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FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

Fraunhofer Institute for Integrated Systems and Device Technology IISB

Annual Report 2017

ANNUAL REPORT 2017

Imprint

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Grid simulator test setup with a three phase modular multilevel converter using 1.2 kV IGBT modules.
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ACHIEVEMENTS AND RESULTS

ANNUAL REPORT 2017

FRAUNHOFER INSTITUTE FOR

INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

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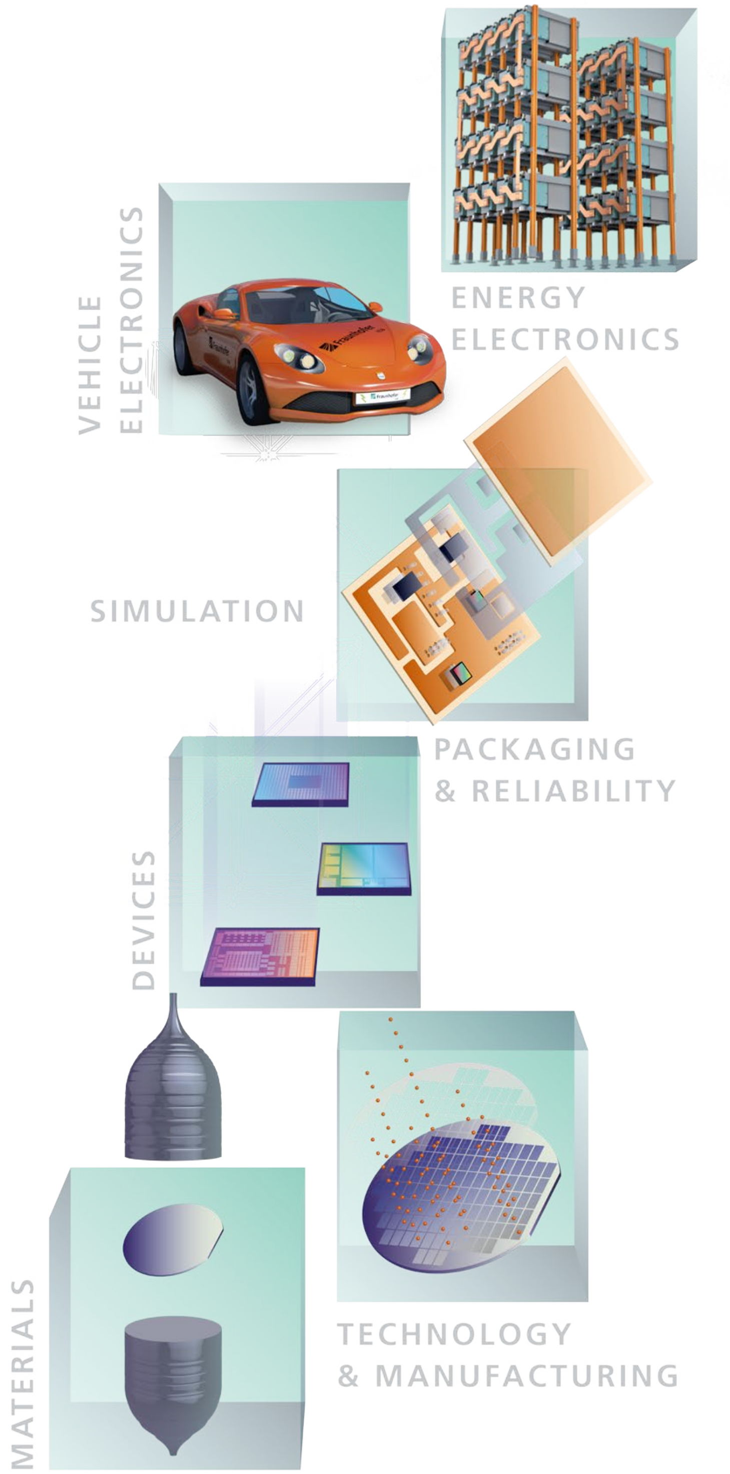
PREFACE



1 *The R&D activities of Fraunhofer IISB cover the complete value chain for electronic systems, from basic materials to devices and modules up to application, with power electronics as a continuous backbone of the institute.*
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2 *Prof. Dr. rer. nat. Lothar Frey, director of Fraunhofer IISB.*
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A cooperative and trustful network is a key feature for successful research and development. For this reason, Fraunhofer IISB endeavored to be a reliable innovation partner in 2017 as well.

One building block is the Leistungszentrum Elektroniksysteme LZE, based on a strategic regional collaboration between IISB, Fraunhofer IIS, the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), and industry. In November, the LZE passed the reviewed evaluation of its pilot phase quite successfully and now continues to implement novel models of technology transfer.

On a national scale, the newly founded Forschungsfabrik Mikroelektronik Deutschland FMD (Research Fab Microelectronics Germany) forms a strong network of Fraunhofer and Leibniz institutes to strengthen the position of Europe's semiconductor and electronics industry in global competition, supporting it with a powerful research backbone. IISB hosted the official opening ceremony of the Bavarian FMD members.

Top-class research in energy electronics and a vigorous network also enabled us to organize the 2017 IEEE International Conference on DC Microgrids (ICDCM). The recently demonstrated generation of electricity from hydrogen-rich but impure exhaust gas is a further example of our R&D activities. With the combination of power electronics and smart functionalities in our Cognitive Power Electronics 4.0 approach, we are extending our system competencies into the digital age.

In spring 2017, our Materials Department was able to celebrate the 20th anniversary of its affiliation to IISB. Appropriately, the noteworthy special exhibition KRISTALLE!, which we organized together with the Museum for Industrial Culture in Nuremberg, gave a fascinating overview of industrial crystal growth in the past and in the future.

Taking a glance at upcoming events, we are looking forward to the completion of our extension building, which is scheduled for October 2018. As IISB has now increased its staff to more than 280, this will provide a suitable and eagerly awaited framework for the growth of the institute.

In that respect, I would like to thank all my colleagues at IISB for their successful work in the past year. I also thank our partners in industry and our funding authorities, especially the Bavarian Ministry of Economic Affairs, Energy and Technology as well as the German Federal Ministry of Education and Research (BMBF) for their support.

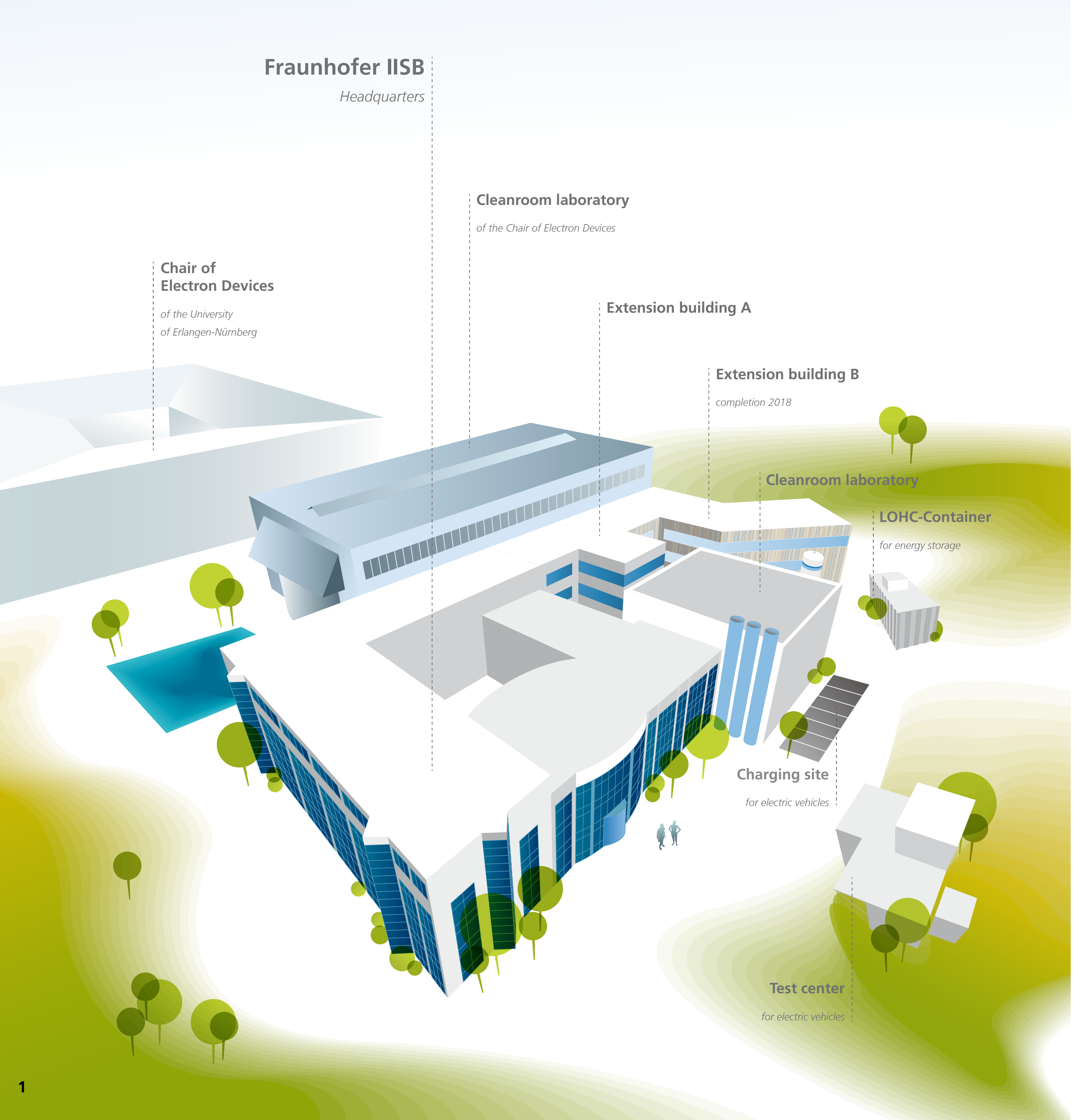
Sincerely yours,
Prof. Dr. Lothar Frey (Erlangen, April 2018)

