR FOUNDATION

The Fraunhofer ISE is the largest solar energy research institute in Europe. Its successful work is based on seven pillars, which define the Institute's own understanding of itself:

- Excellently qualified and motivated staff
- Modern, high-performance research infrastructure
- Broad spectrum of topics and systems competence
- Many years of experience and expertise
- Recognized competence in analysis and testing
- Successful, project-funded business model
- National and international cooperation


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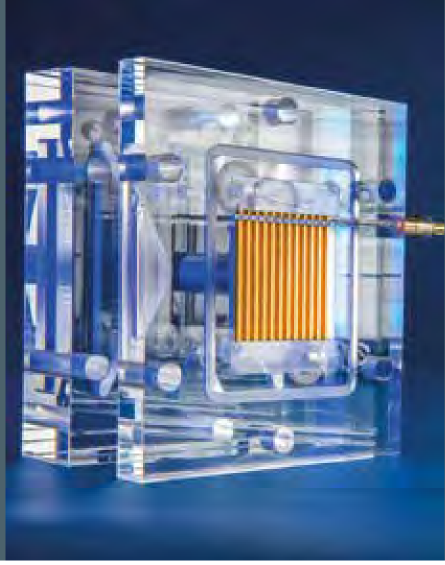

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(from left to right): Dr Andreas Bett, Deputy Director and Business Area Coordinator for "Photovoltaics"; Jochen Vetter, Chief Technical Officer; Karin Schneider, Head of Press and Public Relations; Prof. Eicke R. Weber, Institute Director; Prof. Hans-Martin Henning, Deputy Director and Business Area Coordinator for "Building Energy Technology"; Dr Sonja Reidel, Chief Administrative Officer.

The organizational structure of Fraunhofer ISE is defined, apart from administration, technical services and staff units, by eight scientific divisions: Thermal Systems and Building Technology; Electric Energy Systems; Solar Cells – Development and Characterization; PV Production Technology and Quality Assurance; Hydrogen Technology; Solar Thermal Technology and Optics; Photovoltaic Modules, Systems and Reliability; Materials – Solar Cells and Technology. Five market-oriented business areas are used for external representation: Photovoltaics, Solar Thermal Technology, Building Energy Technology, Hydrogen Technology and Energy Systems Technology. The Institute Directorate consists of Prof. Eicke R. Weber, Dr Andreas Bett, Prof. Hans-Martin Henning, Dr Sonja Reidel und Jochen Vetter.

Fraunhofer ISE is supported by long-standing mentors and experts in the solar energy sector as consultants: 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).

“In recent years, Fraunhofer ISE has become a widely sought contact and generator of ideas for holistic energy system innovations, alongside its excellent competence in photovoltaics.”
Dr Carsten Voigtländer, CEO Vaillant Group

BOARD OF TRUSTEES

“It is particularly impressive that Fraunhofer ISE has continually and successfully developed its field of activities further. It can cover the value chain from materials research up to investigating complete systems with 100 % renewable energy. It will undoubtedly continue its successful course.”
Dr Hubert Aulich, President, SC Sustainable Concepts

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: 31st December 2015).

FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 66 institutes and research units. Most of the nearly 24,000 staff are qualified scientists and engineers, who work with an annual research budget of more than 2 billion euros. Of this sum, around 1.7 billion euros is generated through contract research.

More than 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German Federal and State governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technology and helping to train the urgently needed future generation of scientists and engineers.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

1 *The Fraunhofer-Gesellschaft for applied research takes its name from Joseph von Fraunhofer, a researcher, inventor and entrepreneur.*

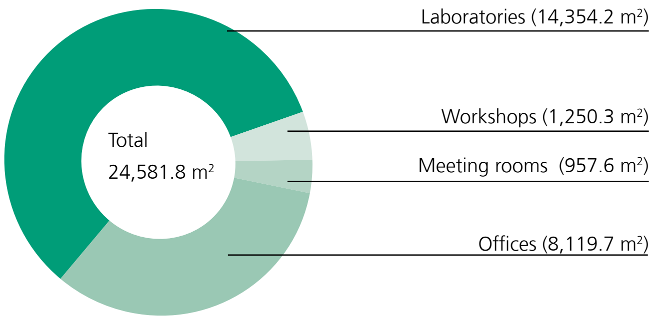
FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE

The Fraunhofer Institute for Solar Energy Systems ISE, which was founded in Freiburg, Germany, in 1981, is the largest solar energy research institute in Europe, with a staff of 1150. It creates technological foundations for supplying energy efficiently and on an environmentally sound basis in industrialized, threshold and developing countries. With its research focusing on energy conversion, energy efficiency, energy distribution and energy storage, it contributes to broad application of new technology.

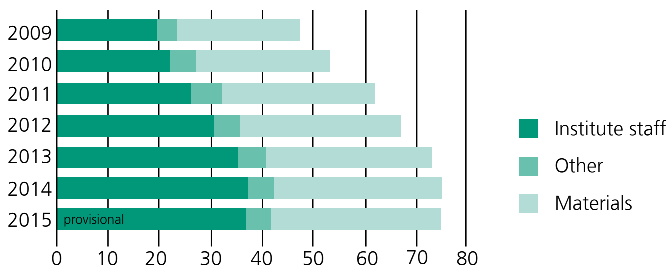
Together with clients and partners from industry, politics and society in general, Fraunhofer ISE develops technical solutions that can be implemented in practice. It investigates and develops materials, components, systems and processes in five business areas. In addition, Fraunhofer ISE also offers testing and certification procedures. It features excellent laboratory infrastructure. Fraunhofer ISE is certified according to the quality management standard, DIN EN ISO 9001:2008.

The Institute finances itself to about 80 percent with contracts for applied research, development and high-technology services. Fraunhofer ISE is integrated into a network of national and international cooperation such as the "Forschungs-Verbund Erneuerbare Energien" (FVEE – German Research Association for Renewable Energy) and the Association of European Renewable Energy Centres (EUREC).

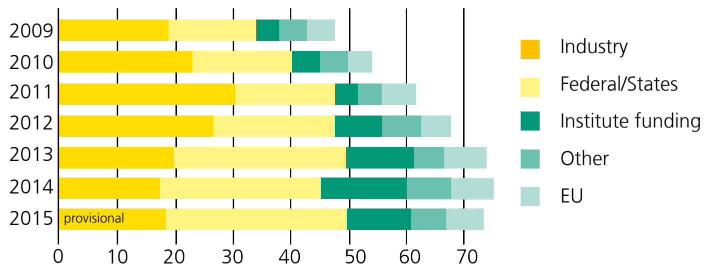
The financial structure of the Fraunhofer-Gesellschaft distinguishes between operational and investment budgets. The operational budget includes all expenses for personnel and materials, as well as their financing with external income and institutional funding. In 2015 our operational budget totalled 73.1 million euros. In addition, the Institute made investments of 10.6 million euros in 2015 (not including investments for building construction and the economic stimulus programme). On 31st December 2015, a total staff of 1142 was employed at Fraunhofer ISE. Included in this total are 111 doctoral candidates, 110 diploma/masters students, 31 trainees and 240 scientific assistants.



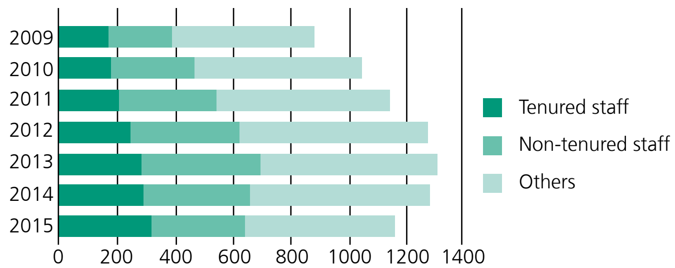
Floor area distribution in the Freiburg premises.



Expenditure (million euros)



Income (million euros)



Personnel

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EXTERNAL BRANCHES AND COOPERATION

In addition to its headquarters in Freiburg, Fraunhofer ISE has three external branches in Germany and specific collaboration with two international bodies.

Laboratory and Service Center, Gelsenkirchen LSC

The Fraunhofer ISE Laboratory and Service Center LSC, which was founded in 2001 on the initiative and with the continuing support of the State of North Rhine-Westphalia (NRW), specializes in production-relevant process development to manufacture thin-film silicon solar cells, silicon hetero-junction solar cells and multicrystalline silicon solar cells. It has two excellently equipped technological divisions and possesses comprehensive measurement facilities to characterize thin films and solar cells.

Fraunhofer Center for Silicon Photovoltaics CSP

The Fraunhofer Center for Silicon Photovoltaics CSP in Halle/ Saale was jointly founded by the Fraunhofer Institute for Mechanics of Materials IWM Freiburg and Halle (in future Fraunhofer Institute for Microstructure of Materials and Systems IMWS), and Fraunhofer ISE. The main research work is carried out in two groups, the one addressing "Reliability and Technologies for Grid Parity" (CSP-ZTN) and the "Laboratory for Crystallization Technology" (CSP-LKT). Together with the Silicon Materials Technology and Evaluation Center SIMTEC at Fraunhofer ISE, the latter provides a comprehensive technological platform for industrially relevant crystallization processes applying industrial-type equipment, which goes well beyond the current state of the art.

Technology Center for Semiconductor Materials THM

The Technology Center for Semiconductor Materials THM in Freiberg, Saxony, operates in cooperation between Fraunhofer ISE and the Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen. THM supports companies by research and development on materials preparation and processing of 300 mm silicon, solar silicon and III-V semiconductors. In addition, THM offers services in the fields of analysis, characterization and testing.

1 *Fraunhofer ISE Laboratory and Service Center LSC.*

2 *Fraunhofer Center for Silicon Photovoltaics CSP.*

3 *Fraunhofer Center for Sustainable Energy Systems CSE.*

Page 11 : Main building of Fraunhofer ISE, Freiburg.

Fraunhofer Center for Sustainable Energy Systems CSE

The Fraunhofer Center for Sustainable Energy Systems CSE in Boston was founded in 2008 as a result of cooperation between Fraunhofer ISE and the Massachusetts Institute of Technology MIT. Expertise and technology that is already established in Europe is further adapted and introduced to the American market by Fraunhofer CSE. Together with the Canadian Standards Association (CSA), Fraunhofer CSE is operating a test facility for PV modules, the CFV Solar Test Laboratory, which is located in Albuquerque, New Mexico.

Fraunhofer Chile Research – Centro para Tecnologías en Energía Solar (FCR-CSET)

The Fraunhofer-Gesellschaft has further expanded its activities in Chile with the "Centro para Technologías en Energía Solar" (Fraunhofer Chile Research – Center for Solar Energy Technology). Scientists from the Fraunhofer Institute for Solar Energy Systems ISE, the Pontificia Universidad Católica de Chile and other Chilean universities are conducting research there particularly on the solar generation of electricity and process heat and on water purification.

Networking within the Fraunhofer-Gesellschaft

- Fraunhofer Alliances: Energy, Batteries, Building Innovation, Nanotechnology, Space and Water Systems (SysWasser)
- Fraunhofer Electromobility Systems Research
- Fraunhofer Group: Materials, Components
- Fraunhofer Networks for Electrochemistry, Energy Storage Systems and Grids, Intelligent Energy Grids, Sustainability, Wind Energy
- Fraunhofer Initiative "Morgenstadt – City of the Future"

SPECTRUM OF ACTIVITIES

Fraunhofer ISE conducts application-oriented research and development for key technologies of the future. To this purpose, the Institute addresses a wide range of subjects and pursues a holistic, systemic approach. This maximizes synergy between the five business areas:

Photovoltaics

- Silicon Photovoltaics
- III-V and Concentrator Photovoltaics
- Emerging Photovoltaic Technologies
- Photovoltaic Modules and Power Plants

Solar Thermal Technology

- Material Research and Optics
- Thermal Collectors and Components
- Thermal Systems Engineering
- Thermal Storage for Power Plants and Industry
- Water Treatment

Building Energy Technology

- Building Envelope
- Heating and Cooling Technologies
- Energy Concepts and Building Performance Optimization
- Thermal Storage for Buildings
- Materials and Components for Heat Transformation

Hydrogen Technologies

- Thermochemical Processes
- Hydrogen Production by Water Electrolysis
- Fuel Cell Systems

Energy System Technology

- Power Electronics
- Smart Grid Technolgies
- System Integration – Electricity, Heat, Gas
- Battery Systems for Stationary and Mobile Applications
- Energy System Analysis

R&D Activities

Our research activities have the goal of developing new products, processes or services and improving existing products. To do so, the Institute finds promising technical solutions and transfers technology from science and research to industry and society at large. Furthermore, Fraunhofer ISE orientates itself according to our clients' requirements. It is a partner for industry and contributes toward the economic added value generated by its clients. Small and medium-sized enterprises often do not have their own R&D department. By cooperating with Fraunhofer ISE, they gain access to high-performance laboratory infrastructure and excellent research services.

We carry out research and development projects at various phases in the lifecycle of a given technology. Depending on the task and requirements of our clients or the technological maturity of the subject, the Institute delivers results in various forms:

- New material / process
- Prototype / pilot series
- Patent / licence
- Software / application
- Analysis based on measurement technology / quality control
- Advice / planning / studies

In the following chapters, the projects presented are labelled according to these categories for easier orientation.

Service Units

As a complement to our research and development work, Fraunhofer ISE operates 16 service laboratories, which cover the entire bandwidth of research subjects addressed at the Institute. These include six accredited testing or calibration laboratories. The laboratories offer services to the industry, each based on its specific set of measurement and testing equipment. At the same time, these laboratories also have a research function, as the insights gained during characterization, certification or testing can also be used in R&D projects.

PHOTOVOLTAICS

Photovoltaic technology is an essential component to transform today's carbon-based energy system into one with its foundations in renewable and sustainable energy sources. Analyses and models prepared by Fraunhofer ISE demonstrate clearly that the energy transformation cannot occur without tapping the enormous potential offered by photovoltaics. It is thus essential that photovoltaic technology continue to be developed further. The technical progress so far and scaling effects of mass production have resulted in a recent reduction in the levellized cost of electricity from photovoltaics, which had been considered impossible previously. One consequence is world-wide growth of the photovoltaic market. In 2014, a total of 44 GWp was installed, which corresponds to an increase of 14 % compared to the previous year.

Nevertheless, the photovoltaic sector has recently undergone consolidation, despite the global market growth. Since 2012, all German PV enterprises have either been restructured or have disappeared completely from the market. This also affected the income derived from industrial sources at Fraunhofer ISE and resulted in refocussing of the current PV research projects. In order to orient the Institute optimally toward the market development, Fraunhofer ISE underwent an intensive strategy process in 2014. The results were subsequently discussed in an audit with external specialists from the branch, who gave valuable input. The auditors confirmed that the technological developments at Fraunhofer ISE are proceeding at the highest international scientific level and are simultaneously highly relevant to the industry. We will thus continue our approach of orientation towards the new market situation.

Also in future, Fraunhofer ISE will concentrate on silicon photovoltaic technology (Silicon Photovoltaics, pp. 14–21). With more than 90 % of the global photovoltaic turnover, crystalline silicon continues to dominate the market. We are convinced that numerous innovations in this technological branch are feasible and necessary to further reduce the price of a PV-generated kilowatt-hour. Current research at Fraunhofer ISE and its outposts in Freiberg, Gelsenkirchen and Halle addresses materials development, cell architecture, cell production technology, quality control and module production, to explicitly name just a few examples. At the Institute, about 380 employees work on silicon photovoltaic technology – from materials to modules and from quality assurance to the power plant scale.

A further focus on photovoltaics at Fraunhofer ISE is on III-V and Concentrator Photovoltaics (pp. 22–25), in which 80 employees are involved. One of their goals is to further develop the extremely efficient solar cells based on III-V semiconductors. We proudly hold the current efficiency world record of 46 %. This type of multi-junction solar cell is applied in space or concentrator systems. In the latter technology, the incident light is first concentrated by an optical system and then directed onto the solar cell. In addition to the cell itself, we develop all further components required (optics, module, tracking controls, measurement technology) and investigate system-level issues. This applies not only for highly concentrating systems with two tracking axes and based on III-V semiconductors but also for low-concentrating systems with single-axis tracking, which use our silicon cells that are specially developed for this purpose.

Finally, our research on photovoltaics also includes newly emerging technological topics and concepts for the future (pp. 26–29). In this field, Fraunhofer ISE is investigating technologies such as organic and dye-sensitized solar cells, particularly the perovskite solar cells that have been very successful in recent years. About 50 employees are working within emerging photovoltaic technologies on concepts which will need significantly more than five years until they can be implemented industrially. Examples include up-conversion and down-conversion, photonic structures and tandem structures on silicon, where we combine our competence from a wide range of technological areas (e.g. the combination of perovskite or III-V solar cells with silicon).

Photo: In recent years, Fraunhofer ISE has developed a whole range of innovative PV technologies at the cell and module level on a laboratory scale. To demonstrate how these technologies can be applied with industrially relevant production processes in substantial volumes and suitable formats for a building-integrated application, 70 edge-sealed modules applying "TPedge" technology were integrated into the façade of a new laboratory building at Fraunhofer ISE. The modules are based on HIP-MWT solar cells (high-performance metal wrap-through) and structured cell interconnectors for back-contact cells. Comprehensive tests based on IEC 61215 have demonstrated the reliability of the modules.

SILICON PHOTOVOLTAICS

Interview with Dr Ralf Preu
and Prof. Stefan Glunz
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stefan.glunz@ise.fraunhofer.de

Fraunhofer ISE has set itself the goal to address the entire value chain for silicon PV. Now that the PV sector in Europe is struggling, do you still have customers for all production steps?

Ralf Preu: The consolidation during the last few years has strongly affected not only the European market but also the Asian PV industry. The gap between supply and demand is closing again now, so that the commercial opportunities for European cell, module and system manufacturers are increasing again. In particular, Germany has taken a leading role in the process technology for back-surface passivated solar cells.

How can your R&D work support the German PV sector in becoming more competitive?

Stefan Glunz: Technology is a major driver for the PV industry. Neither solar cell manufacturers nor system installers have much chance of commercial success without innovation. We want to help the branch to become competitive and maintain this position.

New processes and systems can be tested in PV-TEC. What goals do you follow there?

Ralf Preu: In PV-TEC, we test new technology which can help to reduce the levellized cost of electricity, i.e. to increase the efficiency and reduce processing costs. We have just introduced several novel prototypes, e.g. to extrude metallization pastes for producing highly conductive, narrow and high contacts, and to use foils and local laser alloying for the metal contacts on back-surface passivated solar cells.

Which trends can you recognize in making metal contacts for solar cells?

Ralf Preu: The leading screen-printing and other paste-based printing technologies still offer considerable potential and will dominate the field for a long time yet. However, we see the need to examine alternatives, particularly for novel cell structures with the potential for very high efficiency. For that reason, we are investigating evaporated and galvanically deposited metal contacts very intensively.

In 2015, Fraunhofer ISE set a new world record for Si solar cells that are contacted on both surfaces, applying TOPCon technology. Is this technology the most promising one for the future?

Stefan Glunz: TOPCon technology is based on a thin tunnel oxide, on which a strongly doped Si layer has been deposited. This can be used to produce selective contacts which allow only one type of charge carrier to pass. TOPCon has great potential but the experience gained over the last few decades has shown that only those technologies which remain close to the main existing technology have a real chance of being adopted. We have thus used our TOPCon contact on the back of a solar cell which otherwise has been produced with conventional technology. We still have to solve several practical problems concerning industrial implementation before commercial maturity similar to that of the PERC technology is achieved.

NexWafe is the newest spin-off from Fraunhofer ISE. What does it adress?

Ralf Preu: NexWafe is a spin-off which will now implement technology that has been under development at the Institute for more than ten years. The production costs of wafers can be reduced by up to 50 % by epitaxially manufacturing silicon wafers that can be directly used industrially – a real breakthrough for further cost reduction in photovoltaics.

Which new types of solar cells are you investigating?

Stefan Glunz: The best Si solar cells reach efficiency values that exceed 25 %. As the practical limit is around 26 %, there is not much room for further improvement. Thus, we are now working intensively on Si-based tandem solar cells with the potential for significantly higher efficiency. The technology is still in the initial stages but is making rapid progress. Fraunhofer ISE is an international leader in this field and is well prepared for Si solar cell version 2.0.

Total staff	288
Full-time equivalent staff	217
Journal articles and contributions to books	97
Lectures and conference papers	62
Granted patents	16

www.ise.fraunhofer.de/en/publications/1-01

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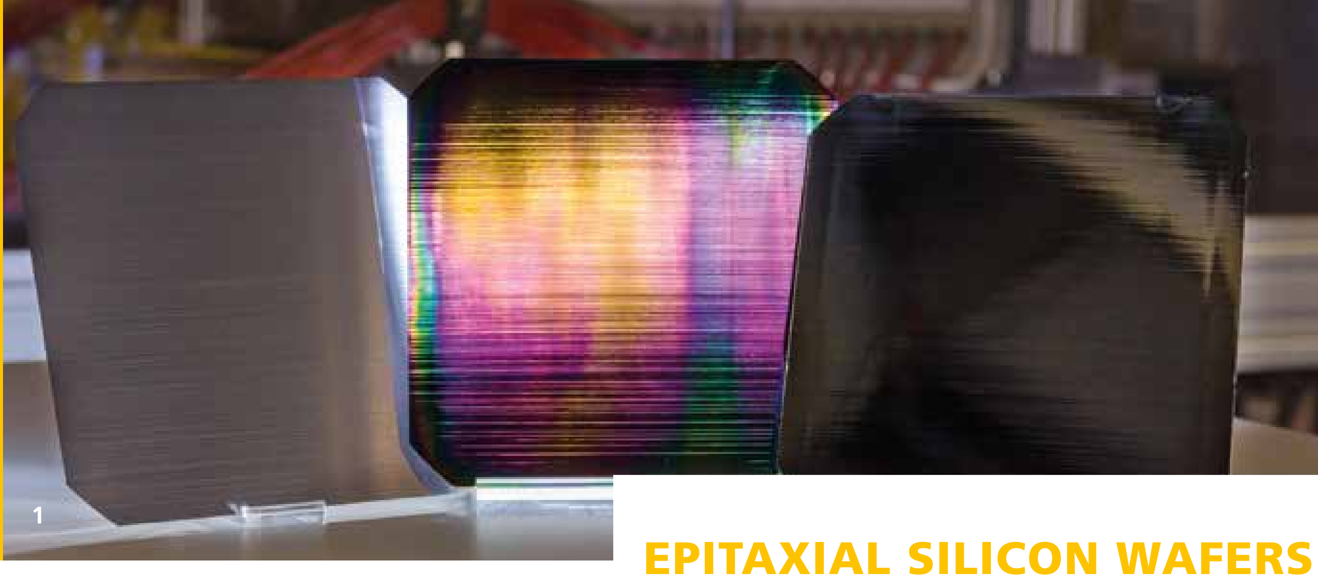
R&D PROJECTS IN 2015

- Galvanic contacting processes for cells with back-surface pn junctions
- Modelling of aluminium alloying processes for silicon solar cells
- PVD layer stack stable to tempering for conventional module connection of solar cells
- Identification of limiting impurities in silicon by photoluminescence imaging
- Development of a process suitable for in-line quality control of multicrystalline silicon wafers

More information on these and further R&D projects:
www.ise.fraunhofer.de/en/research-projects/1-01

New materials / processes
Measurement-based analysis / quality control

Photo p. 14: In-line furnace with two processing tracks to temper crystalline silicon solar cells in the PV-TEC of Fraunhofer ISE.



EPITAXIAL SILICON WAFERS FOR PHOTOVOLTAICS

Fraunhofer ISE develops equipment, processes and technology to produce epitaxial silicon wafers (EpiWafers), which can be used to produce solar cells with efficiency values exceeding 20 %. EpiWafers are monocrystalline and about 150 micrometres thin. Our special deposition process allows the thickness to be controlled, such that thin films with a thickness of only a few tens of micrometres can also be produced. In addition to flexible wafer thickness, we offer different concentrations of n and p dopants within narrow tolerance ranges.

The first processing step in producing an EpiWafer is electrochemical porosification of a monocrystalline silicon wafer which is almost 1 mm thick. Together with partners, we have developed in-line equipment for treating wafers with an area of 156 x 156 mm^2 in this way.