TABLE OF CONTENTS

The „Names and Data“ chapter is exclusively available in the online version of the annual report:

https://www.iisb.fraunhofer.de/annual_reports

FRAUNHOFER IISB AT A GLANCE



PROFILE AND HISTORY

PROFILE

The Fraunhofer Institute for Integrated Systems and Device Technology IISB conducts applied research and development in the field of electronic systems for application in, e.g., electric vehicles or energy technology. In this connection, the IISB extensively covers the complete value chain from basic materials to entire power electronic systems. With its two business areas, semiconductors and power electronics, the institute provides innovation and solutions in materials development, semiconductor technology and manufacturing, devices and modules, as well as in system development for vehicle power electronics, energy electronics, and energy infrastructures. This is supplemented by broad activities in reliability, simulation, characterization, and metrology.

The headquarters of the IISB is located in Erlangen, Germany. The institute has branches in Nuremberg, Freiberg, and Chemnitz. As one of the 72 institutes of the Fraunhofer-Gesellschaft, the IISB does contract research for industry and public authorities. Moreover, it closely cooperates with the University of Erlangen-Nürnberg. The IISB has more than 250 employees plus numerous students working as research assistants. The institute is equipped with high-class laboratories, such as a test center for electric cars and an application center for DC grid technology. Together with the University, it operates 1500 m² of cleanroom area for semiconductor technology on silicon and silicon carbide.

The IISB is a close partner of national and international industry. Its main objective is to provide excellent research to its customers and to set technological benchmarks as one of the leading research institutions in electronic systems. Cooperation includes research and development projects, prototyping, consultancy, licensing, and studies.

HISTORY

The Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen is an important center of applied R&D for electronic systems, power electronics, semiconductor technology, and materials development in the Nuremberg metropolitan region, Germany, and Europe. It was founded in 1985 as the Electron Devices department AIS-B of the Fraunhofer Working Group for Integrated Circuits. In 1993, it became a Fraunhofer institute (IIS-B), but was still formally linked to its sibling institute IIS-A, today's Fraunhofer Institute for Integrated Circuits IIS. In 2003, IIS and IISB became completely independent from each other as two individual Fraunhofer institutes. From 1985 until his retirement in 2008, Prof. Heiner Ryssel was the head of the IISB. Since 2008 Prof. Lothar Frey has been director of the institute. From the beginning, the institute has been closely cooperating with the University of Erlangen-Nürnberg (FAU). In 2015, IISB together with IIS and FAU founded the "Leistungszentrum Elektroniksysteme" (LZE).

1 *Schematic overview of Fraunhofer IISB headquarters in Erlangen.*

ORGANIZATIONAL CHART 2017

DIRECTORS

L. Frey, M. März (deputy director)

- H. Hermes – ADMINISTRATION
- J. Schöneboom – INFRASTRUCTURE
- B. Fischer – STRATEGY & PR
- G. Ardelean – IT
- R. Öchsner – ENERGY TECHNOLOGIES

SIMULATION – J. Lorenz
- DOPING & DEVICES – P. Pichler
- STRUCTURE SIMULATION – E. Bär
- LITHOGRAPHY & OPTICS – A. Erdmann

MATERIALS – J. Friedrich
- SILICON – C. Reimann
- SILICON CARBIDE – P. Berwian
- NITRIDES – E. Meißner
- ENERGY MATERIALS – U. Wunderwald
- EQUIPMENT SIMULATION – J. Friedrich

TECHNOLOGY & MANUFACTURING – A. Bauer
- π-FAB – V. Häublein
- THIN-FILM SYSTEMS – M. Jank
- NANO TECHNIQUES – M. Rommel
- MANUFACTURING CONTROL – M. Pfeffer
- EQUIPMENT & APC – M. Schellenberger

DEVICES & RELIABILITY – A. Schletz
- DEVICES – T. Erlbacher
- PACKAGING – C.Bayer
- TEST & RELIABILITY – A. Schletz

VEHICLE ELECTRONICS – B. Eckardt
- DRIVES & MECHATRONICS – M. Hofmann
- AC/DC CONVERTERS – S. Zeltner
- DC/DC CONVERTERS – S. Matlok
- RF POWER & EMC – B. Eckardt
- GRID INTERFACES – S. Endres
- AIRCRAFT ELECTRONICS – F. Hilpert

ENERGY ELECTRONICS – M. März
- APPLICATION – M. Billmann
- ENERGY SYSTEMS – D. Malipaard
- BATTERY SYSTEMS – V. Lorentz
- DC GRIDS – B. Wunder

ADVISORY BOARD 2017

IISB is consulted by an Advisory Board, whose members come from industry and research:

Dr. Stefan Kampmann (Chairman of the Advisory Board)
OSRAM Licht AG

Dr. Helmut Gassel
Infineon Technologies AG

Thomas Harder
European Center for Power Electronics (ECPE)

Prof. Dr. Reinhard Lerch
Friedrich-Alexander-Universität Erlangen-Nürnberg

Markus Lötzsch
Nuremberg Chamber of Commerce and Industry

MinR Dr. Stefan Mengel
Federal Ministry of Education and Research (BMBF)

Dr. Andreas Mühe
PVA Crystal Growing Systems GmbH

Dr. Martin Schrems
AT&S AG

Dr. Karl-Heinz Stegemann
X-FAB Dresden GmbH & Co. KG

Dr. Thomas Stockmeier
ams AG

MR Dr. Stefan Wimbauer
Bavarian Ministry of Economic Affairs, Energy and Technology

RESEARCH AREAS

The R&D activities of the IISB cover the complete value chain for electronic systems, from basic materials to devices and modules up to application, with power electronics as a continuous backbone of the institute.

MATERIALS

Together with its industrial partners, Fraunhofer IISB develops equipment and processes for the production of crystalline bulk and layer materials for electronics. This comprises silicon, wide-band-gap semiconductors (e.g., silicon carbide, gallium nitride), materials for optical applications, detectors, and energy technology.

TECHNOLOGY & MANUFACTURING

The IISB operates extensive semiconductor technology lines, cleanroom infrastructure, and metrology on silicon and silicon carbide for the development of custom-tailored processes and prototype devices in power electronics and microelectronics. Furthermore, IISB works on nanotechniques, particle and thin-film systems. Manufacturing aspects such as process and quality control, equipment optimization, automation, and efficiency are also considered.

SIMULATION

The research activities of the IISB and its customers are supported by extensive competencies in simulation, modeling, and software development in the fields of, e.g., process and device simulation in semiconductor technology, crystal growth simulation, or thermal simulation for designing power electronic systems.