The subsequent atomic reorganization to form a crystalline template and allow epitaxial growth of the silicon layer occurs in a prototype system developed exclusively at Fraunhofer ISE, named "ProConCVD". Different chemical vapour processes in this equipment allow a wide range of diverse film stack variants to be deposited. It achieves a throughput of about 1000 wafers per hour and can process samples up to an area of 500 x 500 mm^2. During atomic reorganization under a hydrogen and argon atmosphere, we generate not only the template for epitaxy but also a dividing layer which defines the intended separation plane. The separation and thereby the production of the EpiWafer happens in a vacuum-assisted separation unit. In order to manufacture solar cells, the EpiWafer is treated in exactly the same way as the monocrystalline wafers used in the standard process. We demonstrated minority charge carrier lifetimes of more than 1000 µs for n-type EpiWafers with a thickness of about 100 µm, and the first solar cells with an area of 2 x 2 cm^2 achieved an efficiency value of 20 %.

In addition to preparing internationally unique equipment, we have gained many years of expertise in characterizing and processing epitaxial silicon layers. We offer routine and developmental services for all processing steps, but also support in substrate selection, diverse procedures to transfer the films onto inexpensive substrates and adapted solar cell processes.

The long-term exploratory research was financed with public funding from the German Federal Ministry for Economic Affairs and Energy (BMWi) and the EU. The "Fraunhofer Zukunftsstiftung" (Foundation for the Future) participated in funding the work on the ProConCVD facility. With the goal of transferring EpiWafer technology to industrial production, the spin-off NexWafe has been founded under the management of the experienced former Head of Department for Silicon Materials at Fraunhofer ISE, Dr Stefan Reber. Currently, we are cooperating with NexWafe to continually improve the quality and commercial maturity of EpiWafers.

1 *Seed wafer, porosified wafer and epitaxially grown Si layer (from left to right).*

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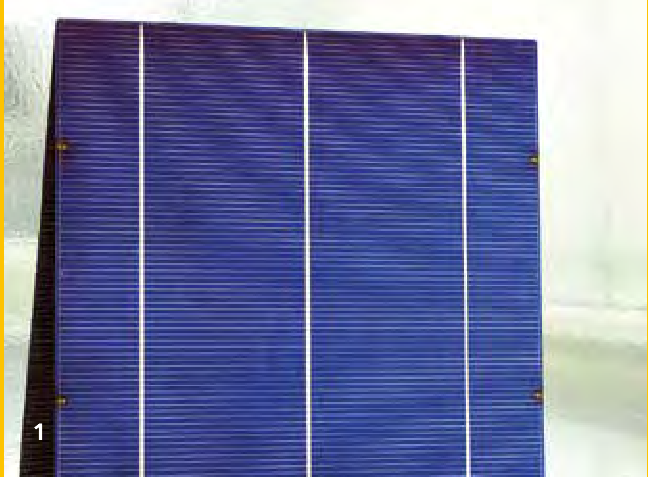


LOCALLY CONTACTED, PASSIVATED SOLAR CELLS OF CRYSTALLINE SILICON

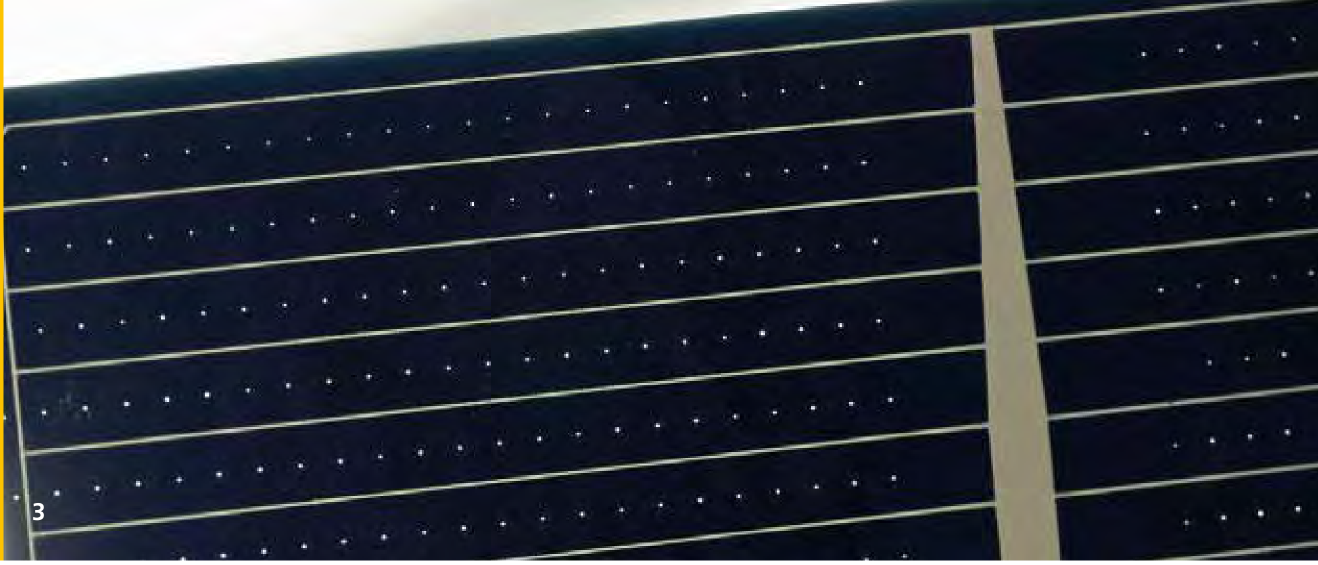
During the past decade, PV module efficiency values have increased by 0.3–0.4 % annually. In order to reduce the levellized cost of electricity still further, greater efforts must be made to upscale solar cell concepts with the potential for higher efficiency and transfer them to industrial production. The high-efficiency concept of dielectric passivation with local contacts was introduced as PERC (passivated emitter and rear cell) in 1989 to p-doped silicon. The basic idea is to use dielectric films with a thickness of about 10 nm. These improve the optical properties appreciably and reduce charge carrier recombination on the surface. In order that current can be conducted through the dielectric, it must be perforated locally over 1–10 % of the surface area. This approach has long been the industrial standard for the front surface. Locally applied pastes containing silver penetrate the dielectric. However, at present the back-surface electrode is usually produced industrially by screen-printing a paste containing aluminium over the whole surface and subsequently alloying it at temperatures of around 800 °C (Al back-surface field – BSF). In order to introduce PERC technology into a process similar to Al BSF production, the structure was created before metallization by combining a dielectric thin-film stack with a local contact structure, which can be produced very efficiently with a laser. A major advantage of this approach is that the components can be integrated directly into the currently dominating production technology for screen-printed solar cells, with the contact alloyed into the entire back surface.

Simplifying the production process and transferring the PERC structure to an industrial scale has been a central component of the work at Fraunhofer ISE for more than 15 years. During the past three years, this type of cell has been introduced to industrial production in increasing quantities and is presently the most important contributor to efficiency increases in industrially screen-printed solar cells. The fundamental technologies which we have developed and transferred for this purpose include local contact structuring by lasers and the deposition of aluminium oxide as a dielectric passivation layer. In our pilot line in PV-TEC (Photovoltaic Technology Evaluation Center), we have developed an industrially relevant solar cell process for large-area PERC solar cells. Applying it, we reach efficiency values of 20.7 % on monocrystalline silicon and 19.0 % on multicrystalline silicon. Our technological partners among equipment manufacturers, including Roth&Rau, Innolas and Manz, are international leaders in equipping or upgrading about 10 % of the current global production capacity.

The linear form of the printed back contacts for PERC solar cells means that the back of the cell is partly transparent. In combination with a transparent back cover and encapsulation, e.g. with glass, the additional electricity-generating potential of bifacial modules can be exploited. To this purpose, we have developed the biPERC technology, for which we have achieved efficiency values with multicrystalline silicon of 18 % with front illumination and 14 % with back illumination, without taking account of additional yield due to illumination of the other side.

Our BOSCO (both surfaces collecting and contacted) solar cell also allows material with a shorter diffusion length to be used. This is achieved with an emitter which is diffused from both sides and is interrupted on the back surface only near the back-surface electrodes. It is connected with the emitter on the front surface through holes which are created and diffusion-doped by laser processes. With the emitter being located and collecting charge carriers directly under the back surface, the efficiency value for back-surface illumination achieves almost the same values as for front-surface illumination.

1 *Front surface of a solar cell.*
2 *Back surface of a solar cell.*



Further development of these solar cells with dielectrically passivated back surfaces and local contacts focuses on cost-saving and efficiency-increasing technological components. For instance, we have further developed the phosphorus diffusion process to create the emitter, and have achieved a significantly lower surface phosphorus concentration with excellent homogeneity over the wafer and in the processing crucible. It allows us to produce emitters with a concentration of 2 to 3 x 10^{19} cm^{-3}, which possess a specific contact resistance to currently used silver screen-printing pastes of less than 5 mΩ cm^{-2}. In order to improve the contact topology of the printed silver front electrodes, we extrude the metallic pastes through hair-fine nozzles, resulting in contact fingers that are only 27 µm narrow and have an excellent aspect ratio of 0.8. On the back surface, we replace the conventional pastes by aluminium foil with very low material costs, better electrical conductivity and optimized optical properties. In addition, the process flow is simplified significantly and two processing units can be saved. Increasing the diffusion length in the material is an essential aspect in improving the efficiency of PERC cells. The base in conventional silicon is doped with boron, meaning that so-called light-induced boron-oxygen degradation occurs, which is particularly significant for monocrystalline silicon and can lead to efficiency value losses of 2 $\%_{abs}$. We have developed an extremely rapid regeneration process, with which the material can be annealed in less than 1 s per wafer and transformed into a state which is stable under operating conditions and is very close to the initial state. Our 3D simulations predict that the combined effect of these innovations has potential for an efficiency value of 22.5 %.

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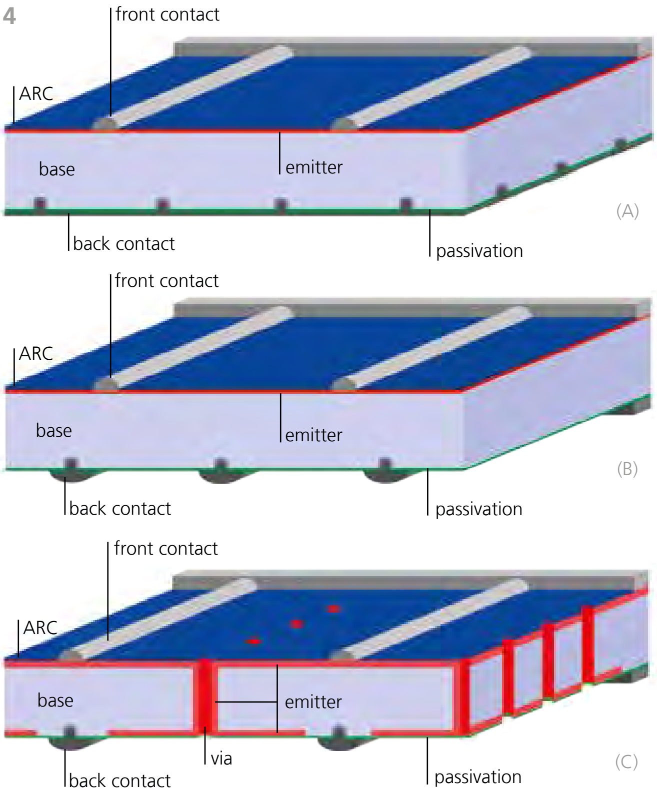

We are also developing PERC solar cells on the basis of n-doped silicon. To this purpose, we have designed a laser-based process for strong doping from a passivation layer that contains phosphorus as the dopant. By further developing these so-called PassDop layers, we have achieved an efficiency value of 20.9 % on large-area screen-printed n-type solar cells. It is also possible to improve the local contact quality for p-type solar cells with boron-doped PassDop layers.

3 *BOSCO solar cell with holes (vias) which serve to contact the back-surface emitter with the front surface.*

4 *(A) Structure of the PERC solar cell; (B) Structure of the biPERC solar cell; (C) Structure of the BOSCO solar cell.*

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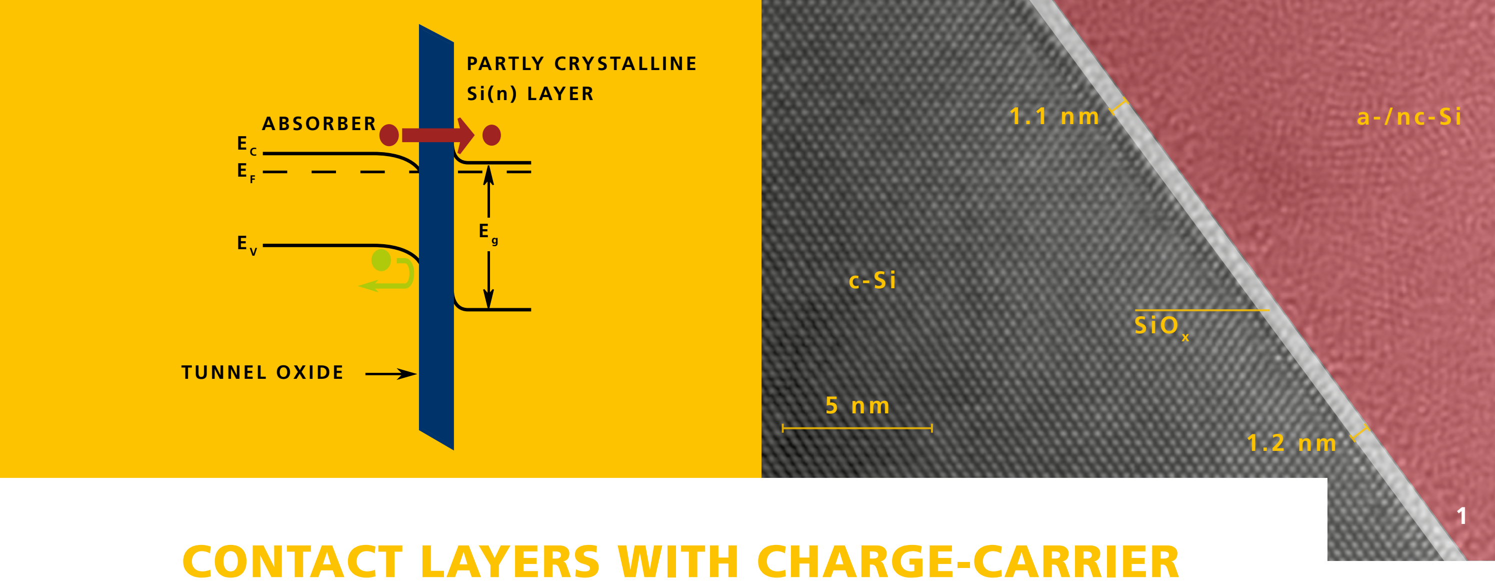


CONTACT LAYERS WITH CHARGE-CARRIER SELECTIVITY FOR HIGHEST EFFICIENCY VALUES

Application in High-Efficiency Solar Cells

The efficiency of industrial silicon solar cells has recently improved appreciably with the introduction of the PERC structure (passivated emitter and rear cell), see pp. 18 and 19. Detailed loss analysis of these modern solar cells has identified the central role of charge carrier recombination at the contacts. To reduce these losses generally, a doping profile underneath the contact is created by diffusion or alloying to prevent minority charge carriers from reaching the highly recombination-active metal / semiconductor interface (e.g. in the aluminium back-surface field). Additionally, the surface area covered by contacts can be strongly reduced (e.g. PERC solar cell structure). However, both concepts have inherent disadvantages, particularly when highest efficiency values should be achieved.

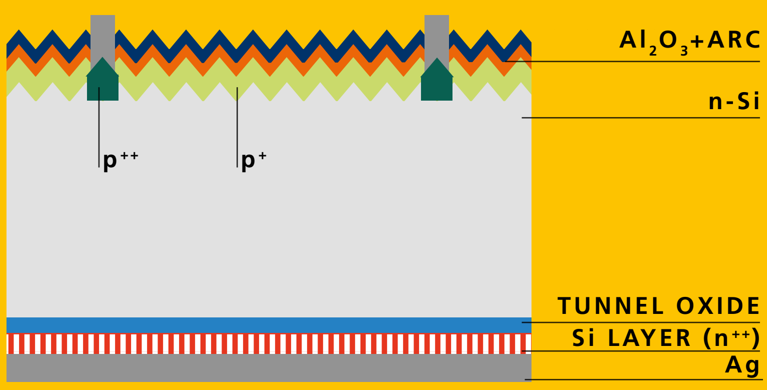
An alternative is offered by passivated or carrier-selective contacts. The best-known example is offered by hetero-junction solar cells, which achieved record efficiency values. The central component of this type of solar cell is a hetero-junction from crystalline to amorphous silicon (a-Si/c-Si). This junction has a very advantageous electronic band structure, so that only one type of charge carrier can pass it. As a result, charge carrier recombination on the actual contact is effectively suppressed and extremely high open-circuit voltages of up to 750 mV are achieved. However, amorphous silicon is very temperature-sensitive, so that special metallization procedures have to be applied.

At Fraunhofer ISE, we have now developed a contact structure with materials which are more stable at high temperatures. The so-called TOPCon contact (tunnel-oxide passivated contact) consists of an extremely thin tunnel oxide (< 1.5 nm) and a strongly doped silicon layer which is deposited by PECVD (plasma-enhanced chemical vapour deposition, Fig. 1). Test samples show that the TOPCon contacts have very low recombination currents (< 10 fA cm^{-2}) and very low contact resistances (< 10 mΩ cm^2). Encouraged by these results, we have applied TOPCon technology as a full-area back contact for an n-type solar cell with a boron-diffused emitter. The cell has a relatively simple configuration (Fig. 2) and does not have the structured back surface which is needed otherwise.

This cell structure with contacts on both surfaces has achieved efficiency values of 25.1 % for small-area cells. The obtained open-circuit voltage of 718 mV and the fill factor of 83.2 % demonstrate that both the recombination and the transport properties of this cell are excellent. The achieved efficiency value is noteworthy, as values exceeding 25 % are seldom achieved anywhere in the world. Most often, cells with back-surface contacts were involved, as they do not suffer from shading losses caused by front-surface contacts. However, the configuration and production of such back-contact cells is significantly more complex. In general, a cell structure with contacts on both surfaces is simpler to implement. With the same cell structure and TOPCon technology, we have also achieved a very good efficiency value of 19.6 % on multicrystalline silicon.

At present, we are upscaling this cell concept, which could prove to be the technological successor to the currently applied PERC technology. We are devoting particular attention to the metallization of the TOPCon contact and the front surface of the solar cell. Traditional screen printing may not be suitable to exploit the full potential of this cell structure. We are therefore working on metallizing the front surface with galvanized Ni/Cu contacts and on chemical processes to make the metal films, which have been deposited onto the back sur-

1 *TOPCon technology: Band structure (left). Transmission electron micrograph of a cross-section (right).*



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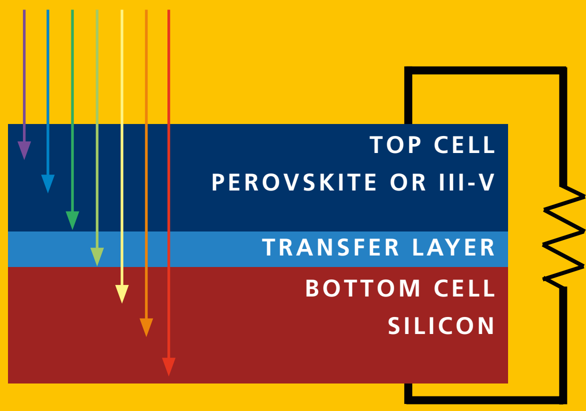


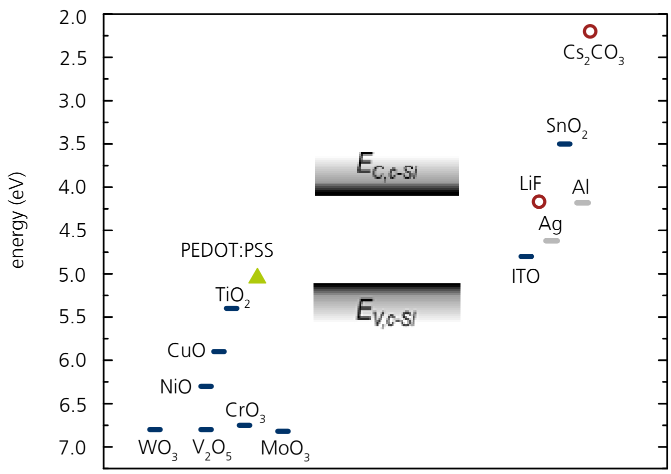
3

face by PVD processes, solderable. A further challenge is the development of selective contact layers for the front surface of the solar cell. Both the well-known a-Si/c-Si hetero-junctions and the TOPCon structure feature parasitic light absorption, which reduces the short-circuit current of the solar cell. We have therefore investigated a large number of different layers experimentally and theoretically (Fig. 3) and tested them for electrical and optical suitability.

Application in Tandem Solar Cells

With efficiency values exceeding 25 %, silicon solar cells are approaching their practically achievable limit of about 26 % more and more closely. As the efficiency is decisive for further cost reduction, particularly at the system level, technologies must be found which circumvent the physical limits of a purely silicon solar cell. One particularly attractive variant is the silicon-based tandem solar cell, in which a solar cell with a larger band gap is deposited onto a silicon solar cell. We are currently working on combinations both with III-V solar cells and perovskite solar cells (p. 29). In both cases, we are focussing on a monolithic configuration of the entire tandem cell. This would allow us to retain the classic module construction. Furthermore, industrial production of purely III-V-based tandem cells for concentrator applications showed that this configuration is more promising than mechanically stacked structures. In order to produce a monolithic tandem solar cell with only two contacts, the two individual solar cells must be electrically "connected" to each other. If this is done with an additional layer, this in turn must be transparent and electrically conductive. This presents another application for layers with charge-carrier selectivity. Thus, carrier-selective contact layers will play a key role both for the next generation of solar cells and concepts for the future.

The work was supported by the German Federal Ministry for Economic Affairs and Energy (BMWi).



4 *Different contact layers with the potential for charge-carrier selectivity on Si. The y axis indicates the energy of the work function for an electron to escape from the material surface and the band gap of silicon ($E_{C,c\text{-}Si}$ und $E_{V,c\text{-}Si}$).*

2 *Configuration of the n-type solar cell with a TOPCon contact over the entire back surface.*

3 *Fundamental configuration of a monolithic, silicon-based tandem solar cell.*

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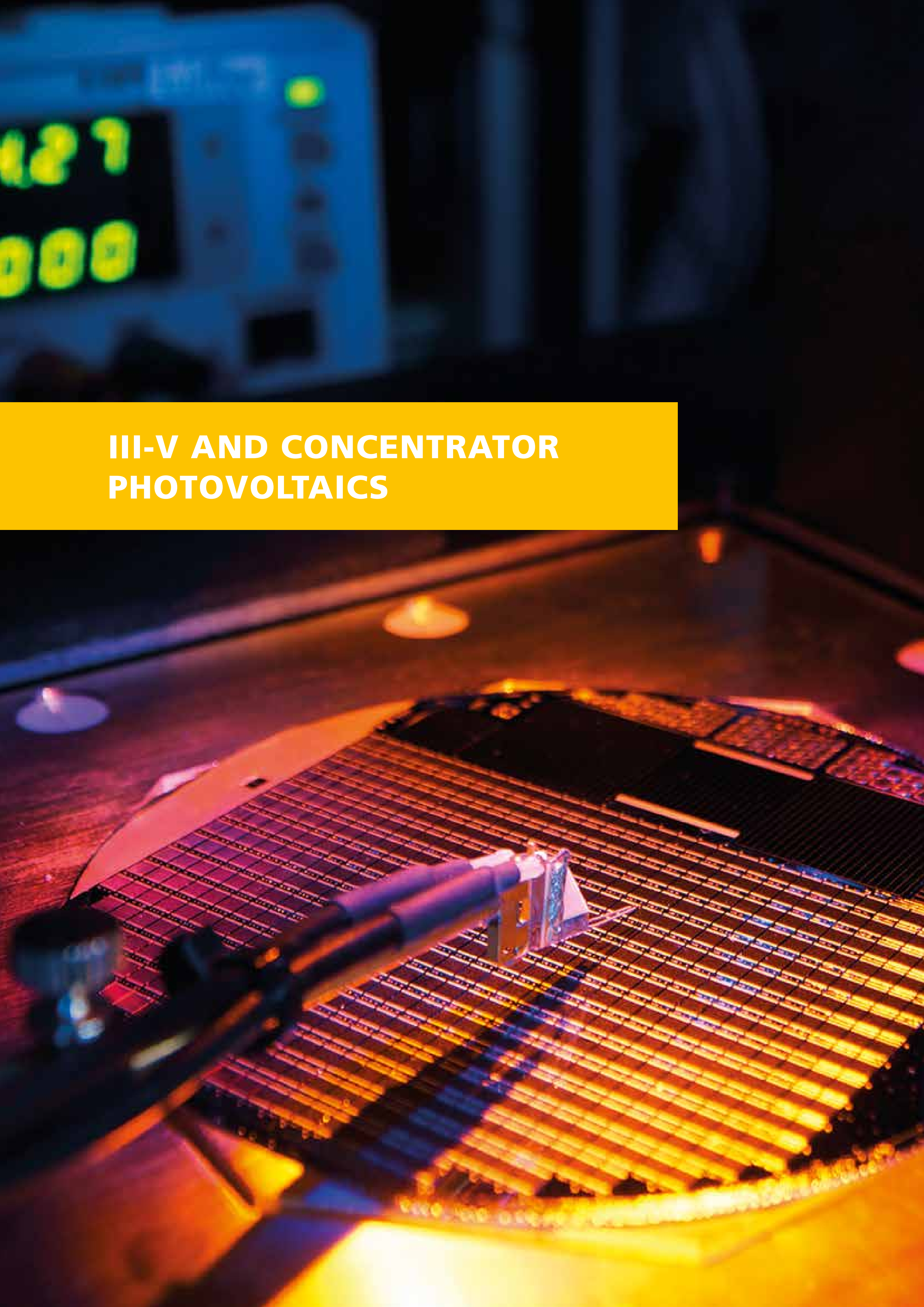
III-V AND CONCENTRATOR PHOTOVOLTAICS



Interview with Dr Andreas Bett
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Fraunhofer ISE is the world record holder for the efficiency value of multi-junction solar cells and achieves top values for concentrator modules. What is the cause of the Institute's technological leadership?