DEVICES

The institute develops customer-specific active and passive electron devices on silicon and silicon carbide for application in power electronics, microelectronics, and sensors. This includes novel device concepts and the development of cost-efficient processes tailored towards implementation and realization of customized products.

PACKAGING & RELIABILITY

New methods and materials for packaging, cooling, lifetime and failure analysis, and reliability play an important role. At IISB, packaging and reliability research are closely combined with each other. By analyzing the exact failure mechanisms after lifetime and reliability tests, the joining technologies, materials, concepts and mechanical designs are further improved. On the other hand, new packaging designs have a direct impact on the test methodologies and accelerating factors.

VEHICLE ELECTRONICS

Efficient, compact, and robust power electronic systems for all kind of vehicles are in the focus of the IISB. This comprises electric drives, battery systems, and the charging infrastructure of electric cars. Benchmark values for energy efficiency and power density are regularly set for the work of the IISB. Further fields of application are shipping and aviation.

ENERGY ELECTRONICS

Power electronic systems are indispensable for realizing a modern energy supply and the transition to predominantly regenerative energy sources. The developments of the IISB contribute to this on all levels of the power grid through, e.g., electronic components for HV DC transport, local DC micro grids or the integration of electrical storages and regenerative sources in the power grid.

ENERGY INFRASTRUCTURE TECHNOLOGIES

The goal of this field of activity is the coupling of electric and non-electric energy and the development of the necessary interfaces for implementing a sustainable energy infrastructure, especially for industry-size environments.

LOCATIONS

HEADQUARTERS OF FRAUNHOFER IISB ERLANGEN

Schottkystrasse 10, 91058 Erlangen

The headquarters of Fraunhofer IISB in Erlangen are located close to the University of Erlangen-Nürnberg. About 7000 m^2 of laboratories and office area allow research and development on a broad range of power electronics, semiconductor technology, and materials development. A test center for electric cars and extensive cleanroom area for semiconductor technology on silicon and silicon carbide, which is partly operated together with the Chair of Electron Devices of the University, are part of the available infrastructure.

BRANCH LABS OF FRAUNHOFER IISB

Fraunhofer IISB Nuremberg-EnCN
Fürther Strasse 250, "Auf AEG", 90429 Nuremberg

As a member of the "Energie Campus Nürnberg" (EnCN), the IISB operates a 450 m^2 branch lab on megawatt power electronics for energy supply in the joint EnCN building in Nuremberg.

Technology Center for Semiconductor Materials THM Freiberg
Am St.-Niclas-Schacht 13, 09599 Freiberg

The THM is a joint department of Fraunhofer IISB and Fraunhofer ISE. It supports industry in technologies for the production of innovative semiconductor materials to be used in microelectronics, optoelectronics, and photovoltaics. The IISB part of the THM comprises 650 m^2.

Chemnitz Laboratory
Reichenhainer Strasse 29a, 09126 Chemnitz

In Chemnitz, the IISB operates a laboratory of 160 m^2 for the industrial application of power electronics

NETWORK AND PARTNERS

Within its research activities, Fraunhofer IISB pursues cooperation with numerous national and international partners in joint projects and associations, among others:

- Since its foundation, the IISB has been closely cooperating with the University of Erlangen-Nürnberg. The institute is directed by the head of the Chair of Electron Devices of the University. The joint operation of infrastructure as well as the exchange in education and training create extensive synergies.
- The IISB is a core member of the "Leistungszentrum Elektroniksysteme" (www.leistungszentrum-elektroniksysteme.de, www.lze.bayern).
- The IISB is the coordinator of the Bavarian energy research project SEEDs (www.energy-seeds.org).
- The IISB is a member of the "Energie Campus Nürnberg" (EnCN, www.encn.de).
- The IISB is the coordinator of the Fraunhofer Innovation Cluster "Electronics for Sustainable Energy Use".
- The IISB is a partner of the excellence projects at the University of Erlangen-Nürnberg (www.eam.uni-erlangen.de, www.aot.uni-erlangen.de/saot/).
- The IISB closely cooperates with industry and research associations, such as the European Center for Power Electronics, the Bavarian Clusters for Power Electronics and Mechatronics & Automation, or the German Crystal Association DGKK e.V.
- The IISB is the coordinator and partner, respectively, of numerous European research projects.
- Together with the Federal Ministry for Education and Research (BMBF), the IISB initiated and operates the joint student program of BMBF and Fraunhofer for electric mobility, DRIVE-E (www.drive-e.org).
- The IISB is a close partner of the "Förderkreis für die Mikroelektronik e.V."

The IISB is member of the following Fraunhofer groups and alliances:

- Fraunhofer Group for Microelectronics (www.mikroelektronik.fraunhofer.de)
- Fraunhofer Energy Alliance (www.energie.fraunhofer.de)
- Fraunhofer Battery Alliance (www.batterien.fraunhofer.de)
- Fraunhofer Nanotechnology Alliance (www.nano.fraunhofer.de)

NETWORK AND PARTNERS

CHAIR FOR ENERGY ELECTRONICS (LEE), UNIVERSITY OF ERLANGEN-NÜRNBERG

Since September 1, 2016, Prof. Dr. Martin März, deputy director at Fraunhofer IISB, is heading the newly established Chair of Energy Electronics (LEE). The chair conducts research on current topics in the field of power electronics for the electric power supply. Beside stationary decentralized electrical power systems, the addressed application fields also include the power-nets in vehicles, ships, railways, and airplanes. LEE is part of Energy Campus Nuremberg (EnCN) on the former AEG company grounds in the Fürther Strasse in Nuremberg, and the first chair grown out of the EnCN.

CHAIR OF ELECTRON DEVICES (LEB), UNIVERSITY OF ERLANGEN-NÜRNBERG

The Fraunhofer IISB and the Chair of Electron Devices (German abbreviation: LEB) of the University of Erlangen-Nürnberg are both headed by Prof. Lothar Frey.

Within the framework of a cooperation agreement, the two institutions not only jointly operate the University's cleanroom hall and other laboratories but also work closely together with regard to teaching and research.

The cooperation of the Chair of Electron Devices and the Fraunhofer IISB makes it possible to cover the entire chain of topics from basic research to the transfer to industry. For many years, the vocational training as a "microtechnologist" has been offered jointly by IISB and the Chair of Electron Devices. Employees of IISB assist in courses and internships at the University.

The following staff members of Fraunhofer IISB regularly give lectures at the University of Erlangen-Nürnberg:

Dr. Andreas Erdmann
- Optical Lithography: Technology, Physical Effects, and Modeling

Dr. Tobias Erlbacher
- Semiconductor Power Devices

Prof. Dr. Lothar Frey
- Nanoelectronics
- Process Integration and Components Architecture
- Semiconductor Devices
- Technology of Integrated Circuits

Dr. Michael Jank
- Introduction to Printable Electronics
- Nanoelectronics

Dr. Jürgen Lorenz
- Process and Device Simulation

Prof. Dr. Martin März
- Power Electronics for Decentralized Energy Supply - DC Grids
- Power Electronics in Vehicles and Electric Powertrains
- Thermal Management for Power Electronics

Prof. Dr. Lothar Pfitzner
- Semiconductor Equipment Technics

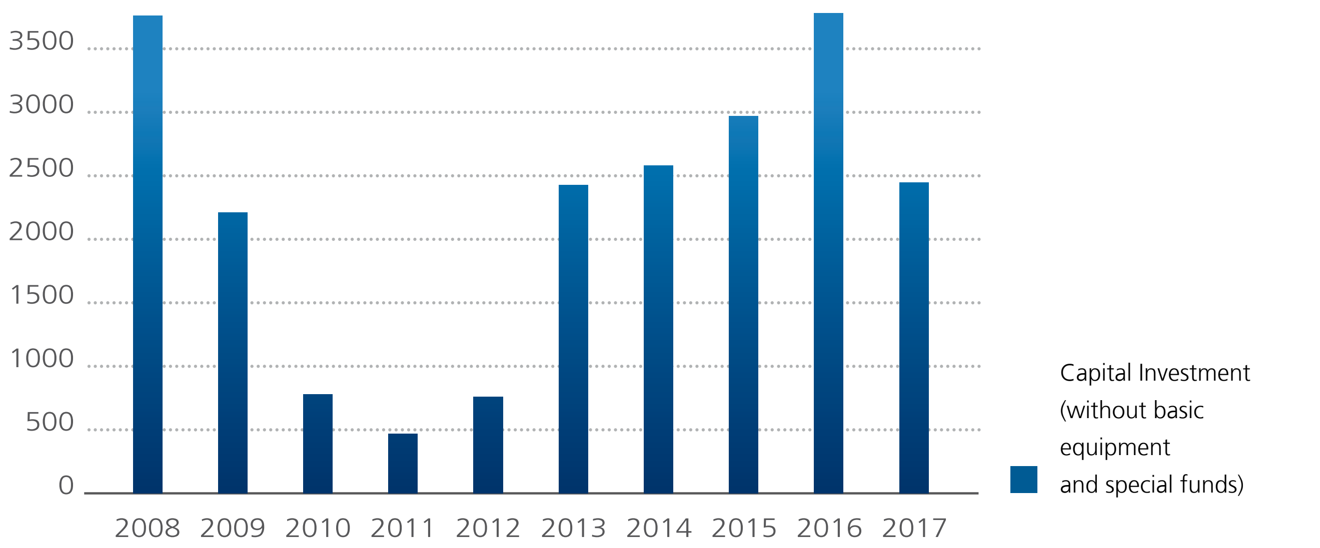
Priv.-Doz. Dr. Peter Pichler
- Reliability and Failure Analysis of Integrated Circuits

1 *Chair of Electron Devices of the University of Erlangen-Nürnberg: main building and clean room laboratory. © LEB*