The foundations are firstly the highly motivated staff members, who consistently respond to the considerable creative freedom offered with innovations, secondly the excellent experimental equipment at the Institute, with which new ideas can be validated convincingly, and thirdly the long-term and thus sustainable financial support by industry and funding bodies. Furthermore, it is decisive that we analyze our experiments with high-quality characterization and modelling, so that optimization potential can be explored systematically.

The market share for concentrating photovoltaics is still very low. How do you rate the chances for a breakthrough by this technology?

Concentrator PV (CPV) with its high efficiency values is ideal for power plants with low levellized costs of electricity in sunny regions. Compared to silicon flat-module technology, however, it has not been long in the market so far. Scaling effects in production could not be fully exploited yet. The number of CPV power plants installed in 2012/2013 increased significantly. The growth setbacks in 2014/2015 are due to the long development times and large financing volumes for large-scale projects in the two-digit megawatt range. These challenges must be addressed better to make further growth of CPV technology and thus a breakthrough feasible.

Which optimization approaches are you pursuing?

The most important goals are to increase efficiency and reduce costs. Our favorite is to combine both! Our target efficiency values are 50 % for multi-junction cells and 24 % for Si concentrator cells. To this end, we are investigating new materials, production and processing technologies. The optimization potential for module technology lies in the concentrator optics and production.

What do you aim to achieve in research on silicon concentrator solar cells?

In addition to PV modules on fixed stands, tracking PV systems are often installed. When they are evaluated regarding the whole energy system, tracking PV systems can be very cost-effective. Low-concentrating modules with concentration factors of 5 to 20 can be implemented. The advantages are the lower consumption of Si semiconductor material and the shorter energy amortization period. In my eyes, this technology has potential and we want to help our customers to develop suitable cells and systems.

What lies behind the recently announced Virtual Lab with CEA LETI in France?

We are already cooperating very successfully with CEA, e.g. to produce multi-junction solar cells on the basis of wafer bonding. The Virtual Lab is an extension of this cooperation. Together, we want to optimize new concepts for III-V multi-junction solar cells, but also innovative Si-based tandem cells. This will strengthen our international competitiveness and maintain the high level of European research.

How does the Power-by-Light technology round out the Institute's portfolio?

In Power-by-Light, light from lasers or light-emitting diodes is transmitted by optical fibres or through the air, and then converted at its destination by a photovoltaic cell into electricity. Energy can thus be transmitted without cables. With our expertise in III-V, concentrator and space PV, we can adapt the cells perfectly to the light source and maximize the efficiency: We have already achieved conversion efficiency values exceeding 57 %. For example, for a current project, we have produced cells for a system to monitor lightning-endangered rotors of wind energy converters. I see many possible applications for this technology.

Total staff	81
Full-time equivalent staff	68
Journal articles and contributions to books	28
Lectures and conference papers	29
Granted patents	6

www.ise.fraunhofer.de/en/publications/1-02

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R&D PROJECTS IN 2015

- Solar cell concepts for next-generation generators for space applications
- Small-angle light scattering in polymethyl methacrylate after up to 27 years in the sun
- Development of a standard to determine the rated power of CPV modules
- "SOPHIA" round robin for concentrator modules
- Receivers and systems for low-concentrating PV
- Highly efficient concentrator module with GaSb-based four-junction solar cell
- Optically powered sensor networks for wind energy

More information on these and further R&D projects:
www.ise.fraunhofer.de/en/research-projects/1-02

New materials / procedures
Prototypes / pilot series
Analysis based on measurement technology / quality control

Photo p. 22: World record cell on 100 mm wafer with approx. 500 concentrator cells.

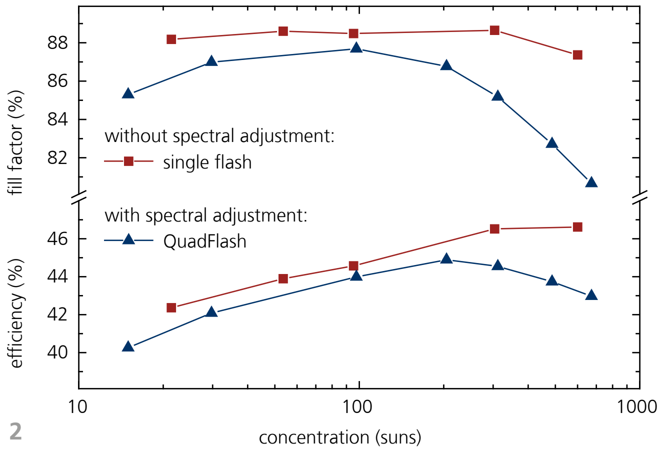
1

CHARACTERIZATION OF MULTI-JUNCTION SOLAR CELLS AND CONCENTRATOR MODULES

High efficiency multi-junction solar cells based on III-V semiconductors are developed at Fraunhofer ISE for space and concentrator applications. With a four-junction concentrator cell, we have achieved a new world-record efficiency value of 46.0 %, as was confirmed independently by AIST in Japan. The solar cell was developed together with Soitec and CEA LETI in France and is based on wafer-bonding technology. Incorporated into our FLATCON® concentrator module, we achieve an efficiency value of 36.7 %. In a concentrator module produced by Soitec, which uses these four-junction cells, a new world-record efficiency value of 38.9 % was measured.

Determining these efficiency values is more complicated than for conventional silicon solar cells due to the cell structure with its four internally connected sub-cells. This is also indicated by the fact that the relative measurement uncertainties for the efficiency values above amount to up to 7 %. Parallel to further development of the solar cells themselves, Fraunhofer ISE is thus working intensively on defining suitable characterization procedures. In doing so, we cooperate closely with our colleagues at AIST in Japan and NREL in the USA.

A particular challenge associated with multi-junction solar cells is adapting the spectral distribution of the solar simulator used. In a four-junction solar cell, the spectra in four spectral ranges must be adjusted independently of each other such that each of the four sub-cells generates the same current as under standard conditions. To this purpose, we use solar simulators with several light sources. To characterize four-junction solar cells under high irradiance, we recently began to use the "QuadFlash" measurement stand with four flash lamps equipped with different spectral filters. It allows spectrally adapted measurements of four-junction solar cells at irradiance values corresponding to concentration factors of up to 700. Figure 2 shows the measurement results for a four-junction solar cell with the "QuadFlash" compared to previous measurements with a single flash lamp. The difference in the measured fill factor and efficiency value is appreciable. The measurement uncertainty is reduced to 5 % by the better spectral adaptation.



2

The international standard on calibrating concentrator modules, IEC 62670-3, is still a draft, but decisive progress has been achieved in cooperation between NREL and Fraunhofer ISE. This applies particularly to the evaluation of the spectrum prevailing during outdoor measurements, input parameters for temperature corrections and the inclusion of laboratory measurements. We characterized a module from Soitec according to the standard and determined a new world-record efficiency value of 38.9 % under Concentrator Standard Testing Conditions (CSTC, AM1.5d, 1000 W/m², T_{cell} = 25 °C).

1 *Outdoor measurement test stand for CPV modules.*

2 *Fill factor and efficiency value for a four-junction solar cell as measured with "QuadFlash", compared to the previously used single flash lamp.*

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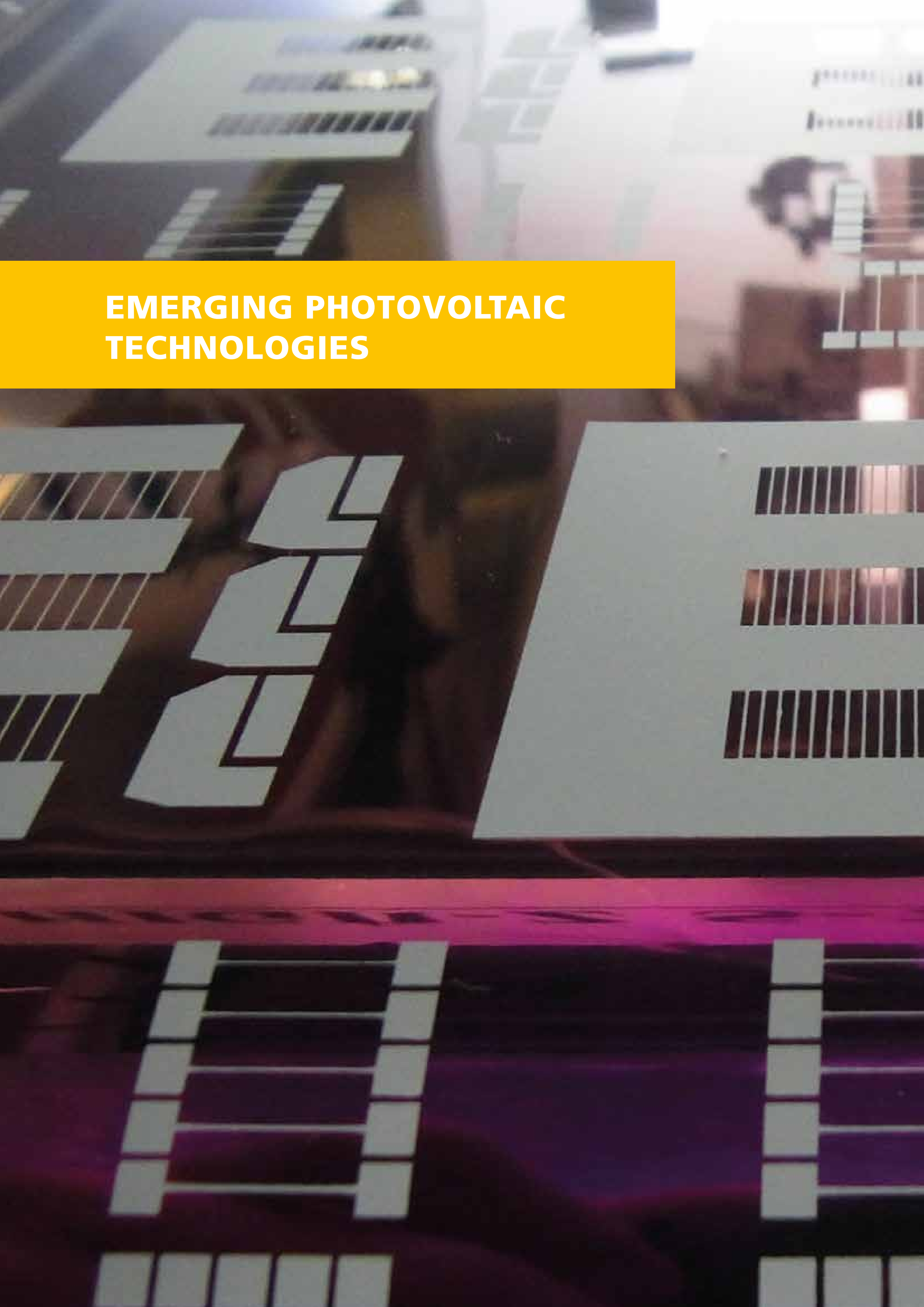
EMERGING PHOTOVOLTAIC TECHNOLOGIES



Dr Uli Würfel
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Emerging photovoltaic technology encompasses dye and perovskite solar cells, organic solar cells, photon management and tandem solar cells on crystalline silicon. The aim is to tap optimization potential in photovoltaics with the help of these novel technologies and to reduce the levellized cost of electricity. This includes improving the efficiency of well-established solar cells, e.g. of crystalline silicon, by improving the absorptive and reflective properties by advanced photon management. Another approach is provided by alternative processes and materials such as dye and organic solar cells, despite their lower efficiency, which are significantly less expensive.

We are conducting basic research on organic solar cells, particularly addressing the fundamental properties of selective contacts and their implementation with inexpensive, durable raw materials and extremely thin films. In addition, we aim to transfer promising results from the cell level to the module level. Another goal is to cooperate with industrial partners in developing stable coating and encapsulation processes on our roll-to-roll coater which can then be used in full-scale equipment.

Perovskite solar cells also consist of very inexpensive raw materials and are produced in low-temperature processes. However, their high degree of crystallinity and the efficiency values achieved so far make them more similar to crystalline inorganic solar cells. In order to improve their stability, we draw particularly on the experience we have gained in upscaling dye solar modules.

Total staff	48
Full-time equivalent staff	36
Journal articles and contributions to books	44
Lectures and conference papers	11

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We are developing silicon-based tandem solar cells to make better use of the solar spectrum by reducing thermalization losses. In addition to adapting the processes for the Si bottom cell and developing tunnel contacts, we are also working on new silicon nano-crystalline materials with adjustable band gaps and III-V-based absorber materials. The two sub-cells are combined either by growing the top cell epitaxially directly on the bottom cell, or by wafer bonding. We are also further developing the perovskite and silicon layers of perovskite-silicon tandem solar cells.

In the area of photon management, we develop concepts, materials and technology to increase the efficiency of conventional photovoltaic technology by applying optical approaches. These include light-trapping structures such as diffractive gratings and scatterers, up-conversion, angular selectivity and spectral splitting. The investigated concepts are usually not restricted to a specific solar cell technology.

Photo: Flexible organic solar cells produced in a roll-to-roll process, with silver electrodes that were applied in a roll-to-roll screen-printing process.

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R&D PROJECTS IN 2015

- Development of nanoporous silicon layers with an in-line process
- Novel electrode materials for organic solar cells with higher efficiency values
- Diffractive back-surface structures for high-efficiency crystalline silicon solar cells
- Greater reliability of transparent glass façades with organic solar cells
- High-efficiency, printed perovskite solar cells

More information on these and further R&D projects:
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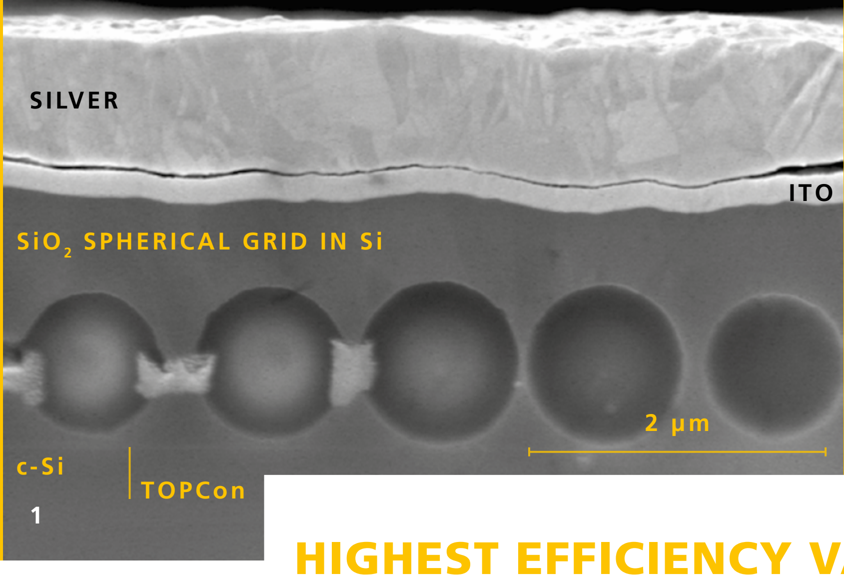
New materials / processes
Prototypes / pilot series
Analysis based on measurement technology / quality control

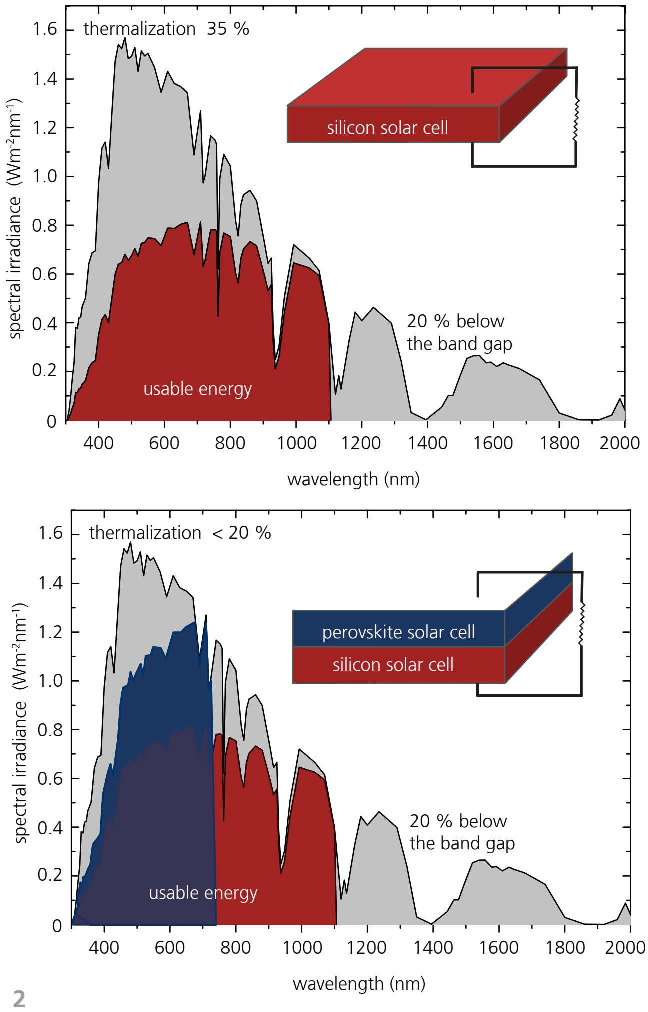


1

HIGHEST EFFICIENCY VALUES WITH SILICON-BASED TANDEM SOLAR CELLS

Higher solar cell efficiency values reduce the levellized cost of electricity. However, purely silicon photovoltaics has almost reached its realistic efficiency limit of about 26 %. In order to achieve significantly higher efficiency values, spectral losses must be reduced. This is possible with tandem solar cells. In doing so, starting with the well-established silicon technology reduces development costs and allows for more rapid market penetration. Fraunhofer ISE is thus developing Si-based tandem solar cells, in which a top solar cell with a larger band gap efficiently uses higher-energy photons, while the bottom Si solar cell converts lower-energy photons into electricity.

A variant of this type of tandem cell is based on the combination of silicon and perovskites. After just ten years of development, perovskite solar cells have achieved efficiency values exceeding 20 %; in addition, they can be produced inexpensively on Si solar cells. The perovskite solar cells must be adapted, and transparent electrically conductive layers must be developed and their stability increased. In doing this, we profit from our long years of experience in developing dye and organic solar cells. We also optimize charge carrier transport and the electric connection between the sub-cells and develop adapted Si solar cells. In order to increase light absorption, we create optical nanostructures and microstructures with improved light-coupling and light-redirecting properties. Alternatively, we investigate the application of III-V semiconductors in conventional thin-film stacks and as nanowires. We have already achieved an efficiency value of 25.6 % with a III-V tandem cell bonded onto a Si solar cell. Challenges are presented by cost-effective production and connection of the sub-cells. In order to reduce the losses due to low-energy photons with energy less than the silicon band gap, we are also developing up-conversion of these photons.



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1 Si/SiO$_2$ spherical grid on the back surface of a Si solar cell to increase the current in a tandem solar cell.

2 Tandem solar cells (below) use the solar spectrum significantly better than simple silicon solar cells (above).

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PHOTOVOLTAIC MODULES AND POWER PLANTS

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Module technology converts solar cells into durable products for safe operation in PV power plants. Fraunhofer ISE supports product development toward optimal efficiency, reduced costs, enhanced reliability and specialized applications such as building integration. We characterize modules at the highest level of accuracy, analyze their service lifetime and offer comprehensive module testing. From the planning process through to long-term operation, we offer quality-control services for PV power plants.

The Photovoltaic Module Technology Centre (MTC) is equipped with a wide range of processing and analytical platforms for mounting and connection technology, especially for testing materials, as well as developing products and processes. We apply measurement and simulation to analyze electrical, optical and mechanical effects and transfer developments from the laboratory phase to module pilot production in relevant module quantities and formats.

Total staff	95
Full-time equivalent staff	68
Journal articles and contributions to books	14
Lectures and conference papers	16
Granted patents	3

www.ise.fraunhofer.de/en/publications/1-04

The lifetime and degradation behavior of components in a PV power plant are decisive in determining its profitability. We monitor PV modules under different climatic conditions with equipment that has been developed in house. Preferably non-destructive, analytical methods (e.g. Raman and infrared spectroscopy) help to understand aging mechanisms and identify them as early as possible. We develop simulation models and accelerated testing procedures to investigate aging behaviour, particularly to characterize new materials and components. Not only the equipment of our TestLab PV Modules, which has been accredited since 2006, is available for testing, but also special testing facilities for combined loads or accelerated aging, some of them developed in house.

With the five phases of the Fraunhofer ISE quality cycle – development, engineering, procurement, commissioning and operation – we guarantee comprehensive quality control of PV power plant projects. Good planning, which takes site-specific and climatic factors into account, accurate yield predictions, project-specific selection of high-quality components, comprehensive power-plant testing during commissioning and continuous quality and power measurements during long-term operation are decisive for the economic viability and thus also for the "bankability" of a PV system. Highest accuracy is also offered by our accredited calibration laboratory, CalLab PV Modules, which is one of the internationally leading laboratories in this field, with its measurement uncertainty of better than 1.6 % for crystalline modules.

Based on our expertise in photovoltaics and energy supplies for buildings, we investigate topics concerning the integration of photovoltaics into the building envelope. Not only energy-relevant and architectural aspects but also building science and structural requirements are taken into account.

Photo: Non-destructive materials analysis of PV modules by Raman spectroscopy. This technology is applied to determine the spatially resolved degradation behaviour of polymer encapsulation material in PV modules. It allows degradation indicators for lifetime models to be measured simply and aging mechanisms to be identified.

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R&D PROJECTS IN 2015

- Efficient and reliable wire connection of solar cells
- Development of an industrially applicable recycling process for PV modules
- Pilot building-integrated installation of MWT-TPedge modules at Fraunhofer ISE
- UV stability tests of module back sheets
- Optimization of module testing procedures based on statistical evaluation
- Customized BIPV shingles for façades or roofs

More information on these and further R&Dprojects:
www.ise.fraunhofer.de/en/research-projects/1-04

New materials / processes
Prototype / pilot series
Patent / licence
Analysis based on measurement technology / quality control

1

FAILURE ANALYSIS OF PV MODULES – CAUSES AND EFFECTS

Analyzing failures found in some PV modules delivers valuable information on the extent, causes and effects of failures which become evident e.g. as reduced power output or optical defects. Affected modules are often received from PV power plants but they can also come directly from production or be sampled after laboratory testing. The analysis helps material and module manufacturers to identify and eliminate critical properties of the material combinations used and weak points in production quality control. Power plant operators receive recommendations about replacing modules in their plant to solve problems that compromise performance and safety. Fraunhofer ISE identifies causes and possible resulting damage in continued plant operation for operators, proprietors and insurance companies.