NUMBERS AND STATISTICS

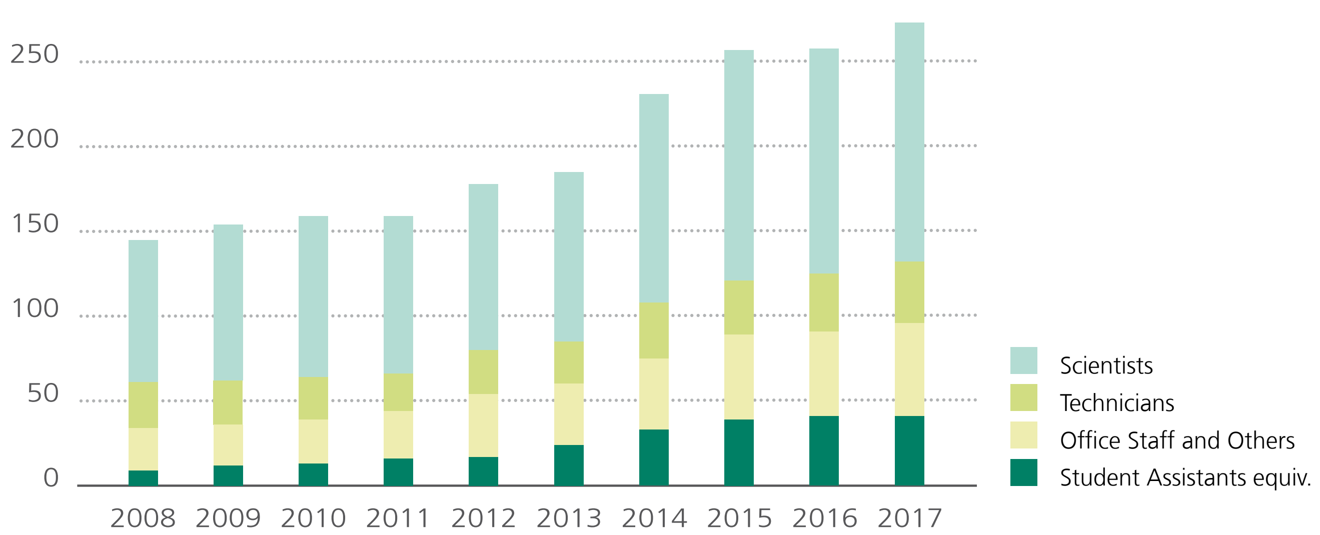
INVESTMENT IN K€

2.301.000 Euro in 2017



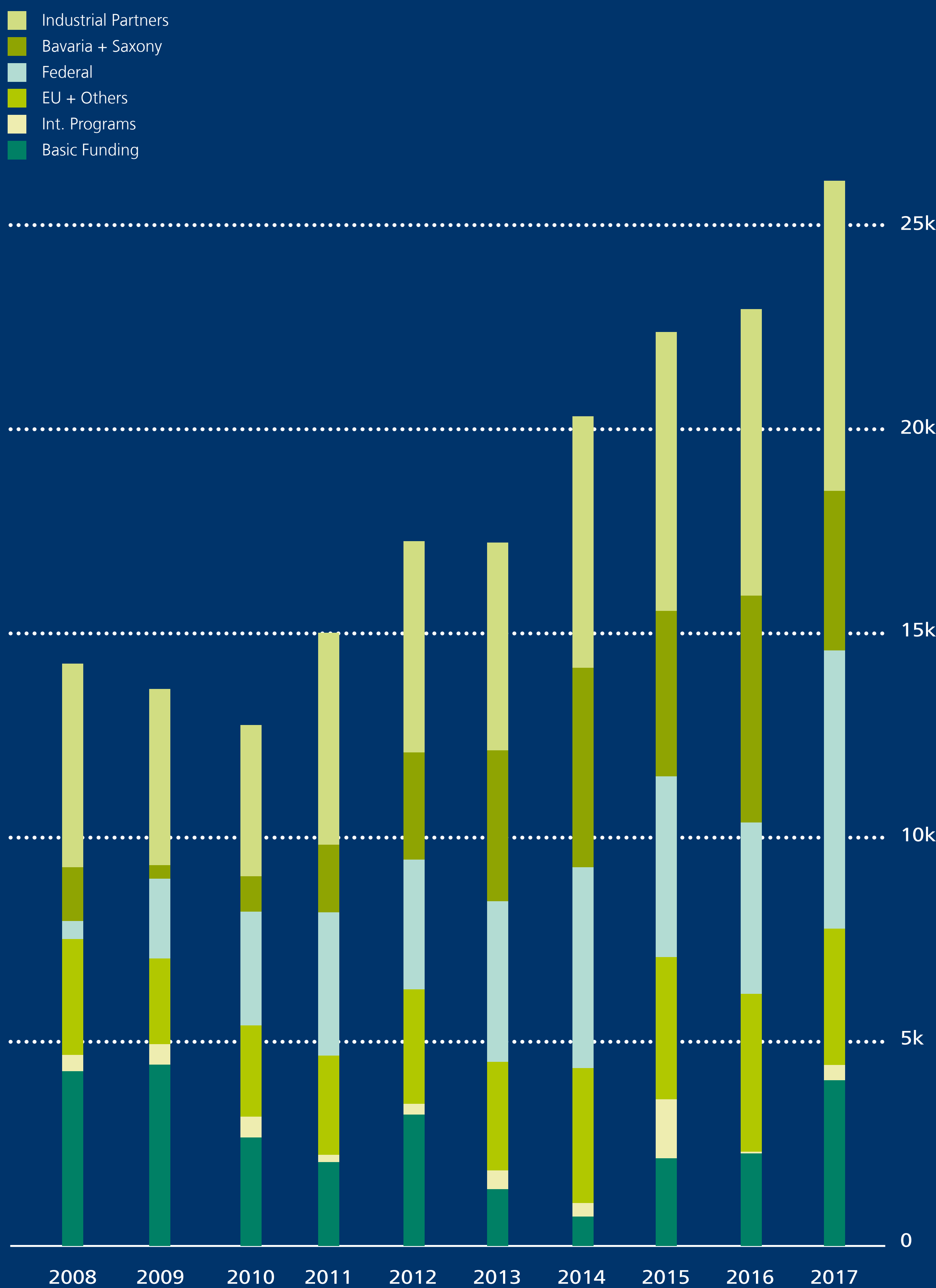
STAFF DEVELOPMENT

273 Employees in 2017

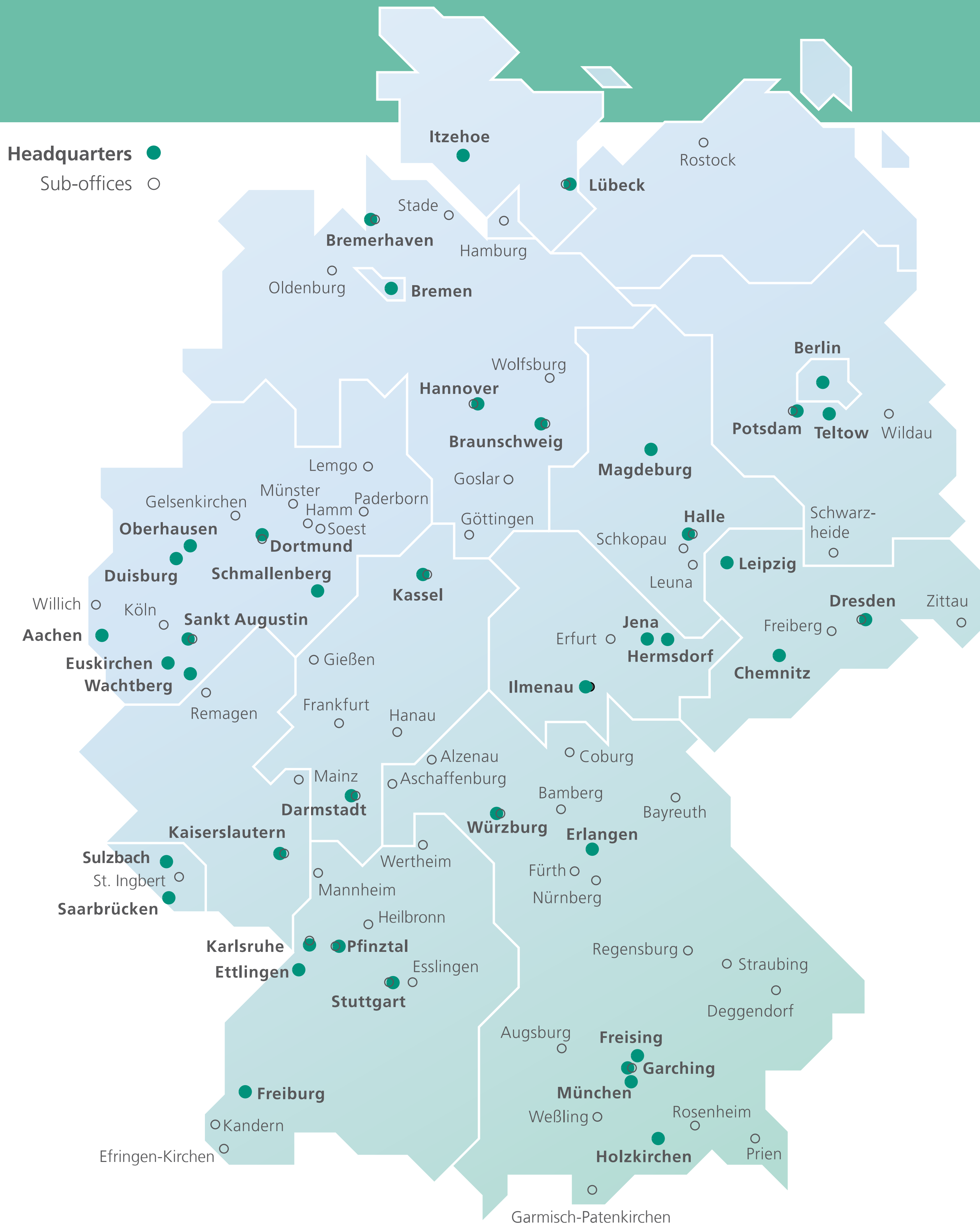


OPERATING BUDGET IN K€

26.082.000 Euro in 2017



FRAUNHOFER



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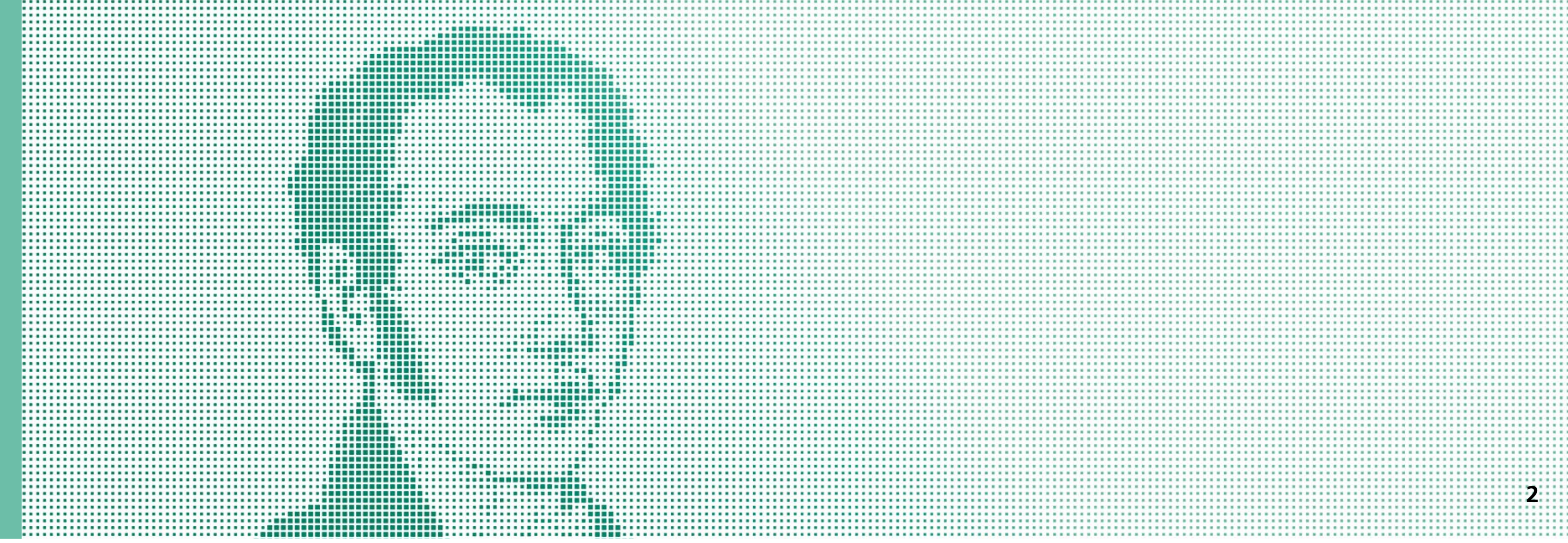

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THE FRAUNHOFER-GESELLSCHAFT

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 72 institutes and research units. The majority of the more than 25,000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 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 technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

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 *Locations of the Fraunhofer-Gesellschaft in Germany.*
© Fraunhofer

2 *Joseph von Fraunhofer (1787 – 1826): researcher, inventor, entrepreneur.*
© Fraunhofer IISB

SIMULATION

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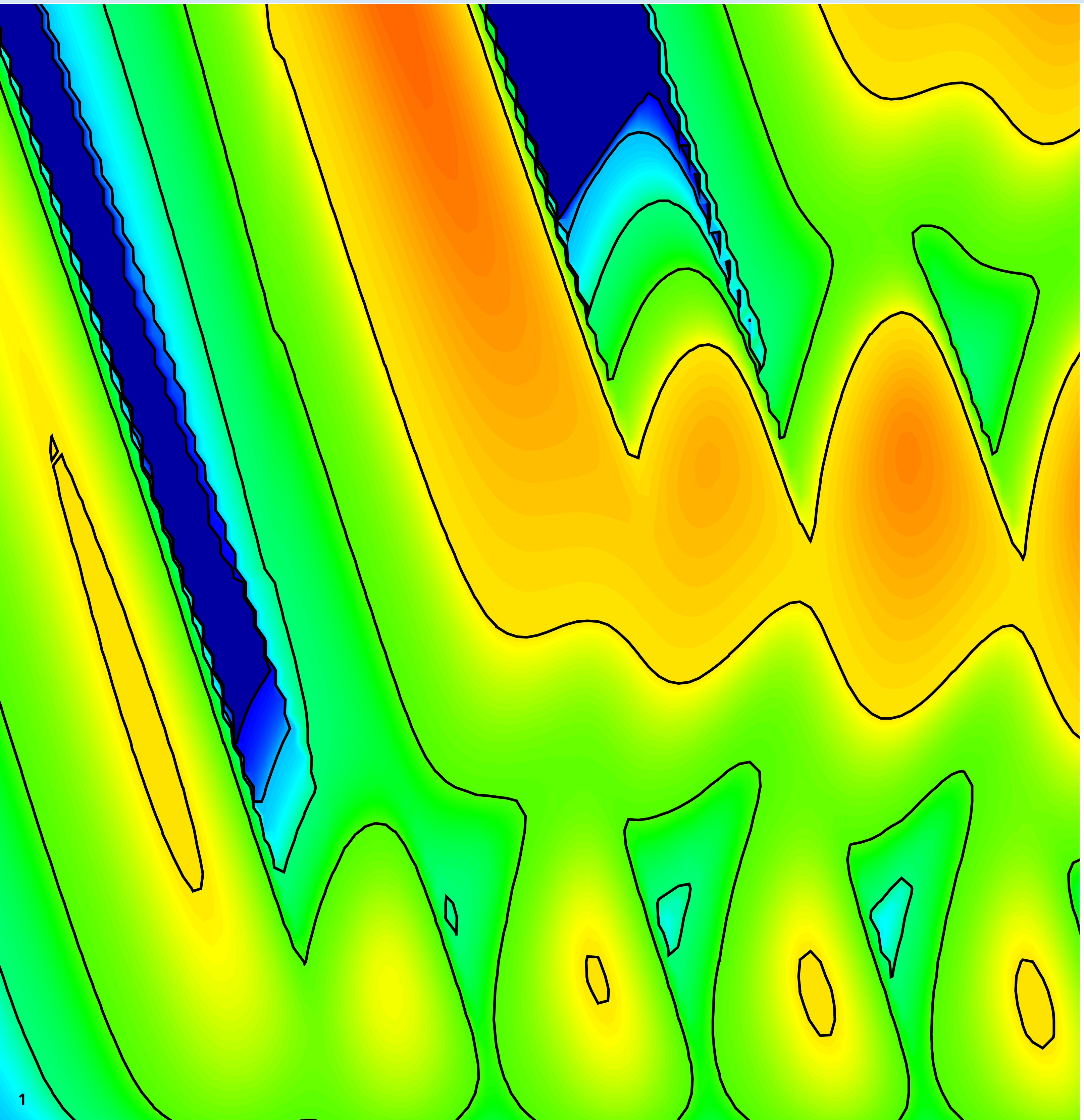

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During the last decades, modeling and simulation have become indispensable for developing and optimizing technologies and applications in most industrial areas. Their methods range from first-principle calculations frequently done on the atomic or molecular scale to large-area simulations using heuristic models that do not solve detailed physical equations but employ simplified analytical expressions and elaborated methods to extract the required parameters.

In micro- and nanoelectronics, the simulation of semiconductor fabrication processes, devices, circuits, and systems greatly helps to reduce development costs in the semiconductor industry. This has been confirmed for micro- and nanoelectronics in the International Technology Roadmap for Semiconductors (ITRS), among others.

The Simulation department contributes to this by developing physical models and programs for the simulation and optimization of semiconductor fabrication processes and equipment. Furthermore, it supports the development of lithography (incl. masks, materials, and imaging systems) and other processes, devices, circuits, and systems by providing and applying its own and third-party simulation and optimization tools.

Whereas the research effort in modeling and simulating processes for aggressively scaled devices has been the core of the activities of the department since the foundation of the institute, in recent years the activities of the department have been strongly expanding into the area of "More than Moore", which consists of fields such as analog / RF, low-power electronics, power electronics, and microsystems technology. These new fields of application in particular often require the combination of heterogeneous competencies because thermal, mechanical, optical, and chemical effects also occur in addition to electronic effects. This gives rise to an additional demand for research.

The department also continues to make important contributions to support the further scaling of advanced nanoelectronic devices. These activities have been mainly carried out in three cooperative projects on the European level, funded either by the European Commission or by the member states: The EU Horizon 2020 project "Stability Under Process Variability for Advanced Interconnects and Devices Beyond 7nm Node" (SUPERAID7) coordinated by the department deals with the simulation of the impact of process variations on advanced transistors and circuits. SUPERAID7 started at the beginning of 2016 as a follow-up project to the FP7 project SUPERTHEME, which was successfully completed at the end of 2015. The traditionally optics-driven resolution improvements through extreme ultraviolet (EUV) lithography are addressed in the ECSEL KET pilot lines "Seven Nanometer Technology" (SENATE) and "Technology Advances and Key Enablers for 5nm" (TAKE5) by a large consortium of companies, research institutes, and universities, coordinated by ASML (the German part by Zeiss), the leading vendor of lithography steppers.

1 *Simulated room-temperature characteristics of a SET based on a highly doped silicon nano-pillar with a diameter of 10 nm. The 3 nm silicon quantum dot is embedded in a 6 nm thick oxide layer.*
© Fraunhofer IISB

2 *Dr. Jürgen Lorenz, head of the Simulation department.*
© K. Fuchs / Fraunhofer IISB

SIMULATION

Exploration of Mask Options for (Future) EUV Lithography

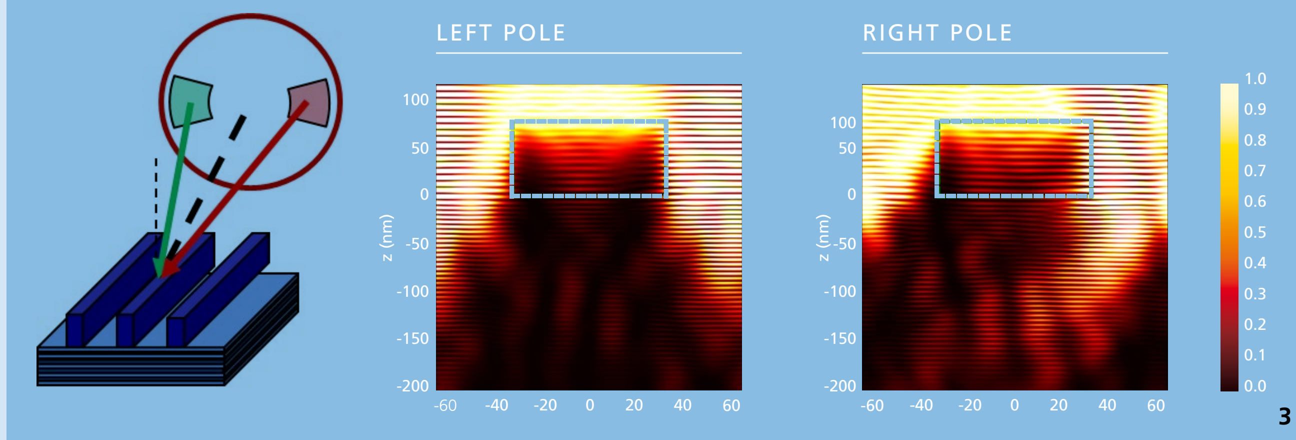
Here, the department contributes with the expansion and especially the application of its leading-edge lithography simulator Dr.LiTHO.

Furthermore, the department also earns license fees for software developed within "More Moore" projects. Our solid expertise gained in the field of "More Moore", for instance regarding tailored numerical methods for model implementation, provides a sound basis for the development and application of simulation in other fields, such as "More than Moore". In 2017, our department was correspondingly involved in several recent cooperative projects funded by German or European authorities, including two EU FP7 projects: In the project ATHENIS_3D ("Automotive Tested High Voltage and Embedded Non-Volatile Integrated System on Chip platform employing 3D Integration"), the department investigated and simulated the distortion of integrated capacitors due to fabrication and reliability problems that occur with the 3D integration of ICs with power devices. In the project "Multi Sensor Platform for Smart Building Management" (MSP), the department applied its own and commercial third-party software to optimize the three-dimensional integration of sensor systems, especially via so-called "through silicon vias" (TSVs). Lithography simulation is used not only for the development of advanced lithography technology but also for metrology and inspection.

Software engineering techniques are provided and applied in other areas of the institute for, among others, smart battery management, which is an important area in power electronics. Genetic algorithms, neural networks, and hierarchical modeling approaches are utilized for component and system optimization. Multiphysics simulations that include electrical, mechanical, and/or thermal effects on a case-by-case basis are employed for applications especially in the power electronics area.