A specific case of failure analysis starts with non-destructive analysis of the affected modules. This often allows us to limit the number of possible causes or to attribute the defect to a specific component. Fraunhofer ISE is equipped with modern, non-destructive characterization equipment such as (dark lock-in) thermography, electroluminescence and dark IV measurement systems, as well as light microscopy and confocal Raman microscopy. For more detailed analyses, a special method to prepare samples was developed, with which we can isolate damaged parts of a PV module. This allows us to extract e.g. cell segments from PV modules for subsequent chemical analysis of the aging products.

By applying this technique and subsequent Raman spectroscopy, we were the first to distinguish different types of "snail tracks" on affected cell segments. Knowledge of the chemical products which cause the discoloration allows us to assess the risk posed by the affected PV modules. Up to now, four

2

different silver salts (Fig. 2) have been identified, which were present as crystallites on the front-surface metallization of accordingly prepared cell segments of several modules from PV plants in Europe. The reactions leading to formation of these degradation products differ markedly, meaning that we can use this knowledge together with information from the bill of materials (BOM) to analyze the causes and derive the potential risk of future power losses for modules with an identical configuration.

1 *PV module affected by "snail tracks".*

2 *Four different snail track products, which were analyzed by Raman spectroscopy.*

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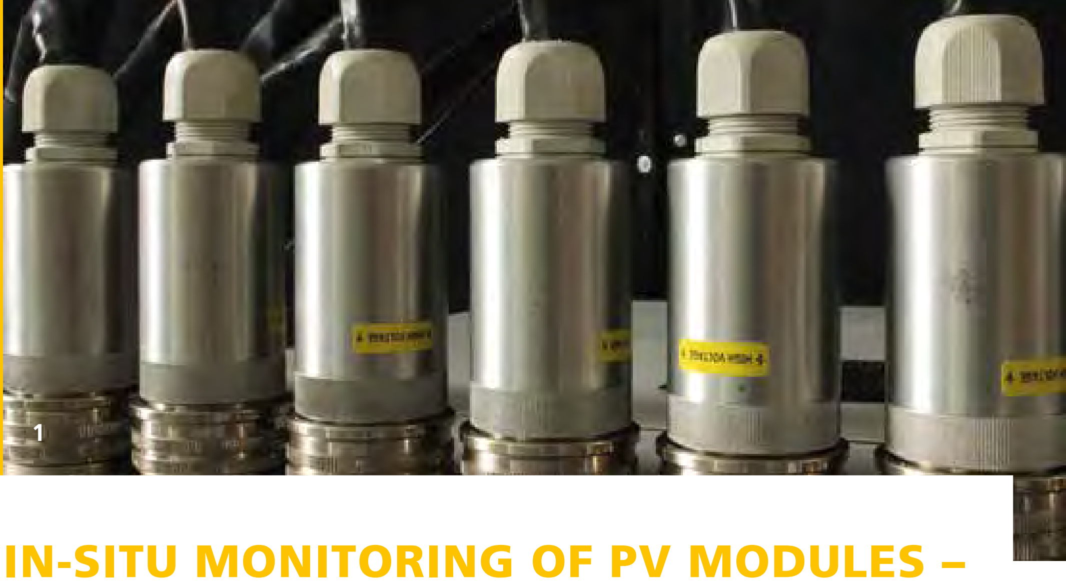
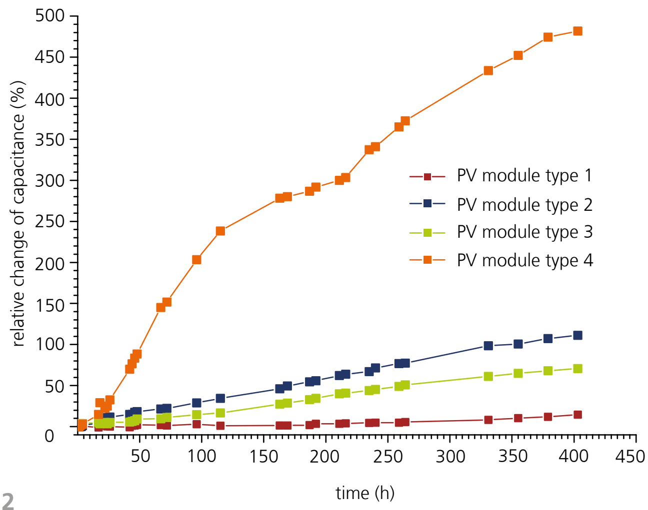


1

IN-SITU MONITORING OF PV MODULES – CONTINUOUS OBSERVATION OF AGING

For lifetime and reliability tests of PV modules testing procedures have been established, in which the modules are subjected to defined loads in climatic chambers. Normally characterization measurements are carried out before and after exposure to the load, in order to identify changes to materials or power output losses. The disadvantage of this sequential procedure is that a result is not available until the complete exposure time has passed. Due to the growing cost pressure along the entire photovoltaic value chain, the demand for more efficient and yet still informative testing procedures is increasing.



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Fraunhofer ISE has developed different in-situ measurement methods in its TestLab PV Modules, with which aging processes can already be detected during exposure to a load. This allows testing times to be optimized and costs for elaborate initial, intermediate and final characterization to be saved. Furthermore, more information can be gained from the testing procedure, as the change of the degradation processes with time can be documented.

Among others, we have developed a monitoring system for tests of potential-induced degradation (PID). Parallel to application of the load, the Dark IV curves of up to eight modules are measured at pre-defined time intervals. The high-resolution measurement over a range of up to +70 V and +14 A allows characteristic module parameters to be determined and their changes to be tracked. This makes not only conclusions on the effect of the load over time feasible, but also observation of cell regeneration processes when the electric potential is reversed or no longer applied. A further example for the introduction of in-situ monitoring to TestLab PV Modules is exact measurement of the complex insulating properties of PV modules. By tracking the capacitive and resistive insulating effect of the cell encapsulation over time, we can qualitatively observe e.g. the process of moisture ingress during a damp-heat test according to IEC 61215. This information helps us to interpret and explain aging effects. Furthermore, this system can be used to determine the complex insulating properties of PV modules under well-defined environmental conditions. Accurate knowledge of these properties helps to prevent disconnection of inverters due to complex currents, when such modules are used in power plants.

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1 Connectors of the automatic monitoring system for PID testing. The cables are used to apply test voltages of up to ± 1000 V and to measure the dark characteristic curves.

2 Relative change of capacitance due to ingress of moisture during a damp-heat test.

1

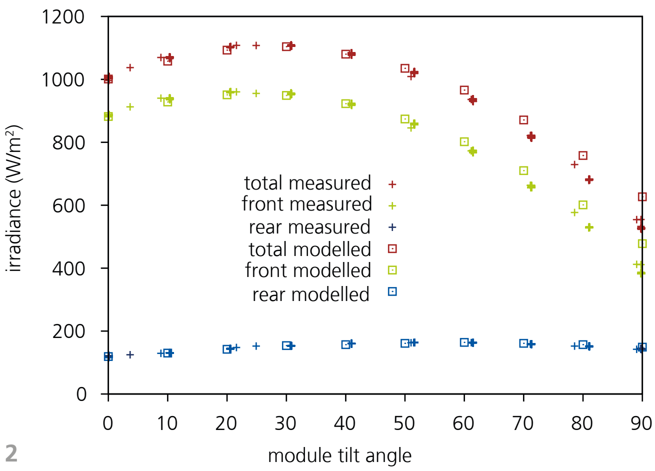
CHARACTERIZATION AND YIELD PREDICTION FOR BIFACIAL PV MODULES

Bifacial PV modules can use light which is incident on the front and back surfaces to generate electricity and thus offer great potential to increase the yield of PV power plants. The additional yield when compared to conventional modules depends on the back-surface efficiency and the irradiance incident on the back of the cell. As this irradiance is affected by the geometrical configuration of the installation and the surrounding conditions, the additional yield does not depend only on the module but also on system properties.

Bifacial modules pose new challenges to measurement procedures. To calibrate bifacial modules, the power generated under standard test conditions for illumination of one surface can be measured by covering the other surface with a light-absorbing material. Other relevant properties determining the yield, such as temperature coefficients and low-light performance, are also determined with illumination of one surface.

In order to analyze the module power under bifacial illumination, Fraunhofer ISE has developed a measurement stand in CalLab PV Modules, which allows different irradiance values and conditions to be applied simultaneously to the two module surfaces. In this way, we can simulate the typical irradiance conditions that can be expected for different installation topologies. This makes bifacial Power Rating feasible, with results that can be used for yield calculations.

Bifacial modules also pose new challenges to yield calculations. To date, none of the well-known simulation programs has been capable of calculating the back-surface irradiance correctly. Fraunhofer ISE has thus developed a ray-tracing procedure to calculate the optical gains by the back-surface within time-step simulations. In this way, we have extended our existing procedure for PV yield prediction appreciably.



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Based on these tools for module characterization and system simulation, we will be able to accurately analyze and optimize future bifacial PV power plants, from the individual module through the mounting system to the installation topology.

1 *Measurement of back-surface irradiance and module output power as a function of the module tilt angle.*

2 *Measured and calculated irradiance values on the front, back and both surfaces for the free-standing PV module shown in Fig. 1 and different tilt angles on a clear day.*

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SOLAR THERMAL TECHNOLOGY

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For the transformation of thermal energy systems, solar thermal energy is a central component alongside energy efficiency. How this role is interpreted in different national economies and climatic zones also depends on cost developments in production and distribution. Research and development can make its contribution by developing more cost-effective materials, manufacturing processes and complete systems which are optimized with regard to investments and yield.

In our work on solar thermal technology, we are concerned with optics and surface technology to better transmit, reflect, absorb, redirect or concentrate solar radiation, depending on the application. Also, solar thermal technology and systems technology are developed further: Solar thermal flat-plate and evacuated tubular collectors find diverse applications from domestic hot water and space-heating systems to coolers and chillers. Competition with photovoltaics for installation space means that new developments in façade-integrated collectors or thermal collectors combined with photovoltaic power generation are important. Linearly concentrating collectors can reach operating temperatures from 150 °C up to 550 °C. They are used in large power stations not only for solar thermal electricity generation but also in often simpler and less expensive variants to generate process heat, processing steam and heat to drive absorption chillers.

Total staff	73
Full-time equivalent staff	55
Journal articles and contributions to books	17
Lectures and conference papers	36
Granted patents	1

www.ise.fraunhofer.de/en/publications/2-00

Energy efficiency in industrial plants also represents an important application field for solar thermal technology. For example, we are working on improving the supply of heat by steam or other heat-transfer media, on storage units for high-temperature heat, or on increasing the efficiency of production processes with the help of innovative heat transfer. Membrane-based processes, driven by solar or waste heat, can be used to purify industrial waste water or to concentrate residual materials so that they can be recycled better.

Fraunhofer ISE possesses expertise ranging from materials science, component design, characterization and testing procedures, theoretical modelling and simulation through systems control, up to systems technology for the different applications.

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Photo: The "Crescent Dunes Energy Project" is a 110 MW solar thermal power station in Nevada, USA.

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R&D PROJECTS IN 2015

- Intelligent and energy-efficient windows based on new material combinations
- Determination of the reflectance and absorptance of solar cells with bifacially textured surfaces
- Cooling of shaping tools by bionic methods
- Neuronal networks for solar thermal applications
- Development of accelerated aging test procedures for solar thermal collectors and components

Further information on these and other R&D projects:
www.ise.fraunhofer.de/en/research-projects/2-00

New materials / processes
Software / application
Analysis based on measurement technology / quality control
Consultancy / planning / studies

NEW TECHNOLOGY FOR SOLAR THERMAL FAÇADES

Active solar building envelopes form an important component of a future energy system based on renewable energy sources. The trend toward lowest-energy buildings is supported by more stringent legal requirements on existing and new buildings and the increasing value of such buildings as real estate. Building-integrated solar systems (BISS) can already save costs today, as the demand for materials and labour is lower than when the building envelope and solar system are constructed separately. In addition, they offer high aesthetic quality. Building-integrated photovoltaic (BIPV) and solar thermal (BIST) systems are available for constructing active solar building envelopes.

The development of solar thermal façades differs markedly from that of conventional solar collectors. For example, architectural aspects such as dimensioning flexibility, functionality as a building component and aesthetics become much more relevant. Fraunhofer ISE has developed, modelled and characterized innovative BISS technology for years. The multi-functional usage of insulation, daylight and solar control allows building-integrated solar thermal systems to achieve greater utilization factors and lower heating costs. We have developed a broad spectrum of models to simulate the complex interaction of energy flows in multi-functional façade elements. Simplified models for BIST allow approximations to be evaluated in the early planning stages, whereas detailed physical models offer planning certainty, also for large-scale projects.

Starting from our innovative ideas, we have developed practically relevant new approaches for the building sector. One example is pre-fabricated façade elements, which make rapid and robust installation feasible at low cost. Here, an inexpensive, pre-fabricated, building-integrated photovoltaic thermal element was developed, which generates heat and electricity simultaneously. The elements were subsequently installed quickly in a demonstration building and connected to each other applying a click-in system. Façade elements of up to room height are measured using the OFREE test rig (Fig. 2). Together with industrial partners, we have already developed thermal components of ultra-high-performance concrete (UHPC) with integrated flow channels. Efficiency values comparable to conventional collectors were proven to be feasible, so that the concrete pre-fabrication industry can well extend its product portfolio to include active building envelopes (Fig. 1).

In order to give architects additional design freedom, we have developed heat pipe technology further. With it, façade collectors of minimal height and flexible length ("strip collectors") can now be produced with continuous connections to the header pipes. Heat pipes can also be used to construct a solar thermal venetian blind, which can offer renewably generated heat and solar control or an unobstructed view as desired.

1 *Cross-sectional view of a thermal component with integrated flow channels constructed of ultra-high-performance concrete (UHPC).*

2 *Using the OFREE test rig, the collector yield and the energy flux into the building are measured simultaneously.*

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1

OPPORTUNITIES FOR SOLAR PROCESS HEAT – FROM MINING TO LAUNDRIES

Solar process heat offers diverse possibilities to supply heat in the temperature range from 50 ° to 250 °C to trade and industry, which is currently based on fossil fuels, in an environmentally friendlier way. Whereas mainly flat-plate and evacuated tubular collectors are used at our latitudes, concentrating collectors, which can even generate steam directly, can be used in sunny regions. In order to integrate solar energy effectively into an existing heating circuit, it is important also to simultaneously improve the energy efficiency and optimize operation management.

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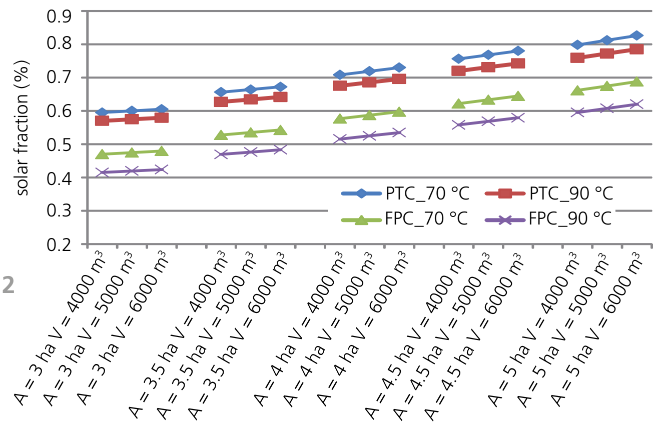

This allows the potential for using waste heat to be better exploited and heat losses to be avoided. Solar heat can be integrated flexibly at the supply level into an optimized circuit or used with optimal efficiency for selected individual processes. To assist in complex decision-making about such options, we develop validated planning tools. Our high-quality monitoring, supplying data for exact error analysis, reliable operation optimization and validation of simulation models, rounds out our work.

In the "SoProW" project, we are investigating the savings potential of the laundry sector in detail. To this purpose, a model laundry was developed which is available for further investigations and optimization. At present, we are discussing the advantages and disadvantages of specific integration points with our industrial partners.

In another project, we are addressing the properties of a solar heat supply for Chilean copper mines. Refining copper from ore is an energy-intensive process in several stages. One extraction method is so-called "bio-leaching", in which copper is released from the ore by bacteria. The results of our simulation model show that optimal temperature conditions for the bacteria could be provided by solar thermal technology, which leads to an increase of 18 % in the copper yield. An economically optimized collector array area would cover a quarter the area of the tailings heap and increase the production yield by 9 %.

In an electrolytic process, copper is deposited onto the cathode plates. The temperature must be maintained between 47 °C and 57 °C for this process. Solar thermal heat already meets up to 85 % of the heat demand for two plants in Chile. Both concentrating and non-concentrating technology are suitable for this application.

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1 *Parabolic trough array for the "El Tesoro" mine in Chile.*

2 *Increasing the solar fraction by increasing the array area and storage volume in systems based on flat-plate (FPC) and parabolic trough collectors (PTC).*

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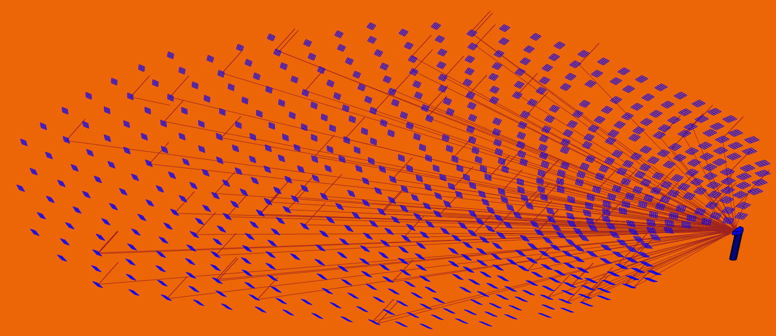

2

RESEARCH FOR SOLAR POWER TOWERS

Along with parabolic trough and linear Fresnel collectors, solar thermal power towers present a very promising technological option to generate electricity cost-effectively. They consist of a multitude of tracking reflectors (heliostats), which redirect beam solar radiation onto a central absorber (receiver) at the top of a tower. Very high temperatures are reached in the receiver due to the very high concentration of radiation there. The thermal energy gained in this way is used to generate electricity by a turbine in a power station. Alternatively, the energy can also be fed into a thermal storage unit and is then available for time-shifted electricity generation. For this, the potentially high temperatures and a short distance between the receiver and the storage unit are particularly advantageous. Thus, solar thermal power towers can generate electricity as required around the clock and can in the long term contribute in regions with a high proportion of direct radiation to stabilizing grids with large shares of energy from regenerative sources.

At the Fraunhofer ISE, we are working in different projects on further reducing the costs for this technology. Concerning the heliostats, current research topics include alternative reflector facets, tracking drives and controls, and optimized operation control and reflector cleaning. We are currently constructing a heliostat test site near our Institute. Furthermore, we are investigating and simulating different designs for the tower receiver. Due to the high temperatures, our focus is on concepts applying gas or molten salts as heat-transfer fluid. The development of cost-effective storage units including their optimal integration into the complete system and operation management are further main subjects of our work. The application of special photovoltaic receivers in solar power towers is also being investigated.

The cost-reduction potential can only be realized if all components of a power station are optimally matched to each other. In order to take account of this already during the developmental stage, we simulate components at the necessary level of detail, but also simulate their function in power station models which allow their function and yield to be predicted. In doing so, we apply simulation tools that we have developed ourselves, where we can adapt the models and level of detail very flexibly to answer different questions. Combined with cost data from industrial production, we also carry out techno-economic optimization.

Our research activities and service offers are complemented by investigations of the suitability of potential sites for solar thermal power stations, coating development for absorbers and reflectors, aging investigations and reliability tests. Similarly, we offer the characterization and quality control of components, as well as studies on combining solar power towers with other power stations and their integration into power supply systems.

1 *Aerial photo of the "Ivanpah Solar Electric Generating System" in California, USA, a solar power tower with a total power rating of 377 MW_{el}.*

2 *Partial visualization of an optical simulation with the in-house developed ray-tracing software, "raytrace3D".*

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BUILDING ENERGY TECHNOLOGY

Interview with
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The German energy transformation cannot succeed without buildings becoming more energy-efficient, so many laws and regulations addressing this issue have been introduced. How can Fraunhofer ISE contribute to their cost-effective implementation?

The fundamental measures concerning energy-efficient building envelopes are well known and understood today. However, improvements are still necessary to enable widespread and cost-effective application in existing buildings. We are working on concepts which aim to integrate technical building components for heating and ventilation into the insulation layer. In this way, cost savings will become possible, also by a greater degree of pre-fabrication, and the inconvenience to building occupants during renovation can be reduced at the same time.

Within the Building Energy Technology business area, the laboratory area for heat transformation technology, particularly heat pumps, was expanded appreciably in 2015. Why is this segment so important for you?

To transform our energy system, it is essential to increasingly merge heat and electricity. Our studies indicate that heat pumps, both electric and gas-fuelled systems, will become the dominant heating technology in the medium to long term. Important research topics thus range from their further development, through their integration into building energy systems, up to the development of flexible, grid-supporting operating concepts.

Heat pumps are primarily used in single family houses today. Their use in multi-family houses and multi-storey buildings is still unusual. Our work is aiming to develop sustainable concepts for the application of heat pumps in these buildings and to support market implementation by accompanying work on quality control. In doing so, we can well draw on our many years of extensive experience in scientific monitoring of buildings and systems.

Increasingly, buildings are becoming "energy generators". Which trends can you recognize here?

An important topic for the future is called "grid-reactive buildings", buildings and their technical energy systems will become integral components of the superior energy system. To achieve this, not only must the technology be further developed, e.g. for dynamic operation with many load changes, but particularly the operation management concepts must be developed and market models identified which will enable optimized grid-supporting operation. At the same time, comprehensive architectural and structural integration of solar energy converters (photovoltaic, solar thermal) into the building envelope is becoming increasingly important.

Doesn't that make our buildings and their energy supply more and more complicated?

That is true, more components and interaction with the grid mean more complexity. This means that powerful, safe and user-friendly operation management concepts, another of our important areas of work, will also become more essential.

Perspectives are increasingly extending beyond individual buildings to neighbourhoods and cities. What approaches are you following in this field?

Here, our main approach is to support municipalities and other actors involved in urban energy supply with solid, model-based expertise in designing and implementing development plans for the future energy supply. We have been able to develop powerful models and tools to support decision-makers, e.g. when they translate municipal climate-protection goals into packages of concrete technical measures.

Total staff	160
Full-time equivalent staff	121
Journal articles and contributions to books	31
Lectures and conference papers	40
Granted patents	2

www.ise.fraunhofer.de/en/publications/3-00

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Photo on p. 42: Detail of a binary coolant distributor for air-water heat pumps.

R&D PROJECTS IN 2015

- New phase change materials based on sugar alcohols for latent heat storage
- Sorption materials and coatings for adsorption processes
- Efficient re-cooling for solar thermally driven generation of cooling power
- Pre-fabricated, multi-funcional façade components for building renovation
- Data base for monitoring data on innovative operating strategies for buildings
- Quality assurance in the planning and implementation of hydraulic designs in low-exergy heating and cooling systems
- Optimization and operation management of complex building energy supply plants
- Planning and operation optimization of energy-efficient buildings with building information models
- Holistic integration of energy-active façade components into building processes

More information on these and further R&D projects:
www.ise.fraunhofer.de/en/research-projects/3-00

New materials / processes
Prototype / pilot series
Analysis based on measurement technology / quality control
Consultancy / planning / studies

WINDOW AND FAÇADE SYSTEMS FOR THE ENERGY TRANSFORMATION

Building envelope components such as window and façade systems are important components to reduce the heating, cooling and lighting demand in buildings, guarantee thermal and visual comfort, and ensure a healthy supply of daylight. In addition, they should distribute heat, cooling power, electricity and fresh air appropriately into the building or also convert sunlight into electricity and usable heat. Fraunhofer ISE contributes to ensuring that building envelope components meet these requirements better. With its R&D work, the Institute increases the reliability of evaluation methods and planning tools, and develops new high-performance, multi-functional building envelope components in cooperation with industrial partners.

Thus, in the past year, we have advanced the development of a new system of components for the building envelope with integrated BIPV functionality (building-integrated photovoltaics). The new elements were developed within the EU-funded "constructPV" project and can be simply adapted on the building site to the exact dimensions of the building. A further research project addresses the development of insulation systems with a switchable U-value. These can then emit heat via the opaque parts of the building envelope, e.g. during cool summer nights. Furthermore, new façade-integrated distribution systems for heat, cooling power, electricity and fresh air were successfully installed in a pilot building.

In addition, we have developed various new models and extended existing planning tools to optimize evaluation methods for building envelope systems. Our planning tool to design BIPV systems, taking partial shading into account, was extended and can also be used to plan inverters and bypass diodes. A new module for the "Modelica" building simulation program allows solar thermal façade elements to be modelled as part of dynamic building simulation.

Our "FENER" program, which serves to analyze and evaluate switchable façade systems on the basis of whole-year simulation, can now be accessed and used by external partners via an Internet interface. The evaluation encompasses not only visual and thermal comfort and the energy demand for heating and cooling but also innovative control algorithms for façade systems.

Efficient and reliable management of data and information throughout the entire building process is another important pre-condition for cost-effective and high-performance building envelopes to be implemented. Fraunhofer ISE is contributing to this by further developing the methods of BIM (Building Information Modelling) within the "SolConPro" project which started in 2015. To this end, product data models for façade elements are extended such that also the energy-relevant properties of multi-functional building envelope components can be taken into account within BIM.

1 *Seminar room with building-integrated photovoltaics (BIPV) at Fraunhofer ISE – partially transparent PV modules with angle-selective transmission (PV Shade®).*

2 *Façade collector integrated into plaster rendering.*

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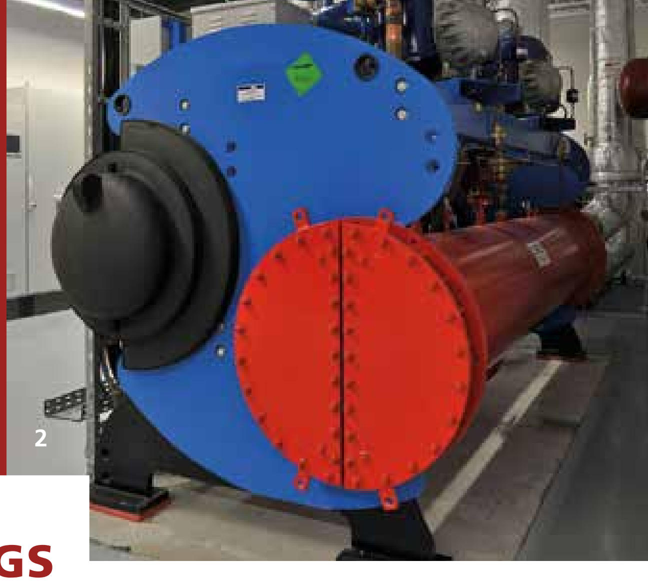

GRID-SUPPORTING BUILDINGS

With an increasing share of electricity in Germany originating from fluctating renewable sources like the sun and wind, the actual time of day when electricity is drawn from the public grid is becoming an increasingly important issue. Sometimes electricity is abundantly available on sunny and windy days; sometimes it must be generated at considerable expense by peak-load power stations. Extrapolation shows that, assuming values for installed power of 66.3 GWp photovoltaics and 91.6 GWp wind energy in 2033, Germany will be completely supplied by wind and solar electricity for more than 1250 hours per year, equivalent to almost two months. From the perspective of the electricity grid, it therefore is becoming increasingly important to smooth the residual load which remains, when the contribution supplied by regenerative sources (wind and sun) has been subtracted, by introducing not only controllable generators and storage units but also flexible loads. "Grid-supporting" electricity consumers should thus shift the largest possible share of their grid electricity consumption to times when electricity is abundant.

Buildings consume electricity, some also feed electricity into the grid (PV, combined heat and power plants – CHP). They thus interact with electricity grids and power stations. Despite this, they have been treated as passive consumers up to now and usual optimization measures and tariff stimuli are limited to reducing electricity consumption, as this is finally reflected in the electricity bill. However, buildings can also contribute their share to making the energy system more flexible by introducing storage units and load management.

The Fraunhofer ISE is preparing operation management concepts for deliberate activation of electric and non-electric generators of heating and cooling power. Depending on the requirements, the form in which end energy is provided is switched between different alternatives (e.g. electricity and gas). If a building is equipped with a local electricity generator, this must also be included when grid-supporting properties are optimized.

With dynamic thermal simulation models, we dimension and evaluate the application of storage to shift the generation of heating and cooling power into "grid-favourable" periods, while still ensuring that the thermal load demands in the building can be met at all times. In principle, both electric (battery) storage and thermal storage – tanks for hot or cold water or latent heat storage applying phase change materials – can be used. In contrast to electricity, large amounts of heat can be stored relatively economically in distributed, intermediate reservoirs. Even buildings with comparatively small technical storage units can be operated in a grid-supporting mode if the time-dependent profile for transferring heat or cooling power to the rooms is adapted accordingly. In doing so, the building mass is used as a thermal buffer. In our work, we were able to demonstrate that this is possible without restricting thermal comfort – in contrast to limiting the allowed usage times of electric appliances. In order to implement these grid-supporting building concepts on a broad scale, economic stimuli must be created by corresponding business models and market boundary conditions that are yet to be developed.

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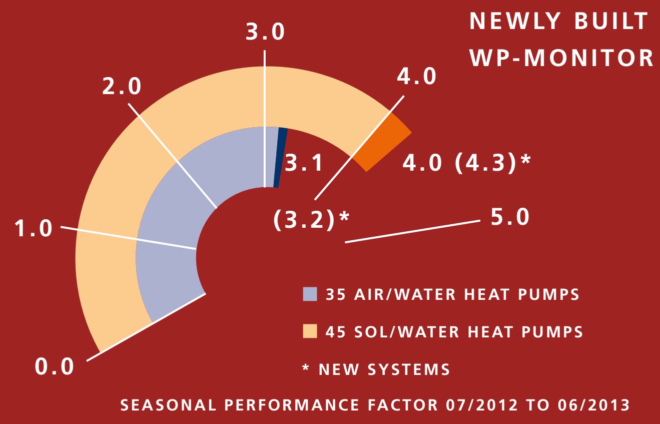
1 / 2 *Heating and cooling units for non-residential buildings incorporating a ground-coupled heat pump.*



HEAT PUMPS – ENERGY-EFFICIENT HEATING AND COOLING

Heat pumps play a key role for the energy transformation. Combined with electricity generation that is continually emitting less and less CO_2, electric heat pumps provide heat very efficiently. Gas-fueled heat pumps convert fuels significantly more efficiently than modern boilers. In cooperation with industrial partners and other research institutes, Fraunhofer ISE is contributing with much R&D effort to improve the state-of-the-art of such heat pumps. The research topics range from materials and component development up to system evaluation and optimization.

Already in 2005, Fraunhofer ISE conducted large-scale field studies on electric heat pumps for space heating and domestic water heating in unchanged, partly renovated and new single family homes. To date, more than 200 systems have been monitored with data acquisition during real operation, such that comprehensive information on their efficiency was obtained. In the future energy system, electric heat pumps can contribute to load management and thus to relief of the electricity grid. In the current project "WPsmart im Bestand" (smart heat pumps in the existing building stock), in which 13 heat pump manufacturers and energy utilities are participating, the goal is to identify their potential for grid-supporting operation and simultaneously to reduce efficiency losses.

The components of a heat pump are decisive in determining its efficiency and life-cycle costs. Our component development work for cold steam processes is concentrating on systems requiring smaller quantities of refrigerant, components to prevent incorrect distribution of air and refrigerant and technology to improve the safety of systems applying flammable refrigerants. Some of this work forms a part of European research projects, such as the EU-funded "Green Heat Pump" project.

In addition to electric heat pumps, increasing numbers of gas-fueled sorption heat pumps are entering the market. They represent a promising type of heating technology for the future. Fraunhofer ISE has been working for many years on the development of new sorption materials and improved components for sorption heat pumps and chillers, supporting manufacturers in all development phases up to system assessment in the field. In the EU-funded "Heat4U" project, we characterized a prototype of a novel gas absorption heat pump in the laboratory. An appreciable increase in efficiency compared to that of the most modern condensing boiler was proven.

In July 2015, we opened a new testing and development centre for heat pumps and chillers. It is equipped with the most modern air conditioning and measurement technology and is designed to carry out both standardized and dynamic measurements (including "hardware-in-the-loop"). The equipment also allows us to investigate and develop systems based on natural refrigerant (e.g. CO_2, ammonia and propane.)

1 *Development of a binary refrigerant distributor for air-water heat pumps.*

2 *Efficiency results from heat pump systems in the "WP-Monitor" project (www.wp-monitoring.de).*

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HYDROGEN TECHNOLOGIES

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With the expansion of renewable energy, the share of electricity generated from fluctuating sources is increasing and thus the need for matching supply and demand for electricity in the grid. Hydrogen, a secondary form of energy produced by electrolysis of water using electricity from renewable energy sources, is the only energy transfer medium which possesses the potential to store large amounts of energy also over long periods of time in a chemical form. Water electrolysers present an increasingly valuable control option for grid operators to quickly adapt electricity generation to consumption and also to stabilize the grid frequency. Hydrogen as a fuel for fuel cell vehicles forms a link between the energy economy and zero-emission mobility, with tank filling times and trip ranges corresponding to modern mobility.

With our activities in the area of hydrogen technologies, we offer R&D services addressing the generation, conversion and storage of hydrogen. In electrochemical generation of hydrogen, we are concentrating on electrolysis of water in polymer-electrolyte membrane electrolysers (PEM). We carry out multi-scale physical simulation and electrochemical characterization of cells and stacks. In addition, we construct functional working models from the cell stack up to fully automated complete systems for pressurized operation up to 50 bar. Test stands for cell stacks up to 4000 ampere currents (1 MW_{el} power demand) are available to us. We prepare studies on the technology of water electrolysis and the usage of hydrogen within a sustainable energy economy.

Total staff	83
Full-time equivalent staff	56
Journal articles and contributions to books	10
Lectures and conference papers	21
Granted patents	2

www.ise.fraunhofer.de/en/publications/4-00

Fuel cells convert hydrogen into electricity and heat with high efficiency. We develop fuel cell systems for real outdoor conditions, especially for automotive technology and decentralized stationary systems. Our research encompasses the development, simulation and characterization of single cells, cell stacks and systems as well as the testing of peripheral and cell components under extreme climatic conditions.

We have many years of experience in the chemical engineering and process technology of thermochemical processing of fossil and biogenic fuels. These processes include reforming and pyrolysis, as well as the synthesis of liquid fuels from hydrogen and CO_2. We develop processes to synthesize sustainable liquid fuels or also chemical building blocks. In experimental investigations or studies, we assess the technological feasibility of new, energy-efficient and resource-conserving processes and complement these with economic feasibility analyses. With this work, we are facilitating the transition from fossil-fueled applications to sustainable, zero-carbon energy technology.

Photo: Model in transparent plastic of a measurement cell for water electrolysis to visualize the segmented end plates with channel structures (parallel flow field). We use such laboratory cells to screen components and carry out long-term measurements for lifetime investigations.

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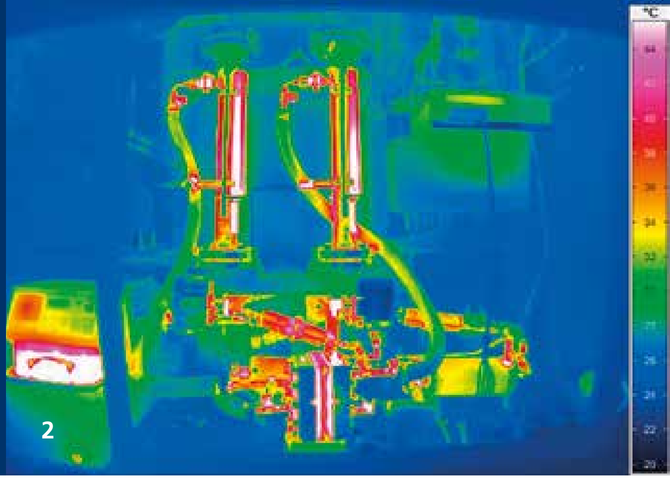
R&D PROJECTS IN 2015

- Characterization and modelling of a polymer-electrolyte membrane (CCM)
- Novel materials and system designs for PEM electrolysers
- Start-stop aging of PEM fuel cells
- Residue-free evaporation of liquid fuels
- Spatially resolved characterization of single cells for automotive applications
- Contamination studies and component screening with the 30-cell tester
- Solar hydrogen generation with a HyCon system
- Technical and economic systems analysis for power-to-gas systems
- Sustainable carbon compounds for current and future catalytic hydration
- Liquid fuels and chemicals from CO_2 and H_2

More information on these and further R&D projects:
www.ise.fraunhofer.de/en/research-projects/4-00

New materials / processes
Analysis based on measurement technology / quality control



NEW CENTER FOR HIGH-POWER PEM ELECTROLYSERS

The electrochemical splitting of water in electrolysers is a clean and efficient process to generate hydrogen. If electricity from renewable energy sources is used, green hydrogen can be generated as a universal fuel that can be stored easily and subsequently used as required in different applications of the energy economy, transport or the chemical industry. As a result, despite the strongly fluctuating and steadily increasing supply of electricity from renewable energy sources, it can guarantee a reliable energy supply and even enable long-term seasonal storage in a future energy system.

In particular, PEM electrolysis, in which a proton exchange membrane (PEM) is used, is well suited for combination with renewable energy sources. This process offers very good efficiency values at high current densities and can be operated at high pressure very dynamically over a wide operating window, i.e. also under partial-load or overload conditions. For this reason, Fraunhofer ISE has worked for more than 25 years now on component and system development as well as the integration of PEM electrolysers in higher-level energy systems. It has now brought its activities together in a new electrolysis center located at a new site of the Institute in the Auerstraße, Freiburg.

Unique to the new electrolysis center are two test rigs to test PEM cell stacks with currents of up to 4000 amperes and operating pressures up to 50 bar. The larger of the two test rigs allows DC voltages of up to 250 VDC to be applied, so that PEM electrolysis cell stacks with a rated connection power of up to 1 MW can be operated and investigated. No other research institute anywhere in the world has a comparable testing system. The maximum hydrogen output flow is specified as 200 standard cubic metres per hour. This rig is accompanied by a smaller test stand for electrolysis cell stacks with fewer cells. Sophisticated measurement equipment and a very flexible process management system allow the test rigs to be used for comprehensive measurement of cell stacks from different manufacturers. In future, a broad investigation of hydrogen generation in large-area cells and stacks is planned, laying important foundations for application of this technology in the energy transformation.

Research in the new electrolysis center is currently focussing on:

- development of standardized measurement procedures to characterize PEM electrolysers
- evaluation of new cell components and stacks for PEM water electrolysis
- investigation of degradation mechanisms and definition of accelerated stress tests
- characterization of complete prototypes up to the three-digit kW range
- investigations of the grid-supporting features of electrolysers

The new electrolysis center was financially supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) within the energy storage funding programme.

1 *Side view of the new test rig to characterize cell stacks for PEM electrolysis of water.*

2 *Model of an electrolysis test cell to investigate new cell components for PEM electrolysis of water.*

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ENERGY SYSTEM TECHNOLOGY

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Energy system technology, which optimizes the interaction between generators, consumers and their control and addresses the management of energy distribution and storage, is one of the most important areas needing work for the energy transformation and is thus one focus in our portfolio.

Our spectrum ranges from energy system analysis, through the optimization of energy systems, to the development of battery systems, power electronic components or information and communications technology solutions. An invaluable advantage here is that in designing and optimizing at the system level, we can also draw on well-founded technological experience with energy supply components such as PV modules, storage elements or CHP plants within the Institute.

Our work concentrates on the conception and optimized operation management of sustainable energy supply systems for buildings, urban neighbourhoods, industrial plants and energy supply systems up to the national level. This also includes supply structures such as the electricity grid and heating networks as well as the mobility sector, for which we are preparing new solutions to integrate electric vehicles into electricity grids. An essential aspect of our work is to treat different energy forms such as electricity, heat and gas holistically when we are conceiving modern energy systems that are defined by fluctuating generation. This allows maximal flexibility and the most economic usage of energy. To do this, we are also developing innovative solutions for control and communicative networking at both the component and the system level.

Total staff	183
Full-time equivalent staff	144
Journal articles and contributions to books	27
Lectures and conference papers	80
Granted patents	5

www.ise.fraunhofer.de/en/publications/5-00

Battery systems have long been a standard component of autonomous energy systems. However, their significance in grid-connected systems is also growing rapidly. We offer a broad spectrum of R&D services for lead-acid, lithium-ion or redox-flow systems. Part of our new center for storage technology is an extremely modern laboratory, in which, along with the development of redox-flow batteries, primarily battery systems can be designed, analyzed, tested and optimized with regard to operation management.

We are also developing power-electronic components and systems for many application areas. The major topics are inverters, transformers, converters and controls for use in energy supply and transmission, both for stationary and mobile applications. Particular attention is paid to optimal integration into the entire system and achievement of the greatest energy efficiency.

Photo: More and more energy from renewable sources is being fed into the electricity grid.

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Energy System Analysis
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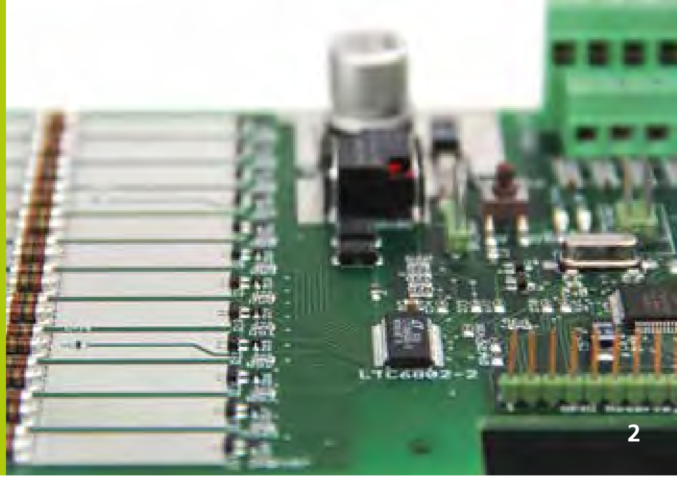
R&D PROJECTS IN 2015

- Simulation, development and construction of a highly efficient DC/DC converter concept for small battery systems
- Solar battery systems – service providers for the electricity grid
- Highly efficient and integrated USV inverter with SiC transistors
- Concept for inverter controllers in PV power plants
- System optimization and operating strategies for PV-diesel power stations in the multi-megawatt class
- Intelligent usage of electric vehicles in the integrated energy concept of a group of energy-plus buildings
- Electricity grids for a future energy system

More information on these and further R&D projects:
www.ise.fraunhofer.de/en/research-projects/5-00

Prototype / pilot series
Software / application



BATTERY STORAGE – FROM THE CELL THROUGH THE SYSTEM TO INTEGRATION

Fraunhofer ISE is working on optimizing battery systems along the entire value chain. This is witnessed by the diversity of current R&D topics and goals in this field.

Prolonging Lifetime

In the EU-funded "Mars-EV" project, we are investigating aging processes in selected types of lithium-ion cell chemistry. We develop aging models and validate them with measurement data from our laboratory. With an optimized testing matrix, we were able to significantly reduce the number of long-term tests needed to investigate aging caused by calendar lifetime and cycling. In addition to accurate modelling of the aging behaviour of the cells, our model development also encompasses the development of exact algorithms for determining the state of charge and state of health. It also includes an end-of-life model and model-based operation management strategies to prolong lifetime at the system level.

Increasing System Efficiency

In the "Cell Booster" project, a new technical approach is being investigated which optimizes the energy and cost efficiency of commonly used battery storage systems and lengthens their operating periods and lifetimes. The targeted innovation applies to systems technology with a focus on novel embedded electronics, the so-called cell booster. It causes direct impedance matching and DC/DC conversion, which leads to decoupling of the 48 V battery pack and formation of a module. The modular configuration not only increases the system efficiency but also enables simple implementation of a hybrid battery.

Optimizing Storage Management

In the "Net PV" project, which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), we are cooperating with our industrial partners to develop economically implementable solutions for distributed storage of PV electricity combined with load management and grid services. Lithium-ion battery systems are being developed here as storage units in combination with highly efficient inverters, which feature long calendar lifetimes and cycling durability. Optimized operation management strategies that are implemented within an energy management system ensure better integration into the distribution grid. In addition to optimization of in-house consumption, the focus is on grid services (e.g. supply of primary control power). The developed solutions are being tested with ten systems in the distribution grid of the Schwäbisch Hall municipal utility.

Developing Operator Models

In a project on operator models for electricity storage, we are cooperating with the "Institut für Energiewirtschaft und Rationelle Energieanwendung IER" and Compare Consulting to develop operator models for profitable application of storage-coupled power stations, based on detailed economic and ecological analysis. Continuous transfer of knowledge to interest groups and citizens in workshops guarantees that acceptance grows and also that goals of the involved actors are taken into account in the operator models. The project is directed toward industrial enterprises, cooperatives and private investors, and demonstrates the conditions under which investment in storage projects can be profitable for them.

1 *Lithium-ion battery module with high energy density for stationary applications.*

2 *Close-up view of a battery management unit.*

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1

COST OPTIMIZATION AND LOCATION DECISIONS FOR THE ENERGY TRANSFORMATION

With the goal of cost-effective integration and the long-term development of renewable energy sources, Fraunhofer ISE is investigating the German energy system within the European context.

To this purpose, we have developed the "ENTIGRIS" model, which reproduces the potentials of renewable energy forms and transmission capacity in a detailed model for optimizing expansion and operation. This allows us to predict the optimal distribution of renewable and conventional power stations, taking grid restrictions and the reinforcement of grid capacity into account. Compensatory effects between sites with less wind or solar resources and sites with very good conditions can thus be analyzed. The detailed integration of potential and present sites allows fine regional resolution for expansion scenarios. This means that the effect of grid restrictions can be taken into account, which will play a major role in a future system with a large share of renewable energy sources.

In order to achieve ambitious renewable energy goals, wind power systems in southern Germany and photovoltaic systems in northern Germany are also becoming attractive. As the model is embedded in the European context, exchange among the states and associated synergetic and compensatory effects can be analyzed, which can be achieved only by increased co-ordination between national energy policies and infrastructural measures. The model can be adapted at any time to evaluate new national goals in energy policy and calculate their effects quantitatively.

1 *Geographical coverage of the Fraunhofer ISE energy system model, "ENTIGRIS", with 53 different demand regions (the individual regions are indicated by different colours).*

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GRID INTEGRATION OF RENEWABLE ENERGY

The transformation of our energy system into an emission-free energy supply poses major challenges. Energy scenarios for the coming years show that this task can be mastered only by suitable combination and integration of different energy systems and grid structures. In this process, ICT technology will become increasingly important to cross-connect the components and allow flexible operation. For several years, we have been investigating the "Smart Grid" concept for electricity grids, which should enable optimal interaction of energy systems in the liberalized energy market. In current research projects, we are addressing the integration of renewable energy generators and storage units into the energy market and grid operation.

Integration of the electricity and heating sectors, e.g. by "Power2Heat" processes, allows compensation of the wide fluctuations in the electricity grid that are caused by input from renewable energy sources. Operation management systems play a key role here, because it is not only a matter of supplying electricity and heat when it is needed but also of managing storage systems predictively. Thus, virtual power stations are already being operated today, which optimize electricity generation with the help of thermal storage buffers on the basis of spot market prices and weather forecasts.

2 *Intelligent operation management allows the requirements of the grid and the market to be communicated and taken into account.*

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ENERGY-EFFICIENT NEIGHBOURHOODS

Neighbourhoods and municipalities provide an important forum for implementing the energy transformation. Here, campaigns for building renovation and communal energy supplies based on local renewable energy sources can be implemented at the social and political levels. Also, transformation of the energy supply infrastructure at the neighbourhood level is necessary, leaving behind combustion of fossil fuels and moving forward to heating supply networks, electrically based heating systems such as heat pumps and storage units for heat and electricity.

By coupling geographic information systems (GIS) with spatially resolved, techno-economic energy system models, we can prepare multimodal goal scenarios for municipal energy utilities and transformation schedules for implementation. We are thus able to provide scientific support for the strategic planning of municipal councils and municipal authorities with respect to sustainable energy supply, thereby making it more robust. By examining electricity and heat simultaneously, cost-optimized systems can be identified, including those with input from fluctuating sources of renewable energy.

In the "GISOPT" project, which is supported by the State of Baden-Württemberg, a tool was developed to analyze the potential and optimize the structure of storage units in regional energy systems. Scenarios for different neighbourhoods were analyzed using this tool.

1 *Scenarios for expanding storage capacity in an urban neighbourhood.*

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POWER ELECTRONICS

Power electronics converters are essential for the transformation of our energy system. Ongoing developments of electronic components and circuit designs aim at making power electronics converters smaller, lighter, more efficient and less expensive than previous generations. In addition, advanced power converters make new services on the system level become feasible.