In both the areas of "More Moore" and "More than Moore", the expertise gained or expanded in publicly funded cooperative projects also provides the foundation for several research and development projects directly commissioned and financed by industry, e.g., for the optimization of lithography masks, the simulation of platinum diffusion for power devices, or inductive coupling.

The department will continue its approach to performing focused work on physical models and algorithms in order to develop the necessary skills and tools on the one hand and to transfer these results to applications in industry on the other. Here, a close and trustful cooperation based on sharing work according to the individual competencies and requirements of the partners has been a key element of the achieved success for many years.



EXPLORATION OF MASK OPTIONS FOR (FUTURE) EUV LITHOGRAPHY

About thirty years ago, several independent research groups in Japan and the US proposed using soft x-rays or extreme ultraviolet (EUV) light for manufacturing nanoscale patterns. Since then, many resources have been invested in the development of EUV lithography. European and German funding in projects such as More Moore, EXCEPT, SeNaTe, and several others have enabled the evolution and continuing progress of this enabling technology. It is expected that EUV lithography will start to be used in manufacturing around 2019 / 2020 and finally pay off these investments.

The Computational Lithography and Optics group of Fraunhofer IISB has participated in the mentioned European projects and developed models, simulation techniques, and software to support the development of EUV lithography. The worldwide reputation of the group has been acknowledged by many invitations to international conferences and scientific journals, among other things.

From April 2015 to March 2018, Fraunhofer IISB participated in the SeNaTE project on the development of seven nanometer technology using EUV. The modeling activities of IISB supported the design of novel EUV imaging systems at Zeiss SMT and the development of new mask technologies and infrastructure at the Belgium research institute imec.

One of our key contributions concerned the characterization and mitigation of 3D mask effects. The absorber on an EUV mask is illuminated from oblique directions, which causes asymmetric shadowing effects (see picture 3) and variations of the feature position versus focus (telecentricity errors). Moreover, the thickness of the absorber is much larger than the used wavelength. As can be seen from picture 4, differences between the refractive index of the absorber and vacuum generated pronounced phase deformation of the transmitted and reflected light. This phase deformation causes a shift of the focus position and other aberration-like effects.

Strategies to compensate for these 3D mask effects include the employment of asymmetric illuminators, asymmetric layout corrections on the mask, and the use of alternative absorber materials. Fraunhofer IISB has extended and used the advanced mask and imaging models and multi-objective evolutionary optimization algorithms in its lithography simulator Dr.LiTHO to identify the most promising combinations of mitigation strategies for future technology nodes. The described 3D mask effects become even more important for the 3rd generation of EUV imaging tools with a numerical aperture of 0.55.

3 Dipole illumination scenario and simulated near fields. Left: Sketch of the mask geometry and illumination directions. The thin and thick dashed lines show the direction of the mask surface normal vector and of the chief ray angle, respectively. The circle and segments indicate a numerical aperture of 0.33 and the positions of the left and right pole in the illuminator. Center and right: Simulated near fields for illumination from the center of the left / right pole.
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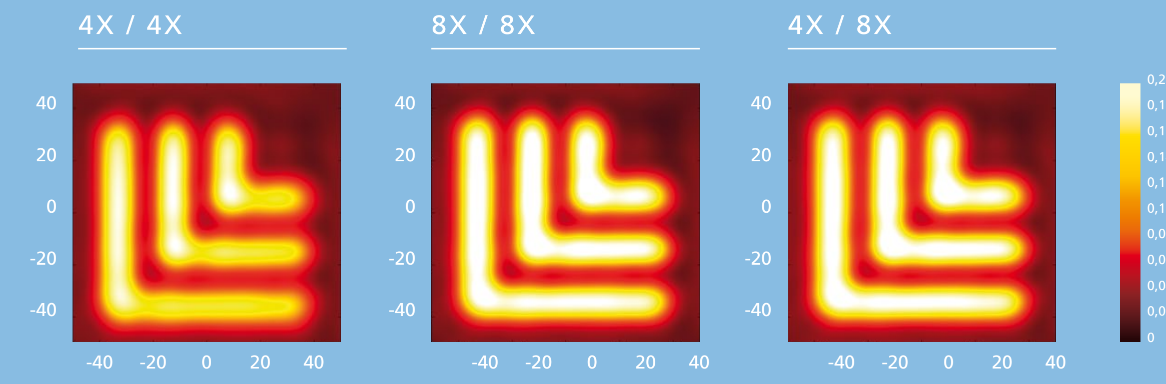
SIMULATION

Exploration of Mask Options for (Future) EUV Lithography



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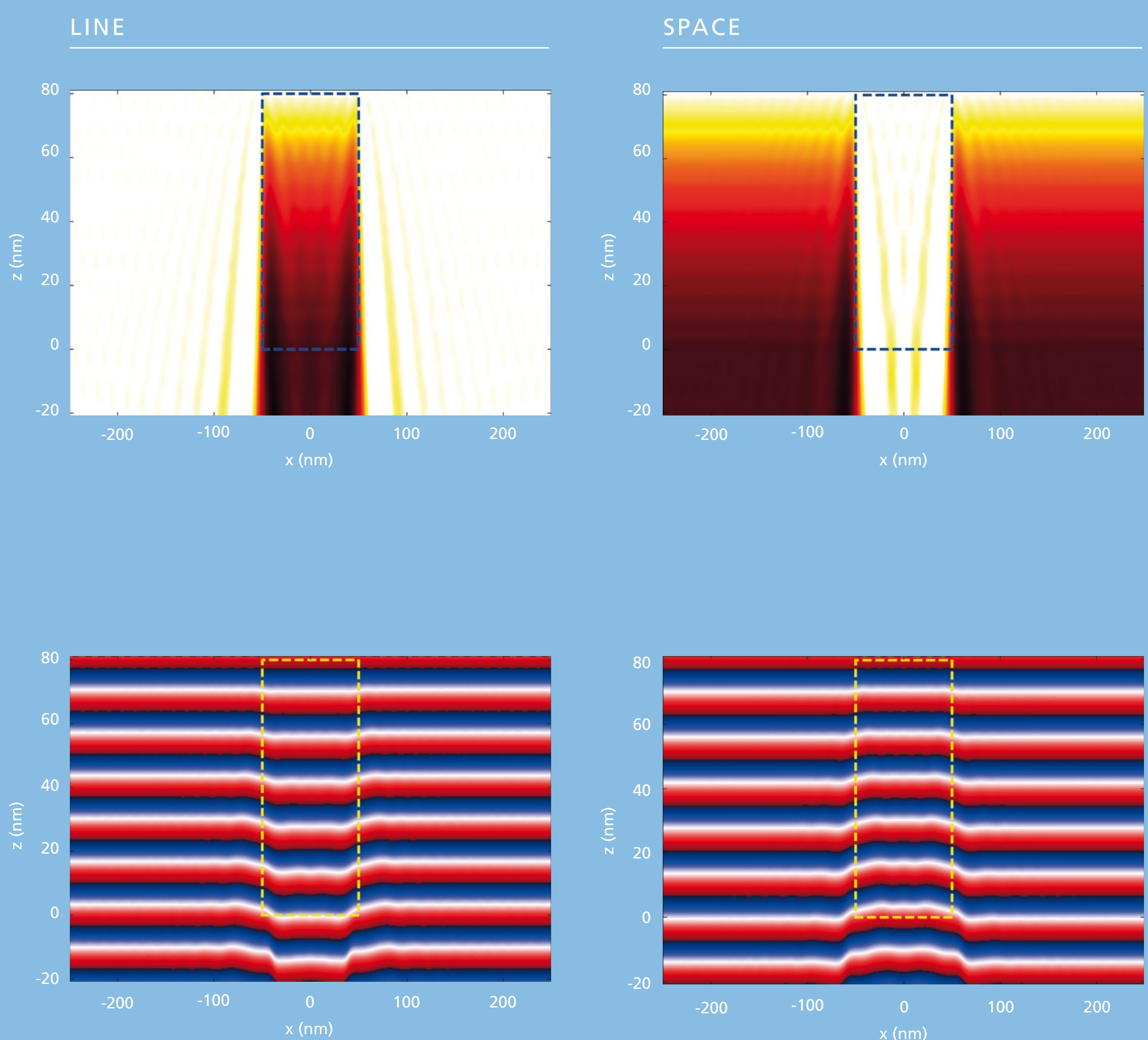

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For this reason, ASML and Zeiss started the development of anamorphic projection systems with different demagnification ratios along and perpendicular to the scan direction, respectively. The imaging algorithms in Dr.LiTHO were extended to describe and analyze such systems. The simulated images in picture 5 demonstrate the advantages of anamorphic imaging and its capability to compensate for mask-induced image asymmetries compared to state-of-the-art 4× reduction systems.