In its modern and well-equipped laboratories, Fraunhofer ISE develops power electronics converters and systems for application areas such as renewables, power supplies, on- and off-grid batteries, electrical drives and electric mobility.

The main focus is on developing power electronics to process the electricity from renewable energy sources, to integrate electrical storage systems into electricity grids and to transmit energy. To this purpose, we develop power converters such as inverters, DC/DC converters and systems for inductive energy transmission over a wide power and voltage range.

Controlling electricity grids is another important aspect of our work. This includes filtering harmonics, and compensating for reactive power at low- and medium-voltage levels but also enabling black start in case of local grid collapse. Furthermore, we work on making existing grid structures more flexible by developing e.g. medium-voltage power converters for bidirectional supply of tram or railway networks.

2 *Triple-phase 10 kW USV inverter with a volume of only 5 litres and an efficiency value of 98.7 %.*

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CALLAB PV CELLS

PHOTOVOLTAICS

CalLab
PV Cells

CalLab PV Cells at Fraunhofer ISE offers the calibration and measurement 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. It is one of the internationally leading photovoltaic calibration laboratories and 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.

CalLab PV Cells is accredited according to ISO/IEC 17025 as a calibration laboratory for solar cell calibration with the Deutsche Akkreditierungsstelle (DAkkS). With the support of the German Federal Ministry for Economic Affairs and Energy (BMWi), and in cooperation with PV manufacturers, we work continuously on improving accuracy and developing new measurement procedures. The change in solar cell parameters at higher temperatures plays an important role for their yield in practical applications. A new procedure, with which the temperature-dependent behaviour can be determined with a previously unattainable accuracy, has proven to be very attractive for manufacturers of solar cells. We apply this and other special measurements in a project to optimize the maximum annual yield of high-efficiency solar cells by highly accurate analysis based on the dependence of cell parameters on temperature and irradiance level.

In order to guarantee the comparability of measurements for solar cells from different types of PV technology, we develop measurement procedures for novel solar cells. New metallization structures on wafer-based solar cells and material combinations for the absorber, as in perovskite solar cells, are specific aspects addressed by our new developments. Various multi-source simulators allow us to make measurements under almost any standard conditions, such as AM0 (ISO 15387) for space applications and AM1.5d (ASTM G173-03) for concentrator applications. Using our spectrally adaptable flash lamp simulator, multi-junction cells with up to four pn-junctions can be measured under concentrated irradiance with appropriate simulator spectra. We are also supporting the development of standards on concentrating and non-concentrating photovoltaics in the working groups WG 2 and WG 7 of technical committee TC 82 of the IEC.

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Multiple-Junction and Concentrator Cells
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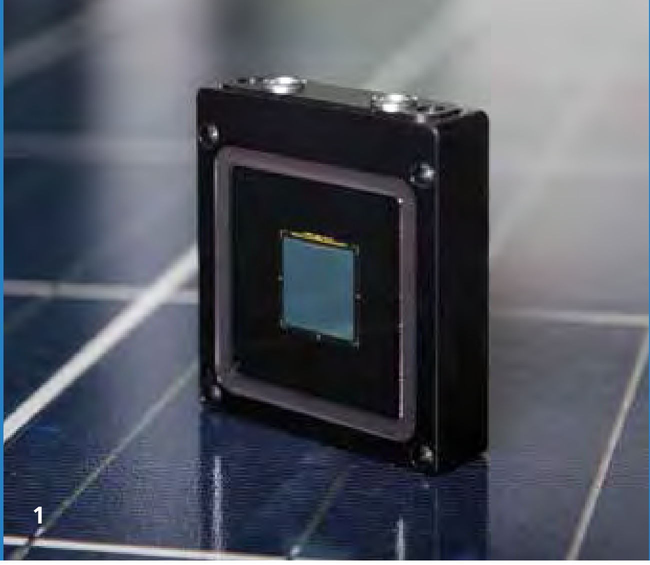
- Continuous and flash lamp solar simulators meeting stringent specifications on spectral distribution and lateral homogeneity
- Measurement units for accurate calibration of multiple-junction solar cells
- Contacting devices for almost all types of solar cells
- Shade-free measurement also of cells with interrupted bus bars
- Measurement of the spectral response for all types and dimensions of solar cells
- Characterization of the conformity of solar simulator radiation with IEC standards

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



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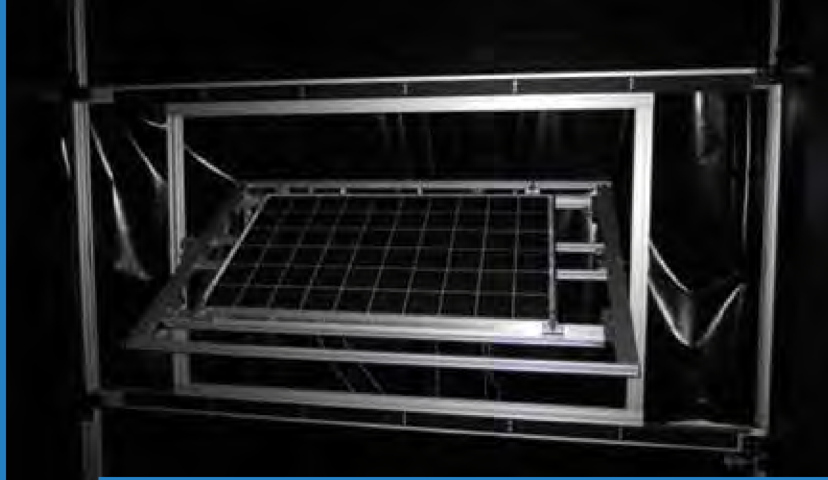

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CALLAB PV MODULES

PHOTOVOLTAICS

CalLab
PV Modules

In our accredited calibration laboratory, CalLab PV Modules, we combine comprehensive scientific know-how with modern measurement technology. Our clients include renowned module manufacturers, EPCs (engineering, procurement, construction) and investors with the highest demands on quality. They value our many years of experience and our excellent reputation in the field of module characterization.

Our service offer ranges from the calibration of single cells and modules to customized tasks such as the calibration of bifacial modules. Our measurement uncertainty of only 1.6 % and our quality assurance measures make us international leaders. In CalLab PV Modules, modules are characterized comprehensively according to the Energy Rating Standard, IEC 61853, and module quality is evaluated on the basis of individual testing procedures. Furthermore, CalLab PV Modules supplies and calibrates client-specific reference cells that we developed in house (WPVS Standard and LARC) for different applications. Our goal is to understand our clients' requirements exactly and to offer customized solutions.

CalLab PV Modules was accredited in March 2015 as the first calibration laboratory in the world to achieve a measurement uncertainty of 1.6 % for photovoltaic modules. The Deutsche Akkreditierungsstelle (DAkkS) confirmed on 24th March 2015 that CalLab PV Modules is authorized according to the conditions of DIN EN ISO/IEC 17025:2005 to carry out calibration of photovoltaic modules.

We can measure the power output from concentrator PV modules (CPV) under standard conditions using several outdoor test set ups equipped with trackers or in the laboratory with a solar simulator. The rating procedures used are documented in the IEC Draft Standard 62670-3. Fraunhofer ISE is actively involved in developing this standard, which was recently accepted by the IEC as a New Work Item Proposal (NWIP).

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- Accurate measurements according to IEC 60904-3 with a measurement uncertainty of only 1.6 %
- Determination of the spectral response at the module and cell level from 300 nm to 1200 nm
- Power Rating measurements according to IEC 61853
- Determination of the angular dependence according to IEC 61853-2
- Determination of the low-light performance down to 100 W/m²
- Measurement of temperature coefficients over the range from 15 °C to 75 °C
- Characterization of bifacial PV modules
- Supply and calibration of WPVS and LARC reference cells
- Evaluation of CPV modules under CSOC and CSTC

1 *A WPVS reference cell that was developed and calibrated in CalLab PV Modules.*

2 *Test set up to determine the angular dependence according to IEC 61853-2.*

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© BSW-Solar

TESTLAB PV MODULES

PHOTOVOLTAICS

TestLab
PV Modules

TestLab PV Modules has offered a broad spectrum of services focussing on quality and reliability testing since 2006. Our laboratory, which is accredited according to ISO 17025, is equipped with modern and innovative testing facilities that can be used for applications extending well beyond standard testing procedures.

Testing Specific to Clients' Requirements and Applications

We advise our clients in the definition of cost-effective and efficient testing programmes as well as on individual quality criteria, depending on the concrete question. The tests can serve to detect potential weaknesses in a module, compare different module types by benchmarking or assess the suitability of a specific type of module for particular application conditions.

Analysis of Defects and Risk Minimization

We apply innovative and recently developed analytical methods to systematically investigate defects such as so-called snail trails and potential-induced degradation (PID). TestLab PV Modules offers specific tests and test sequences for many typical defects.

Accuracy

Our platforms provide extremely accurate measurement values for comprehensive characterization. Very accurate power measurements are carried out in our accredited calibration laboratory, CalLab PV Modules, with an internationally leading measurement uncertainty of only 1.6 %.

Quality Control According to International Standards

In close cooperation with our partner, the VDE Prüf- und Zertifizierungsinstitut, we certify modules according to international quality and safety standards (IEC 61215, IEC 61646, IEC 61730).

Quality Control for the "VDE Quality Tested" Certificate

Together with the VDE Prüf- und Zertifizierungsinstitut, we have developed a quality certificate for PV modules which enables ongoing quality control of module production by an independent body at a high level. We also carry out these module tests in our TestLab PV Modules.

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- Accredited testing laboratory according to ISO 17025 for IEC 61215, IEC 61730
- Fault and materials analysis (e.g. EDX, Raman, Auger spectroscopy)
- Non-destructive analysis (e.g. lock-in thermography, EL, microscopy)
- in-situ monitoring
- Climatic test chamber with UV radiation
- Climatic test chamber with integrated solar simulator
- Mechanical load tests at different temperatures and mounting angles
- Sand abrasion tests
- Salt spray test IEC 61701

1 *The hot-spot test (IEC 61215) is carried out in our double climatic chamber with a solar simulator.*

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TESTLAB SOLAR THERMAL SYSTEMS

SOLAR THERMAL TECHNOLOGY

TestLab
Solar Thermal
Systems

Our TestLab Solar Thermal Systems is recognized as an authorized testing body by national certification institutions around the world, and is fully accredited according to ISO 17025 by Deutsche Akkreditierungsstelle (DAkkS). We test solar collectors, thermal storage tanks and complete systems, thereby supporting our clients around the world in developing solar thermal systems.

Since 2012, we have intensively investigated different aspects concerning the mechanical reliability (at temperatures between -40 °C and +90 °C) of mounting systems, PV modules and solar thermal collectors. The service spectrum here is also designed to address the requirements of the DIBt (German Institute for Building Technology). In combination with TestLab PV Modules, we can offer measurements for complete certification of PVT collectors (IEC and ISO). Our well-established solar air-heating collector test stand is used intensively. Based on the technical characterization carried out during the past year, Solar Keymark certification became feasible.

System and storage tank measurements can be carried out in our systems and storage tank laboratory. This is where the coefficients needed to evaluate tanks according to the Energy Label (ErP) of the EU are determined. Our solar simulator continues to achieve the accustomed high reproducibility. In 2014, our test facilities were extended appreciably, such that efficiency characteristic curves for operating points up to 230 °C can be determined. In addition, we have successfully characterized a large, concentrating collector in situ. This was a new application for TestLab Solar Thermal Systems within the context of extended collector certification. Our testing is fundamentally based on the updated version of EN ISO 9806:2014. This can be offered directly for all of the collector technologies included in its scope and for all modifications to the testing methods within the scope of our accreditation. This continues to be unique to our laboratory.

1 *Hot water tank being tested for the EU Energy Label (ErP) in the TestLab Solar Thermal Systems at Fraunhofer ISE.*

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- Measurements for the Energy Label according to ErP
- Mechanical load tests (e.g. DIBt)
- Certification measurements for air-heating collectors
- Certification measurements for PVT hybrid collectors
- Certification measurements for concen-trating collectors
- Certification measurements for flat-plate and evacuated tubular collectors
- Field measurements, monitoring and in-situ certification
- Highly accurate measurements to accompany optimization (e.g. solar simulator)

1

TESTLAB SOLAR FAÇADES

BUILDING ENERGY TECHNOLOGY

TestLab
Solar Façades

In TestLab Solar Façades, we characterize transparent and translucent materials, test building components and evaluate the energy-relevant, thermal and optical properties of complete façades. This encompasses both "passive" façade components like glazing and solar-shading devices, which offer classic functions such as thermal insulation, solar control and daylighting, and also "active" façade elements which convert solar energy into electricity or heat.

Accredited Testing of Optical Properties, g-Value and U-Value
The laboratory is accredited according to DIN EN ISO/IEC 17025:2005 for determining g-value, transmittance, reflectance and U-value by calculation and measurement. Our speciality is testing objects which often cannot be characterized adequately by conventional testing methods, e.g. building components with angle-dependent properties, light-scattering materials or structured and light-redirecting elements. The services of TestLab Solar Façades are also used for sectors that are not related to building façades.

Complete Energy Evaluation of Passive and Active Façades
We have extensive research experience in solar-control systems, building-integrated photovoltaics (BIPV) and building-integrated solar thermal technology (BIST). We have specialized in the mathematical and physical modelling of optical, thermal and PV electric processes in sunlit façades and analysis of their effects on the energy performance of buildings.

Daylighting and Glare Evaluation
BSDF data sets (bi-directional scattering distribution function) are determined goniometrically and can be used in simulation programs to evaluate daylight use and glare, e.g. for offices with sophisticated window and sun-shading systems. Studies on user preferences and visual comfort are carried out in rotatable daylight measurement rooms.

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g-Value and U-Value Testing
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BIPV, Solar Control
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Solar Thermal Façades
Dr Christoph Maurer
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Spectrometry, Goniometry, SRI and Colour Measurement
Dr Helen Rose Wilson
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Daylighting Test Rooms
Dr Bruno Bueno
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- Modelling and measurement of passive and active façade elements
- g-value test stands (angle-dependent; indoor and outdoor)
- 3D goniometer to determine BSDFs
- Large integrating spheres for angle-dependent spectral measurements

1 *Scanning photogoniometer pgII for BSDF measurements.*

TestLab
Power Electronics

TESTLAB POWER ELECTRONICS

ENERGY SYSTEM TECHNOLOGY

In the TestLab Power Electronics, which is accredited according to DIN EN ISO/IEC 17025, power electronic equipment with a power rating into the megawatt range can be characterized. DC sources with a total power output of 1.4 MW are available for this purpose. They can be flexibly parametrized and simulate e.g. the behaviour of PV generators. Highly accurate measurement equipment with a broad dynamic range are available for the measurements. To operate grid-connected power converters with a power rating of up to 1.25 MVA, voltages can be applied in the laboratory over a wide range from 255 to 790 V. In addition, faults in the medium-voltage grid can be simulated to investigate dynamic grid support of power generating units – so-called "Low Voltage Ride Through" (LVRT) and "High Voltage Ride Through" (HVRT) behaviour.

We also offer our clients field measurements, for instance in large PV power plants. For this purpose, we have six measurement systems, each with 16 measurement channels, which can be distributed as required in the field. In our test field in Dürbheim, a flexibly configurable PV generator with a rated power of 1 MWp is available. It can be used for long term testing of inverters under real world conditions. To this purpose, both low-voltage and medium-voltage connections are available.

Power-generating units can be tested according to international grid codes, e.g. for Germany, China or Great Britain. Highly accurate measurements of the efficiency of power electronic equipment can be made. We support our clients in modelling power-generating units e.g. according to German TR4 and prepare dynamic simulation models of PV power plants or grid segments. We carry out customized measurement campaigns both in the laboratory and in the field. We advise our clients, also prior to such a measurement campaign, and offer accompanying simulations if required.

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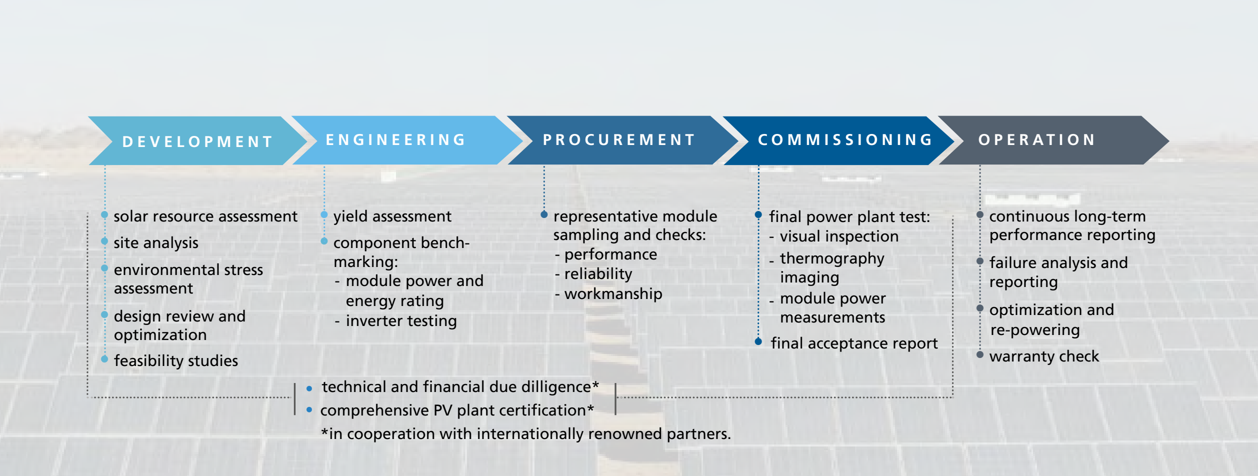
Laboratory Equipment
- 1.4 MW DC source
- LVRT test facility up to 1 MVA
- Adjustable MV transformers (255–790 V / 1.25 MVA)
- 30 kW three-phase grid simulator

Test Field Equipment
- 1 MWp ground mounted PV array
- Mobile 4.5 MVA LVRT test container
- Adjustable MV transformer (264–1120 V / 1.25 MVA)

Measurement Equipment
- High precision power analyzers
- 60–5000 A current transducers

SimulationSoftware
- MATLAB®/Simulink®, PLECS®
- DIgSILENT PowerFactory

1 *The Megawatt Laboratory offers highly accurate characterization of grid-connected inverters with respect to their grid behaviour.*
2 *High-current bus bars (2500 A).*



SERVICELAB PV POWER PLANTS

PHOTOVOLTAICS

PV power plants in the multi-megawatt range are becoming increasingly important internationally. Investors, project developers and EPCs (engineering, procurement, construction), banks and insurance companies must be sure that a power plant will deliver the predicted yield. With the Fraunhofer ISE quality cycle, we offer comprehensive quality assurance of PV power plants in all phases of a PV power plant project – from the development phase to on-going operation.

Already in the planning phase, we advise our clients on component selection and system design, taking the differing climatic conditions at each site into account. The results are also used for our internationally recognized yield predictions. With the help of testing programs developed in house, such as the Quality Benchmarking and the Procurement Check, we investigate selected modules and components in our laboratories, TestLab and CalLab PV Modules, with respect to their quality and suitability for the planned application. This greatly reduces the risk of well-known fault mechanisms in advance.

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 performance. Its quality can be controlled and existing faults can be documented with the help of on-site analysis that includes visual inspection, thermography and determination of the actual power generated. Once a PV system has commenced operation, we determine the actual Performance Ratio of the power plant and compare the results with the values from the yield prediction. Early detection of sub-optimal operation enables power plant operators to take the necessary remedial steps as soon as possible.

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System Testing
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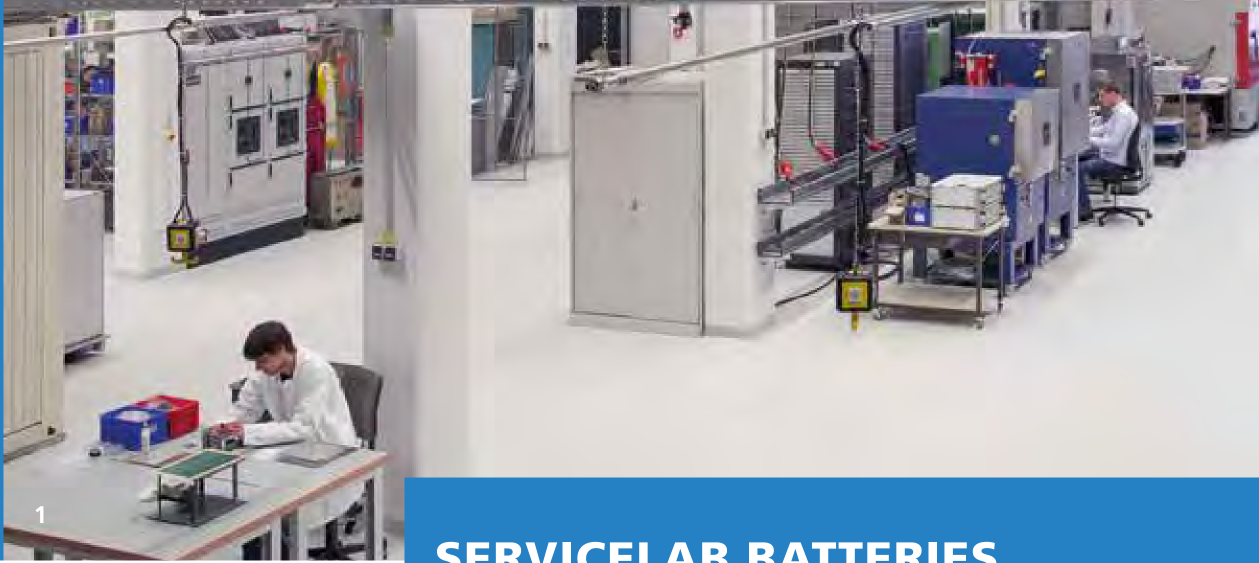
- "One-stop shop" for quality control
- More than 25 years of experience
- Numerous reference projects around the world
- Accurate and independent yield predictions
- Quality assessment of components
- Technical testing and optimization of the entire system after commissioning
- Failure analysis of irregular operating performance
- Independent evaluation of power output and performance
- Optimization and re-powering of existing power plants
- Degradation analysis

1 *Quality control for all phases in the life-cycle of a PV power plant.*



SERVICELAB BATTERIES

ENERGY SYSTEM TECHNOLOGY

In ServiceLab Batteries, we test battery cells, modules and complete battery systems based on lead-acid, NiMH and Li-ion cells, as well as high-temperature batteries and double-layer capacitors. The laboratory with an area of 400 m^2 is equipped with battery testing systems and impedance spectrometers for use either according to the test procedures specified by the relevant standards or in a climatic chamber or a water bath according to clients' specifications. We prepare electrical and thermal battery models, validated with data from our laboratory, which serve as the basis for system simulation and integration.

We offer long-term tests, lasting several months, of batteries and battery systems for durability investigations and lifetime analyzes. The cells and systems can be subjected to accelerated aging under exactly specified conditions. Our aging models enable the lifetime in a real application to be predicted.

A precision calorimeter is available for highly accurate investigations of the thermal behaviour of battery cells. Among other possibilities, this allows the power loss occurring in the cell to be analyzed exactly and thus serves as a basis for developing optimal thermal management and optimizing the system dimensioning.

For the automotive sector, we test systems up to a power of 250 kW with currents up to 600 A and voltages up to 1000 V. The test systems can be controlled via a CAN bus.

Many different home energy storage systems for private customers and large battery storage banks for commercial and industrial applications are currently entering the market. We test stationary electric storage systems in realistic environments for both grid-connected and off-grid applications, making use of solar simulators and our selection of inverters, electronic ballasts and charge controllers.

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- Cell and system tests
- Long-term investigations
- Thermal investigations (calorimetry)
- System tests up to 250 kW
- Test rigs for home storage systems

1 *Interior view of ServiceLab Batteries at Fraunhofer ISE.*

SERVICELAB SMART ENERGY

ENERGY SYSTEM TECHNOLOGY

As they become more economically attractive, distributed electricity generators, electric vehicles, heat pumps and electric storage units can be found in many residential buildings. At the same time, changes in the regulatory boundary conditions 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 control strategies which help to stabilize the local grid. ServiceLab Smart Energy is comprehensively equipped with the types of distributed generators and storage units that will be found in future residential buildings. This includes a simulator for electric loads to emulate triple-phase profiles with single-second accuracy and a PV simulator to provide IV characteristics for inverters with 1 s resolution. The laboratory works with powerful simulation tools, which allow model-based "hardware-in-the-loop" operation to evaluate system controllers. This means that innovative system components such as PV battery systems and heat pumps can be evaluated for any desired dynamic scenario of consumption and generation in the residential building context.

ServiceLab Smart Energy is equipped with the complete infrastructure needed to investigate questions concerning the system integration of distributed energy systems in a Smart Grid. System providers can thus test and evaluate both individual systems and also complete concepts in a realistic environment, such that business models and control strategies can be checked. These customized investigations include performance analyses of novel electricity / heat supply systems in a realistic system environment, the evaluation of grid compatibility of distributed generator systems, the assessment of PV battery systems with respect to efficiency and grid compatibility with the help of any required reference scenarios, the evaluation of thermal storage concepts with respect to distributed generation, the design and prototyping of intelligent operation management concepts and network-connected control systems, and the implementation of prototype systems with any type of interface.

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- Simulator for electric loads to emulate triple-phase profiles with 1 s accuracy
- PV simulator to provide IV characteristics with 1 s resolution for inverters
- Simulation of thermal load and solar thermal technology by computer-supported "hardware- in-the-loop" emulations
- Test rig for all common battery storage systems
- Network-connected charging stations for integration of electric vehicles into the domestic electricity circuit
- Evaluation of system performance compared to reference scenarios obtained by extensive monitoring

1 *Interior view of ServiceLab Smart Energy.*

1

SERVICELAB LIGHTING AND DC APPLIANCES

ENERGY SYSTEM TECHNOLOGY

We test, check and certify lamps, lighting systems and charge controllers of all common technology and configurations for manufacturers, system integrators and users. Our laboratory equipment is designed specially to suit the requirements of photovoltaically powered LED lighting systems. Grid-connected standard lamps and lights can also be measured in our laboratory. The focus is always on the whole system, i.e. the lamp together with its electronic controls, optical periphery, charge-controlling electronics and electric storage units.

Characterization

We carry out accurate measurements of photometric quantities for lamps, lights and lighting systems. These include measurement of the luminous flux, the luminous efficacy and the illuminance distribution with the help of goniometric procedures, and investigations of the operating and long-term performance of the lighting technology under different conditions, e.g. changes in the operating voltage and ambient temperature. We also determine the electrical properties of electronic controls, electronic ballasts and charge controllers, including the efficiency, parasitic consumption, operating management performance, overload response and fault management.

Long-Term Tests

For LED light sources and lamps equipped with LEDs, we determine the L70 and L50 lifetimes under various operating conditions. Using an automated test rig, we measure the achievable lighting duration (duration of autonomy) for battery-powered lamps.

Certification According to Different Testing Standards

We certify the quality of photovoltaically powered lighting systems according to IEC TS 62257-9-5 and IEC TS 62257-9-6 (Pico PV Systems and Solar Home System Kits). ServiceLab Lighting and DC Appliances is one of currently six testing laboratories around the world which have been accredited by Lighting Global. A special test rig for charge controllers allows them to be characterized up to 80 A and 150 V according to IEC 62509.

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- 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 with a photometric integrating sphere of 1.0 m diameter
- Photogoniometer to determine the spatial luminosity distribution
- Luminance camera, luxmeters and long-term test stands
- Accurate broadband wattmeters, digital oscilloscopes
- Programmable, long-term stable power supplies
- Automated test rigs to determine autonomous lighting duration
- Automated test rigs to characterize electric storage units
- Partly automated test rig to characterize e.g. charge controllers

1 *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.*

SERVICELAB FUEL CELLS

HYDROGEN TECHNOLOGIES

ServiceLab Fuel Cells offers measurement services for manufacturers of fuel cell systems and components. We characterize and test membrane fuel cells and systems with an electric power rating of up to 20 kW_{el} in accordance with relevant standards.

Our characterization of stacks and systems allows the operating strategy to be optimized for relevant application and operating conditions. Fuel cell stacks and systems can be investigated under various climates in our walk-in climate chamber. For investigations under conditions similar to those in systems, we can also control peripheral equipment such as pumps, ventilators and valves, also without using the climatic chamber. Inhomogeneity in the stack is identified by simultaneous single cell monitoring of the cell voltage and cell impedance spectrum.

We offer safety checks with respect to electrical safety and leakage. Additional characterization is possible to aid the selection of components and materials. We test single cells and cell components such as gas diffusion layers, electrodes and membranes according to recognized international test protocols. We measure both the performance and the long-term durability of the cell components. For in-situ analysis, we are equipped not only to record current-voltage characteristics but also to apply measurement procedures such as electrochemical impedance spectroscopy, cyclovoltammetry and linear-sweep voltammetry. As we are able to produce electrodes and membrane electrode assemblies, we are also able to investigate materials such as catalysts or catalyst substrates in situ.

In addition, we have access to a low-pressure chamber to simulate altitudes of up to 6000 m. We investigate cell components with respect to their electrochemical stability with a three-electrode configuration and exposure tests.

1 *Fuel cell laboratory to test laboratory-scale single cells, fuel cell components and peripheral aggregates.*

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- Fuel cell test rigs for fuel cell stacks up to 20 kW_{el} and1000 A_{DC}
- Fuel cell test rigs for single cells and cell components
- On-line single-cell monitoring of fuel cell stacks with EIS, HFR and CV
- Insulation and short circuit tests for fuel cell stacks up to 5000 A_{DC}
- Leakage tests of fuel cell stacks
- Climatic chamber with 8 m^3 interior volume and air flow rate up to 2000 Nm^3/h, temperatures from -50 °C to +80 °C, relative humidity from 10 % to 95 % (from +10 °C)
- Climatic chamber with 300 litres Interior volume, temperatures from -40 °C to +95 °C, relative humidity from 10 % to 95 % (from +10 °C)
- Test of peripheral aggregates under hydrogen exposure and extreme climatic conditions
- Ex-situ component tests of electrochemical long-term durability
- Analysis of contact resistances of materials – in-plane and through-plane

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SERVICELAB HEAT PUMPS AND CHILLERS

BUILDING ENERGY TECHNOLOGY

ServiceLab Heat Pumps and Chillers offers the most modern technology for developing, measuring and characterizing heat pumps and chillers, as well as their components. The modular test rig concept makes it feasible to test different types of technology and system configurations over a broad spectrum of operating conditions with different heat transfer media (air, water, brine). In addition to systems with an electric connection power of up to 35 kW, thermally driven equipment – heat, natural gas or test gas – can be measured. The laboratory is equipped with an integrated safety concept which allows components and systems with flammable refrigerants or ammonia to be constructed and measured.

Test objects with heating or cooling capacity of up to 100 kW (50 kW in calorimetric operation) can be measured in a calorimetric double climate chamber at temperatures between -25 °C and +50 °C and air humidity range between 25 % and 95 %. In addition, the laboratory also has several conditioning units for water, brine and air, which can provide the relevant medium at temperatures from -25 °C to +95 °C in a power range up to 40 kW. In the three air units, a volume flow range between 80 m^3/h to 5000 m^3/h can be testet from -15 °C up to +50 °C and humidity range from 15 % up to 95 %.

All measurement and conditioning technology is suitable for measurements according to the common technical standards. Beyond this, we cooperate with our partners to develop individual measurement procedures, which enable efficient and cost-effective development and optimization of devices and more complex systems by realistic, dynamic measurement sequences, including "hardware-in-the-loop".

Furthermore, component-specific test stands are designed and operated, where advanced measurement and analytical technology from fluid mechanics, acoustics, vibrations and gas analysis is used to address specific questions (e.g. particle image velocimetry (PIV), Laser-Doppler-Anemometry (LDA), shadowgraphy and gas chromatography).

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- Design and development of components and systems using specialized software tools
- Specialized component test stands, e.g. for refrigerant distribution, evaporators or adsorbers
- Acoustic measurements in cooperation with Fraunhofer IBP
- Measurements according to EN 14511, EN 14825, EN 16147, EN 12309 and other standards
- Measurements according to VDI, EHPA, ErP, Eurovent and other standards and regulations
- Our staff is certified according to the F gas regulation, Class I.
- Accreditation according to ISO/IEC 17025 is planned for 2016

1 *Equipment to measure the average air temperature and air humidity in the climate chamber.*

SERVICELAB THERMOCHEMICAL AND POROUS MATERIALS

BUILDING ENERGY TECHNOLOGY

ServiceLab Thermochemical and Porous Materials offers a broad spectrum of analytical methods to characterize thermal conductivity, heat capacity, crystalline structure and surface groups. They are applied to analyze porous materials with regard to the internal surface area, pore structure, porosity, morphology and adsorption characteristics for different gases. Our facilities include equipment for gas sorption measurements with various test gases (N_2, CO_2, ethanol, methanol, H_2O) to determine adsorption characteristics.

- Volumetric and gravimetric sorption measurement instruments for a broad temperature range
- Diverse choice of gases, sample forms, sorbants and measurement and analytical methods
- in-situ XRD and FT-IR with humidity cycling
- Thermal conductivity from room temperature to 500 °C
- Hydrothermal stability tests up to 50,000 cycles
- Macro-pore characterization by mercury intrusion
- Helium pycnometry for density determination
- Calorimeters in different dimensions and temperature ranges
- Two laser flash systems
- Light and laser-scanning microscopy to determine particle form and size distribution, roughness and homogeneity of surfaces

1 *Thermal balance to determine the water vapour adsorption capacity of large composite samples as a function of pressure and temperature.*

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SERVICELAB PHASE CHANGE MATERIALS

BUILDING ENERGY TECHNOLOGY

We test and characterize phase-change materials (PCM) but also other thermal storage materials and heat transfer fluids from the materials level to the final product. In addition to materials characterization in our laboratories, we offer application-relevant investigations in test rigs. For example, an adiabatic test room is available which is used for the investigation of heating and cooling systems. We are recognized by the RAL Gütegemeinschaft PCM (PCM quality association) as a testing institute which is authorized to award the RAL PCM quality seal, which was developed by Fraunhofer ISE in cooperation with others for phase change materials and PCM products. The ServiceLab Phase Change Materials offers complete certification by a single body.

- Certification according to RAL PCM quality seal, GZ 896
- Thermal characterization by heat-flux or Tian-Calvet DSC in the range from -90 °C to +800 °C
- Characterization of macroscopic samples with an area of up to 50 cm x 50 cm with dynamic flat-plate equipment
- Determination of rheological behaviour and viscosity by rotational rheometry in the range from -20 °C to +600 °C
- Determination of thermal conductivity by xenon flash, laser flash and heating wire in the range from -50 °C to +1200 °C
- Determination of liquid density up to 100 °C
- Testing the thermal stability of PCM and PCM products under thermal cycling
- Field monitoring of PCM systems

2 *Thermal cycling equipment suitable for a wide range of samples.*

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1

SERVICELAB AIR HANDLING UNITS

BUILDING ENERGY TECHNOLOGY

We investigate and characterize components and equipment for ventilation and air-conditioning. Three air-conditioning units are available, which cover a wide range of temperature, humidity and flow rates. With their modular construction, the air-conditioning units can be combined as required for the scope of investigation. Operation of the equipment under test in either a purely fresh-air input mode or with recirculation can be offered, with a zero-pressure measurement also being possible. With special accessories, small test units on a centimeter scale can also be investigated with a strongly reduced air flow. Investigations relating to safety technology are carried out in a chamber which is equipped with a gas detection system and an emergency extraction. In addition, equipment under test can also be connected to water or brine loops in the ServiceLab Heat Pumps and Chillers or installed in a climatic chamber and investigated there.

■ Air flow ranges	80 to 300 m^3/h, 150 to 1000 m^3/h, 800 to 5000 m^3/h
■ Heating power	2 to 50 kW
■ Cooling power	2 to 15 kW
■ Temperature range	-15 °C to +50 °C
■ Humidity range	15 % to 95 % r. H.
■ Temperature tolerance	±0,3 K
■ Humidification power range	1 to 40 kg/h

1 *One of the three air-handling units.*

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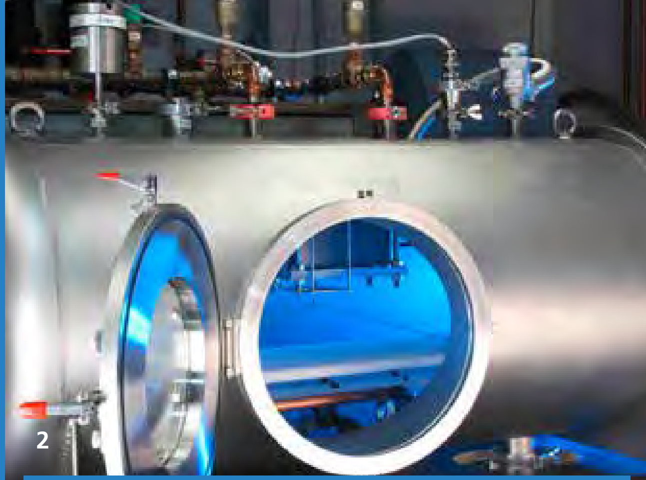

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SERVICELAB HEAT EXCHANGERS

BUILDING ENERGY TECHNOLOGY

We offer various possibilities to characterize and evaluate heat exchangers and segments of typical structures. The goal is to identify the potential to increase the efficiency of heat exchangers and make them useful in building technical applications such as electrically or thermally driven heat pumps. Extensive infrastructure is available, with which both complete heat exchangers and also individual components can be investigated with regard to their transfer properties or detailed flow analysis. We also draw on data from the technical literature and simulation tools for exact analysis of heat transport itself and restrictions to heat transport.

- Measurement of heat exchangers between air and various fluids (water, brine, coolants)
- Dimensions up to 1.5 x 1.5 m^2 (ribbed length / height)
- Measurement of characteristic structure segments (e.g. fin segments, fluid distribution)
- Measurement of dynamic / stationary boiling and adsorption characteristics of water at low pressure on structure segments and heat exchangers
- High-resolution, optical flow analysis
- Dimensioning and pilot construction of heat exchangers
- Application of simulation tools (CFD / FES / heat exchanger design tools / system simulation software)

2 *Gravimetric measurement of water deposited on heat exchangers designed as adsorbers or evaporators / condensers for water in the low-pressure range.*

Contact
service.heatexchangers@ise.fraunhofer.de

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REPORT: WHAT WILL THE ENERGY TRANSFORMATION COST?

Under the title "What Will the Energy Transformation Cost?", Fraunhofer ISE presented a report in 2015 with the results of a study of possible routes and required investments to achieve the energy transformation in Germany. Prof. Hans-Martin Henning, who authored the report together with Andreas Palzer, presented the results to members of various parliamentary committees and at a press conference in Berlin on 5th November, 2015.

The model-based study considers all relevant energy sectors and energy media to provide a detailed analysis on how Germany can achieve its climate goals – reduction of CO_2 emissions by 2050 with respect to 1990 by at least 80 % – by efficient energy use and renewable energy. The scenarios differ with regard to the drive concepts used in future by the mobility sector, the extent of energy retrofits in the building sector and the exact time at which coal is no longer used to generate electricity. Different climate targets for reducing carbon emissions by 80 %, 85 % or 90 % compared to 1990 levels are also taken into account.

In all of the future scenarios, fluctuating renewable energy sources, above all photovoltaics and wind, will play a dominant role in electricity generation. The new mixture of energy generators requires a large amount of flexibility both in electricity generation and consumption. Beyond the established fields of application, new uses for electricity must arise in the building and mobility sectors. The electrification of the heat supply is a prominent feature of the future energy system: In almost all of the investigated scenarios, electric heat pumps are the main technology used to supply heat for single buildings. In all of the scenarios, solar thermal systems are to cover part of the low-temperature heat demand in buildings and in industry. An accelerated withdrawal from coal-generated electricity by 2040 shows a strong positive effect on successfully achieving the emission reduction targets relating to energy supply.

The costs for transforming the energy system were analyzed for different scenarios with respect to the price development of fossil fuels and further external costs, e.g. the penalties on CO_2 emissions. Assuming that the price of fossil fuels remains constant up to 2050 and the penalties on carbon emissions remain low, simulations show that the cumulative total costs for transforming the energy system based on the least expensive scenario are about 1100 billion euros from today up to 2050. This is about 25 % more costly than continuing to use the present energy system without changes up to 2050. If, however, one assumes that the prices of fossil fuels rise annually by 3 %, then the cumulative total costs for carrying out the transformation and achieving the targeted 85 % reductions in energy-related CO_2 emissions are practically identical to the costs incurred by using today's energy system unchanged up to 2050.

This analysis was carried out primarily by using the simulation and optimization model "REMod-D" (Regenerative Energy Model – Germany) developed at Fraunhofer ISE. In this model, simulations are performed on an hourly basis not only to determine the environmental compatibility and cost-effectiveness of the various scenarios but also to ensure the security of supply in all sectors hour-by-hour throughout the year.

www.ise.fraunhofer.de/what-will-the-energy-transformation-cost

1

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PRIZES AND AWARDS

1 Presentation of the SolarWorld Junior Einstein Award 2015: Dr Holger Neuhaus, Chairman of the SolarWorld Einstein Award Jury (left), prize-winner Michael Rauer, Fraunhofer ISE (right).

2 Markus Löning, retired Human Rights spokesperson of the German Federal Government; Dr Manfred Vohrer, President of the Association of Friends of Walter Scheel e.V.; prize-winner James Shikwati, Director of the Inter-Regional Economic Network, Kenya; prize-winner Prof. Eicke R. Weber, Institute Director of Fraunhofer ISE; Prof. Karl-Heinz Paqué, retired Minister of Finance, State of Saxony-Anhalt, Vice-Chairman of FNF (from left to right).

Dr David Lackner, Dr Peter Kailuweit, Dr Simon Philipps, Dr Andreas Bett, WCPEC–6 Paper Award, "Potential for Reaching 50 % Power Conversion Efficiency Using Quantum Heterostructures", 2014, Kyoto, Japan

Johannes Eisenlohr, "Rear Side Sphere Gratings – Improving Light Trapping in Crystalline Si Single-Junction and Si-Based Tandem Solar Cells", Dr Jonas Schön, "Identification of the Most Relevant Metal Impurities in mc n-Type Silicon for Solar Cells" and Martin Bivour "Alternative Contact Materials for Induced Junction Silicon Solar Cells", Silicon PV Awards, March 2015, Constance, Germany

Andreas Hensel, Corentin Gasser, Christian Schöner, Thomas Niebling, Arne Hendrik Wienhausen and David Derix, Best Poster, "Hocheffizienter und integrierter dreiphasiger Wechselrichter mit drei multifunktionalen DC-Eingängen zur Eigenverbrauchsoptimierung", 30. Symposium Photovoltaische Solarenergie, March 2015, Bad Staffelstein, Germany

ENIT Systems, Spin-Off of Fraunhofer ISE, First Prize in "Gründerwettbewerb – IKT Innovativ" (Start-up competition – Innovative ICT) of the German Federal Ministry for Economic Affairs and Energy (BMWi), CeBIT, March 2015, Hanover, Germany

Julian Schrof, "Ernst-Blickle Studienpreis 2014" of the SEW-EURODRIVE Foundation for the Masters Thesis, "Lokale Überkompensation von dotierten Bereichen mittels Ionen-implantation", May 2015, Bruchsal, Germany

Stefan Gschwander, Thomas Haussmann, Georg Hagelstein et al., "Climator" Prize for the paper, "Standardization of PCM Characterisaton via DSC", IEA Greenstock Conference, May 2015, Peking, China

Michael Rauer, "SolarWorld Junior Einstein Award" for "Alloying from Screen-Printed Aluminum Pastes for Silicon Solar Cell Applications", Intersolar Europe, June 2015, Munich, Germany

Florian Schindler, "Best Student Paper Award" for the paper and presentation, "High Efficiency Multicrystalline Silicon Solar Cells: Potential of n-Type Doping" (Area 4: Silicon Material: Technology). 42^{nd} IEEE PVSC, June 2015, New Orleans, USA

Edo Wiemken, Björn Nienborg, Best Poster, "Storage Selection and Design for Increased PV Power Self-Consumption with Heat Pumps", 6^{th} International Conference Solar Air Conditioning, September 2015, Rome, Italy

Prof. Eicke R. Weber, "Walter-Scheel Prize 2015" of the Friedrich-Naumann-Stiftung für Freiheit and the friends of Walter Scheel for activities supporting solar energy as an economic factor, September 2015, Bonn, Germany

Fraunhofer Institute for Solar Energy Systems ISE "World Technology Award 2015" of the World Technology Network (WTN) in the Energy Category for R&D work on Concentrator Photovoltaics (CPV), November 2015, New York City, USA

SPIN-OFFS, NEW SITES

1 *Test rig for water electrolysers at the new site in the Auerstrasse in Freiburg.*

2 *Epitaxial wafer separated by NexWafe according to the new process (right), re-usable substrate (left).*

Heat Transformation Technology

Since being founded more than 30 years ago, the Fraunhofer Institute for Solar Energy Systems ISE has covered a wide range of complementary technologies, optimally preparing it for the challenges facing the energy transformation. In addition to solar technology research, systems aspects and questions regarding energy storage also played a role right from the start. Today, energy storage technology and efficient heating and cooling processes are two topics particularly in the focus of the energy transformation. Fraunhofer ISE has now consolidated its activities in these areas and significantly expanded its laboratory facilities at its new site in the Auerstrasse in Freiburg. On 2nd July, 2015, the new centre for storage and heat conversion technologies was officially opened in the presence of representatives from several German Federal Ministries as well as from industrial associations and the industry itself.

New technical laboratories are dedicated to battery systems for photovoltaics and mobility, redox-flow batteries, hydrogen generation using electrolysis, high-temperature solar thermal storage systems, as well as heat pumps and chillers powered by electricity, gas or heat.

New Spin-Off: NexWafe GmbH

In order to further reduce the costs of photovoltaic modules, the photovoltaic industry needs new technological breakthroughs. One contribution was made by Fraunhofer ISE in June 2015 by founding the NexWafe GmbH as a spin-off to transfer the manufacturing process developed at Fraunhofer ISE for epitaxially growing silicon wafers ("kerfless wafer technology") into production. NexWafe's products will serve the multibillion dollar high-end wafer market. Being based on epitaxy, the kerfless wafer is a drop-in replacement for conventional wafers produced from a single-crystal ingot by a wire sawing process. The consumption of materials and energy is drastically reduced in this type of wafer production, resulting not only in a cost advantage but also greater sustainability of the photovoltaic modules. The founder and CEO of the enterprise is Dr Stefan Reber, formerly Head of Department for "Crystalline Silicon – Materials and Thin-Film Solar Cells" at Fraunhofer ISE. The spin-off is supported by Fraunhofer Venture.

www.nexwafe.com

JB Instruments GmbH for Ink-Jet Printers in Solar Cell Production

A spin-off from the Division for "PV Production Technology and Quality Control" was already created at the beginning of the year. Daniel Biro, Head of Department for "Thermal Processes, PVD and Printing Technology for Industrial Cell Structures", and Mike Jahn, an engineer responsible for ink-jet equipment and processes, founded the company, JB Instruments GmbH.

The company goal is to develop innovative products in the field of ink-jet technology. The main focus is on further developing ink-jet printers that are already established in technical fields for applications with functional media, particularly for applications in solar cell production. The first licensing and service contracts have been signed, documenting the attractiveness of this product development, which can contribute to further cost reduction in solar cell production.

www.jbinstruments.de

NEW CENTER OF EXCELLENCE FOR SUSTAINABILITY IN FREIBURG

In March 2015, the "Center of Excellence for Sustainability" in Freiburg was inaugurated as a long-term strategic alliance to promote cooperation between the University of Freiburg, the Fraunhofer-Gesellschaft, industry and society at large, creating a new, transdisciplinary research network in Freiburg as a favoured scientific location. Building on already intensive cooperation between the five Fraunhofer Institutes (EMI, IAF, IPM, ISE and IWM) and the Albert Ludwig University of Freiburg, it stands for multi-disciplinary research and teaching in sustainability and for the development of innovative, sustainable products and services in cooperation with industry. Research and development relating to renewable energy will be one of the fundamental pillars for the Center of Excellence.

Institut für Nachhaltige Technische Systeme (INaTech)

The "Institut für Nachhaltige Technische Systeme INaTech" (Institute for Sustainable Technical Systems), which was newly founded within the Technical Faculty of the University of Freiburg in October 2015, forms the engineering core of the Center of Excellence for Sustainability. In future, INaTech will combine and further expand the scientific and technological strengths of the University and the research activities of the Fraunhofer Institutes in Freiburg on macroscopic technical systems. The goal of this strategic development by the University of Freiburg is to extend engineering competence on sustainability within the Technical Faculty, in close co-operation with local, national and international industry. Particularly the technological challenges posed by the energy transformation, tomorrow's mobility and future urban centers are to be addressed there.

The main research topics of INaTech correspond to the technological subjects of the Center of Excellence:

- Sustainable materials
- Renewable energy
- Resilience

With the establishment of INaTech, the Bachelor and Master's degree programmes in "Sustainable Systems Engineering" will be introduced soon and offered completely in English. At the same time, the Institute closely links the Technical Faculty with the Faculties for the Environment and Natural Resources, and for Chemistry and Pharmacy, including cooperation within the Master's courses on "Sustainable Materials" and "Renewable Energy Management".

LEISTUNGSZENTRUM
NACHHALTIGKEIT FREIBURG

In its final form, INaTech is planned to have up to 14 Chairs, some of which will be coupled with managerial functions in the participating Fraunhofer Institutes. Prof. Stefan Glunz from the Fraunhofer Institute for Solar Energy Systems ISE, has been called to the Chair for "Photovoltaic Energy Conversion", which he will combine with his responsibilities as the Head of Department for Solar Cells – Development and Characterization at Fraunhofer ISE. The new university department will focus on photovoltaic components and systems. The goals are to develop solar cells further, analyze the underlying material properties and design new solar cell structures and measurement methods.

The Center of Excellence for Sustainability will organize networking events regularly to involve actors from industry and society in the current activities. These events include the annual "Sustainability Summit" as well as fireside chats and recruiting days.

www.leistungszentrum-nachhaltigkeit.de/en

INTERNATIONAL NETWORK

USA
- Fraunhofer Center for Sustainable Energy Systems CSE, Boston (Massachusetts)

Chile
- Center for Solar Energy Technology (CSET), Santiago
- Fraunhofer Chile Research, Santiago

USA, Golden (Colorado)
USA, Newark (Delaware)
USA, Berkeley (California)
Brazil, Rio de Janeiro

USA
- CFV Solar Test Laboratory, Albuquerque (New Mexico)
- Georgia Institute of Technology, Atlanta (Georgia)
- Humboldt State University, Arcata (California)
- National Renewable Energy Laboratory NREL, Golden (Colorado)

Brazil
- CTGAS-ER – Centro de Tecnologías do Gás e Energías Renováveis, Lagoa Nova – Natal/RN
- SENAI – DR/RN – Serviço Nacional de Aprendizagem Industrial

A future, global, zero-CO_2 energy supply calls for major effort from all parts of the world. Fraunhofer ISE thus participates actively in an extensive international network, with its own German subsidiaries and international collaborations (■), Memoranda of Understanding with universities and research institutions around the world (■) and, last but certainly not least, numerous international guest scientists from universities and research institutes abroad (■), who carry out their research at Fraunhofer ISE, thereby contributing their specific expertise. ( ) The Global Alliance of Solar Research Institutes (GA-SERI) was founded in 2012 and consists of three internationally leading solar research institutes, AIST, NREL and Fraunhofer ISE. Furthermore, Fraunhofer ISE is active in numerous international bodies, associations and societies: www.ise.fraunhofer.de/en/about-us/organisations

Germany
- Fraunhofer Institute for Solar Energy Systems ISE, Freiburg
- Laboratory and Service Center Gelsenkirchen LSC, Gelsenkirchen
- Fraunhofer Center for Silicon Photovoltaics CSP, Halle/Saale
- Technology Center for Semiconductor Materials THM, Freiberg

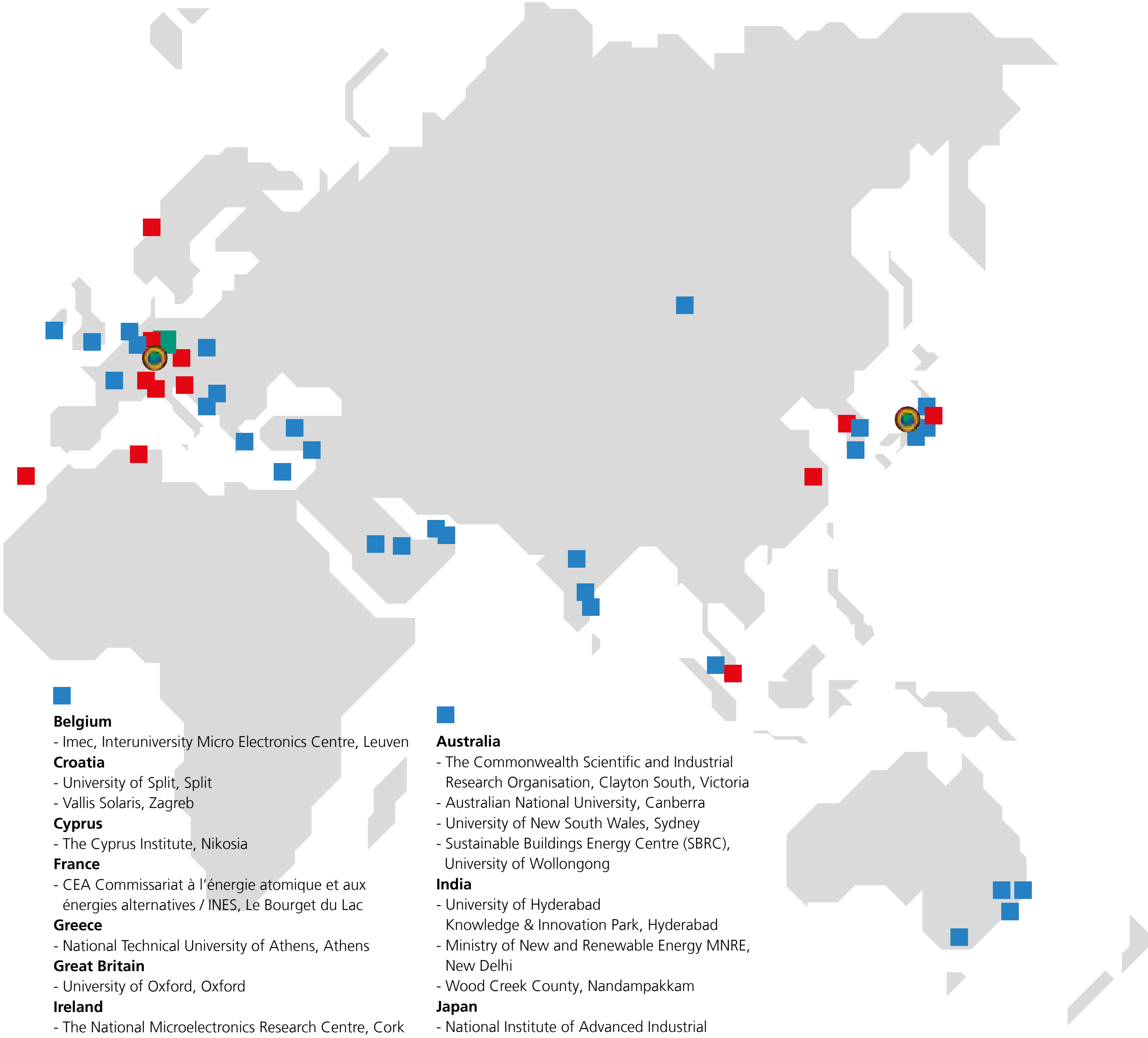
Global Alliance of Solar Research Institutes (GA-SERI)
- Fraunhofer Institute for Solar Energy Systems ISE, Freiburg
- National Institute of Advanced Industrial Science and Technology AIST, Tokyo
- National Renewable Energy Laboratory NREL, Golden (Colorado)

Algeria, Sétif
Austria, Graz
Germany, Karlsruhe
Italy, Alessandria
Norway, Trondheim
Slovenia, Ljubljana
Spain, La Laguna
Switzerland, Geneva

Saudi Arabia
- ADECO, Riyadh
- King Abdullah City for Atomic and Renewable Energy, K.A.CARE, Riyadh

South Korea
- Chonbuk National University Korea, Jeonju
- Seoul Metropolitan Government
- Korea University, Seoul
- Konkuk University, Seoul

United Arab Emirates
- IRENA, Abu Dhabi
- Masdar City Project, Abu Dhabi



Belgium
- Imec, Interuniversity Micro Electronics Centre, Leuven

Croatia
- University of Split, Split
- Vallis Solaris, Zagreb

Cyprus
- The Cyprus Institute, Nikosia

France
- CEA Commissariat à l'énergie atomique et aux énergies alternatives / INES, Le Bourget du Lac

Greece
- National Technical University of Athens, Athens

Great Britain
- University of Oxford, Oxford

Ireland
- The National Microelectronics Research Centre, Cork

Netherlands
- The Netherlands Energy Research Foundation (ECN), Petten

Poland
- Warsaw University of Technology and Institute of Electronic Materials Technology, Warsaw

Turkey
- Middle East Technical University METU, Ankara
- University of Gaziantep, Gaziantep

Australia
- The Commonwealth Scientific and Industrial Research Organisation, Clayton South, Victoria
- Australian National University, Canberra
- University of New South Wales, Sydney
- Sustainable Buildings Energy Centre (SBRC), University of Wollongong

India
- University of Hyderabad Knowledge & Innovation Park, Hyderabad
- Ministry of New and Renewable Energy MNRE, New Delhi
- Wood Creek County, Nandampakkam

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- Fukushima Prefecture
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Malaysia
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Mongolia
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China, Nanjing
Japan, Tokio
Singapore, Singapore
South Korea, Seoul

PROFESSORSHIPS & DOCTORAL THESES

Professorships

Prof. Stefan Glunz
Chair for Photovoltaic Energy Conversion
Technical Faculty
Albert Ludwig University of Freiburg
June 2015

Doctoral Theses

Fabien Coydon
"Holistic Evaluation of Conventional and Innovative Ventilation Systems for the Energy Retrofit of Residential Buildings", KIT Karlsruhe Institute of Technology, 2015

Daniela Dirnberger
"Uncertainties in Energy Rating for Thin Film PV Modules", Carl von Ossietzky University of Oldenburg, 2015

Frank Feldmann
"Carrier-Selective Contacts for High-Efficiency Silicon Heterojunction Solar Cells", Albert Ludwig University of Freiburg, 2015

Katrine Flarup Jensen
"Methodology to Identify Critical Mechanisms in the Dye Solar Cell Related to the Degradation of Triiodide", Albert Ludwig University of Freiburg, 2015

Gerrit Füldner
"Stofftransport und Adsorptionskinetik in porösen Adsorbens-kompositen für Wärmetransformationsanwendungen" (Material Transport and Adsorption Kinetics in Porous Adsorbent Composites for Heat Transformation Applications), Albert Ludwig University of Freiburg, 2015

Aline Gautrein
"Low Temperature Metallization for Silicon Solar Cells", Johannes Gutenberg University of Mainz, 2015

Lena Geimer-Breitenstein
"Surface Analysis for High Efficiency Silicon Solar Cells", University of Constance, 2015

Christian Geisler
"Characterization of Laser Doped Silicon and Overcoming Adhesion Challenges of Solar Cells with Nickel-Copper Plated Contacts", Albert Ludwig University of Freiburg, 2015

Stefan Hess
"Low-Concentrating, Stationary Solar Thermal Collectors for Process Heat Generation", De Montfort University, Leicester, UK, 2014

Oliver Höhn
"Winkelselektive Photonische Strukturen für eine Optimierte Strahlungsbilanz in Solarzellen" (Angle-Selective Photonic Structures for an Optimized Radiation Balance in Solar Cells), Albert Ludwig University of Freiburg, 2015

Rene Hönig
"Lumineszenz-Imaging Anwendungen in industrieller Fertigungsumgebung von Silicium-Solarzellen" (Luminescence Imaging Applications in an Industrial Production Environment for Silicon Solar Cells), Albert Ludwig University of Freiburg, 2015

Sven Roland Holinski
"a-Si:H, aSiO:H und µc-Si:H Schichten für Siliziumdünnschicht-solarzellen" (a-Si:H, aSiO:H and µc-Si:H Layers for Thin-Film Silicon Solar Cells), Ruhr University of Bochum, 2015

Felix Jeremias
"Synthesis and Characterisation of Metal-Organic Frameworks for Heat Transformation Applications", Heinrich Heine University of Düsseldorf, 2015

Andre Kalio
"Study of Contact Formation Using Lead-free and Leaded Silver Model Pastes on Advanced Crystalline Silicon Solar Cells", Albert Ludwig University of Freiburg, 2015

Deepak Kaduwal
"Roll-to-Roll Processing of ITO-free Organic Solar Cells", Albert Ludwig University of Freiburg, 2015

Roman Keding
"IBC-BJ Solarzellen mit Bor-Emitter" (IBC BJ Solar Cells with Boron Emitters), Albert Ludwig University of Freiburg, 2015

René Kellenbenz
"Metallorganische-Gasphasenepitaxie von III-V-Mehrfachsolar-zellen für die Konzentratoranwendung" (Metal-Organic Gas Phase epitaxy of III-V Multiple-Junction Solar Cells for Concentrator Applications), University of Constance, 2015

Achim Kimmerle
"Entwicklung und Charakterisierung von rückseitig sammelnden und lokal kontaktierten Solarzellen mit Aluminium Emitter" (Development and Characterization of Back-Surface Collecting and Locally Contacted Solar Cells with Aluminium Emitters), Albert Ludwig University of Freiburg, 2015

Christoph Kost
"Renewable Energy in North Africa: Modeling of Future Electricity Scenarios and the Impact on Manufacturing and Employment", Technical University of Dresden, 2015

Achim Kraft
"Plated Copper Front Side Metallization on Printed Seed-Layers for Silicon Solar Cells", Albert Ludwig University of Freiburg, 2015

Elmar Lohmüller
"Transfer des Metal-Wrap-Through Solarzellen-Konzepts auf n-Typ Silicium" (Transfer of the Metal Wrap-Through Solar Concept to n-Type Silicon), Albert Ludwig University of Freiburg, 2015

Andrew Mondon
"Nickel Silicide from Plated Nickel for High Adhesion of Fully Plated Silicon Solar Cell Metallization", Albert Ludwig University of Freiburg, 2015

Milan Padilla
"Spatially Resolved Characterization and Simulation of Interdigitated Back Contact Silicon Solar Cells", Albert Ludwig University of Freiburg, 2015

Regina Pavlovic
"Process Development for Crystalline Silicon Thin-Film Modules with Integrated Interconnection", University of Constance, 2015

Maximilian Pospischil
"Entwicklung eines Dispensiersystems mit Paralleldruckkopf zur kontaktlosen Vorderseitenmetallisierung von Siliciumwafern im industriellen Maßstab" (Development of a Dispensing System with a Parallel-Printing Head for Contact-Free Front-Surface Metallization of Silicon Wafers on an Industrial Scale), Albert Ludwig University of Freiburg, 2015

Mohammad Reza Safizadeh
"Theoretical and Experimental Analyses of a Solar/Waste Heat Assisted Air-Conditioning System for Applications in Tropical Climates", National University of Singapore, 2015

Kurt-Ulrich Ritzau
"Transportphänomene in amorph-kristallinen Silicium Hetero-Solarzellen" (Transport Phenomena in Amorphous Crystalline Silicon Hetero-Junction Solar Cells), Albert Ludwig University of Freiburg, 2015

Subarna Sapkota
"Long-Term Stability of Organic Solar Cells", Albert Ludwig University of Freiburg, 2015

Florian Schindler
"Electrical Material Properties and Efficiency Limits of Compensated and Multicrystalline Silicon for Solar Cells", Albert Ludwig University of Freiburg, 2015

Manuel Schnabel
"Silicon Nanocrystals Embedded in Silicon Carbide for Tandem Solar Cell Applications", University of Oxford, UK, 2015

Holger Seifert
"Kalibrierung von Dünnschichtsolarzellen" (Calibration of Thin-Film Solar Cells), University of Constance, 2015

Alexander Vogel
"Konzepte für Speicher in thermischen Solarkraftwerken" (Concepts for Storage in Thermal Solar Power Stations), Technical University of Braunschweig, 2015

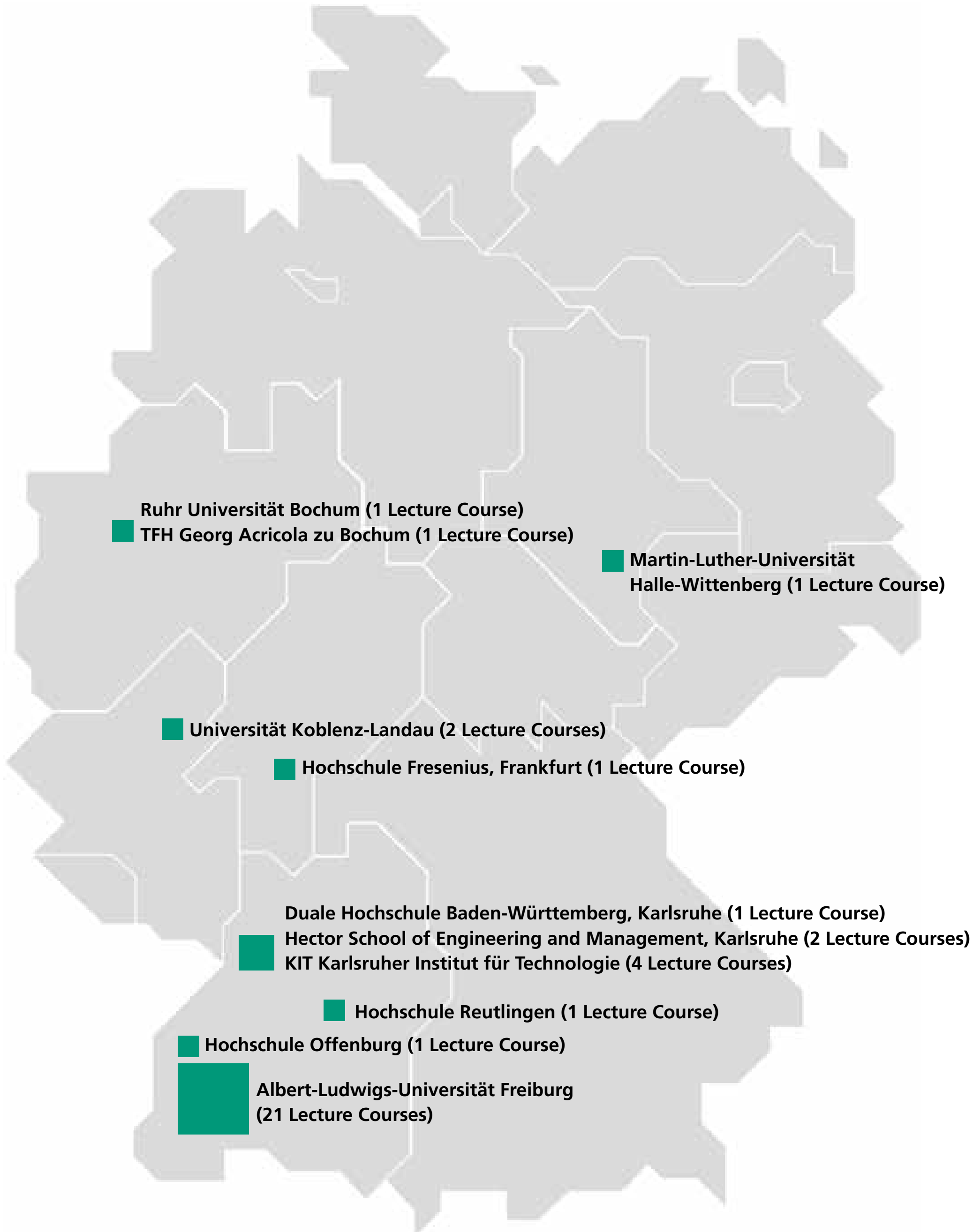
Bernd Weber
"Untersuchung der Material begrenzenden Einflüsse beim Multidrahtsägen von Silicium unter Verwendung gerader und strukturierter Drähte" (Investigation of the Influences Limiting Materials for Multi-Wire Sawing of Silicon Using Smooth and Structured Wires), Bergakademie, Technical University of Freiberg, 2015

Kai Thomas Witte
"Experimentelle Untersuchungen zum Sieden in Metallfaserstrukturen im Bereich niederer Drücke" (Experimental Investigations on Boiling in Metal Fibre Structures in the Low Pressure Range), Technical University of Darmstadt, 2015

At Fraunhofer ISE, the following professors supervise doctoral students: Prof. Peter Dold, Prof. Stefan Glunz, Prof. Adolf Goetzberger, Prof. Hans-Martin Henning, Prof. Joachim Luther, Prof. Hans-Joachim Möller, Prof. Roland Schindler, Prof. Eicke R. Weber, Prof. Gerhard Willeke and Prof. Christof Wittwer.

LECTURE COURSES

Fraunhofer ISE has close connections to universities, technical universities and other research institutions. Scientists from Fraunhofer ISE are involved in academic teaching in various cities in Germany. As well as imparting knowledge and practical experience to students, these lecturers also contribute to the high level of expertise at the Institute.



A detailed overview of all lecture courses offered by staff of Fraunhofer ISE can be found under: www.ise.fraunhofer.de/en/study-jobs-and-career/lecture-courses-seminars

EDITORIAL NOTES

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Press and Public Relations

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EVENTS IN 2016

WITH PARTICIPATION OF FRAUNHOFER ISE

World Future Energy Summit, Abu Dhabi, United Arab Emirates, 18.–21.01.2016

Zukünftige Stromnetze für Erneuerbare Energien, Berlin, Germany, 26.–27.01.2016

12. SiliconFOREST Workshop, Feldberg-Falkau, Germany, 14.–17.02.2016

KONGRESS-Forum ElektroMobilität, Berlin, Germany, 01.–02.03.2016

Brandschutz und Wartung von PV-Anlagen, Kloster Banz, Bad Staffelstein, Germany, 03.03.2016

6th International Conference on Crystalline Silicon Photovoltaics and PV Workshop, Chambéry, France, 07.–09.03.2016

nPV Workshop, Chambéry, France, 09.–10.03.2016

2. Fachforum PV-Diesel-Hybrid-Systeme, Kloster Banz, Bad Staffelstein, Germany, 08.03.2016

31. Symposium Photovoltaische Solarenergie, Kloster Banz, Bad Staffelstein, Germany, 09.–11.03.2016

Energy Storage / 10th International Renewable Energy Storage Conference (IRES), Dusseldorf, Germany, 15.–17.03.2016

The Terawatt Workshop, GA-SERI, Freiburg, Germany, 17.–18.03.2016

10. Entwicklerforum Akkutechnologien, Battery University, Aschaffenburg, Germany, 28.–30.03.2016

Berliner Energietage, Germany, 11.–13.04.2016

26. Symposium Thermische Solarenergie, Kloster Banz, Bad Staffelstein, Germany, 20.–22.04.2016

12th International Conference on Concentrator Photovoltaics (CPV-12), Peking, China, 25.–27.04.2016

Hanover Fair, Hanover, Germany, 25.–29.04.2016

6th SOPHIA Workshop PV Module Reliability, Vienna, Austria, 28.–29.04.2016

Power Conversion and Intelligent Motion PCIM Europe, Nuremberg, Germany, 10.–12.05.2016

11th IIR Conference on Phase Change Materials, Slurries for Refrigeration and Air Conditioning, Karlsruhe, Germany, 18.–20.05.2016

10th SNEC PV POWER EXPO 2016, Shanghai, China, 24.–26.05.2016

43th IEEE Photovoltaic Specialists Conference, Portland, Oregon, USA, 05.–10.06.2016

13th International Conference on the European Energy Market; Porto, Portugal, 06.–09.06.2016

Power Electronics for Photovoltaics, Munich, Germany, 20.–21.06.2016

Intersolar Europe / EU PVSEC 2016 / Electrical Energy Storage, Munich, 22.–24.06.2016

Power Electronics for Photovoltaics, San Francisco, USA, 11.07.2016

Intersolar North America, San Francisco, USA, 12.–14.07.2016

Solar Technologies & Hybrid Mini Grids to Improve Energy Access, Frankfurt / Main, Germany, 21.–23.09.2016

World of Energy Solutions 2016 / f-cell 2016, Stuttgart, Germany, 10.–12.10. 2016

SolarPACES Conference 2016, Abu Dhabi, United Arab Emirates, 11.–14.10.2016

Sustainability Summit, Freiburg, Germany, 12.–13.10.2016

Berlin Conference on Energy and Electricity Economics, Berlin, Germany, 13.–14.10.2016

8. eCarTec, Munich, Germany, 18.–20.10.2016