The close cooperation of Fraunhofer IISB with leading European companies and institutes in SeNaTe has not only enabled the development of mask diffraction and imaging models for future EUV lithography systems but also strengthened the reputation of the Computational Lithography and Optics group. The results of the SeNaTe project and new partnerships have already been used to kick off new publicly funded and bilateral industrial follow-up projects. The development of EUV imaging technology also opens new possibilities for the use of EUV radiation for novel high-resolution metrology solutions for nanostructures with applications in material research and life sciences. The acquired knowledge on the modeling, characterization, and evaluation of EUV imaging systems provides an excellent basis for new activities of the group in these emerging fields.

4 *Near field simulation for an EUV mask without reflective multilayer: TaBN absorber with 88 nm mask scale feature size and 220 nm mask scale pitch. Top row: near field intensities, bottom row: near field phase, left: line feature, right: space feature, dashed line: outline of absorber.* *© Fraunhofer IISB*

5 *Simulated aerial images of elbow patterns consisting of 10 nm spaces. The figure inset between the images of the 4× / 4× and 8× / 8× systems exhibits the orientation of the chief ray angle (red dot) with respect to the NA (circle) and the elbow layout on the mask.* *© Fraunhofer IISB*

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MATERIALS

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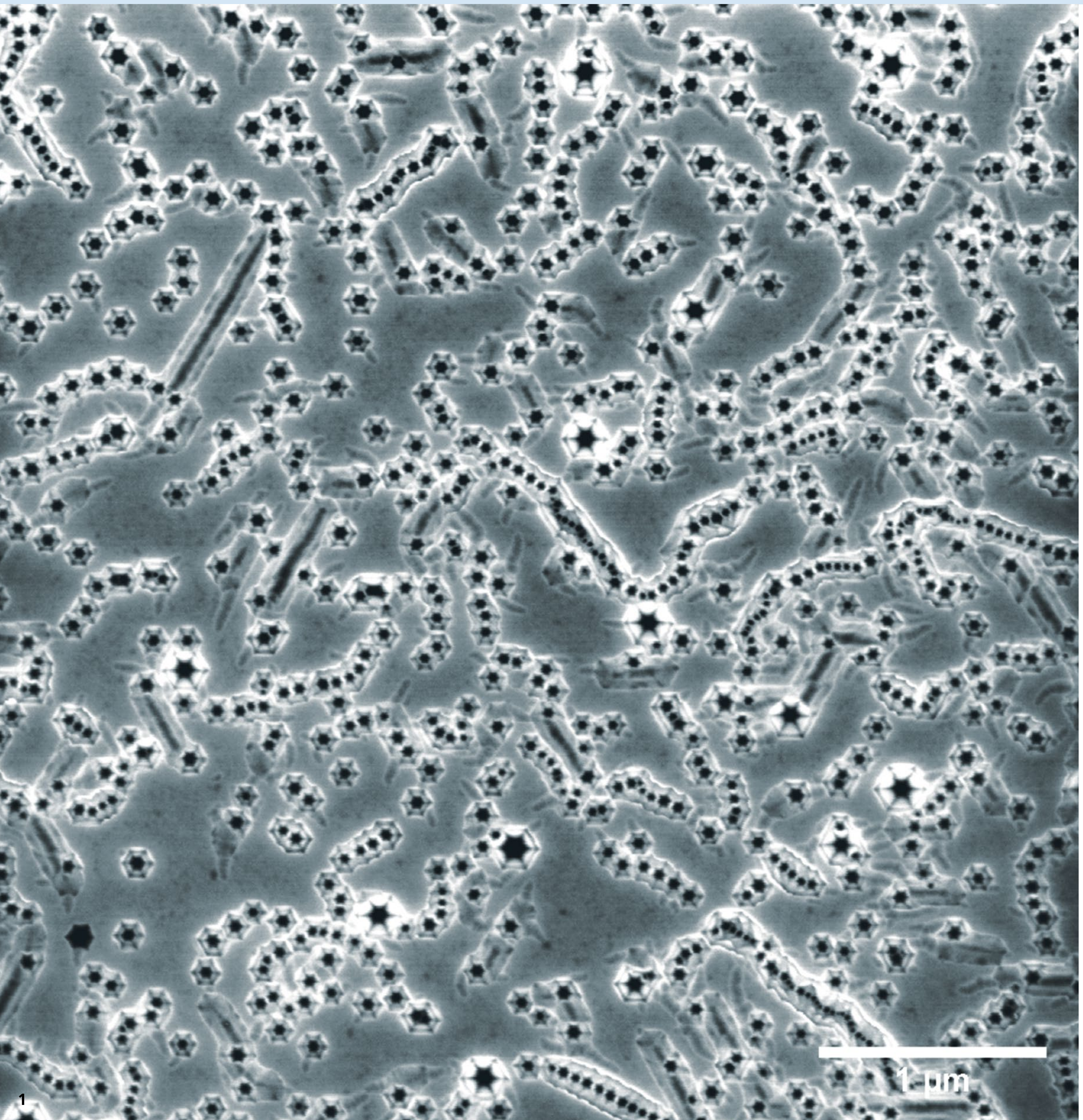

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We provide scientific and technological solutions for the development and characterization of semiconductor materials and their production processes. Our driving motivation is to enable novel applications through the commercialization of these materials.

Special emphasis is placed on silicon and wide bandgap semiconductors (SiC, GaN, AlN) for electronic applications, energy saving, and optical systems. The main aim is to support material, device, and equipment manufacturers and their suppliers in the areas of crystal growth and epitaxy. Our materials are further processed into devices and integrated in system demonstrators in-house or at partner sites. To be close to our customers, we operate our branch lab, the Fraunhofer Technology Center for Semiconductor Materials (THM), in Freiberg/Saxony, Germany.

The investigation of the relationship between the microstructure of the semiconductor material and the performance and reliability of a respective device gives us the best input for the further development of the materials and their production processes. The strategy of IISB is a combinatory approach composed of thorough experimental process analysis, tailored characterization techniques, and numerical modeling. These efforts are supported by a well suited infrastructure consisting of R&D-type furnaces, epitaxial reactors, other thin film technologies, state-of-the-art metrology tools for the investigation of physical, chemical, electrical, and structural properties of materials, as well as powerful and user-friendly simulation programs. These programs are especially suitable for heat and mass-transport calculations in high-temperature equipment with complex geometry.

The Materials department gains its competences from an interdisciplinary team of materials scientists, physicists, chemists, as well as electrical, mechanical, chemical, and computer engineers. We have extensive expertise in the areas of crystal growth, epitaxy, thin film deposition, and the synthesis of functional materials including characterization and modeling. Multiple national and international research awards underscore the scientific and technological achievements of the Materials department. These awards have been granted for outstanding scientific and technological results, as well as for excellent contributions to the education of students and engineers. In collaboration with the University of Erlangen-Nürnberg, the Technical University Georg-Simon-Ohm Nuremberg, and the Technical University Bergakademie Freiberg, the Materials department supervises students carrying out research projects, including bachelor, master, and PhD theses.

In 2017, the majority of research topics at the Materials department were in the areas of silicon, silicon carbide, gallium nitride, and aluminum nitride.

In the field of directional solidification of silicon for photovoltaic applications, we put our focus on finding technical solutions for the reduction of the so-called red zone, i.e., areas of decreased minority carrier lifetime. By introducing novel diffusion barriers and coatings of the inner crucible

1 *Defect selectively etched gallium nitride grown on silicon on a scale of 5 x 5 µm². The etch pits represent crystal defects (dislocations).*
© Fraunhofer IISB

2 *Dr. Jochen Friedrich, head of the Materials department.*
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MATERIALS

Innovative Reliable Nitride-based Power Devices and Applications

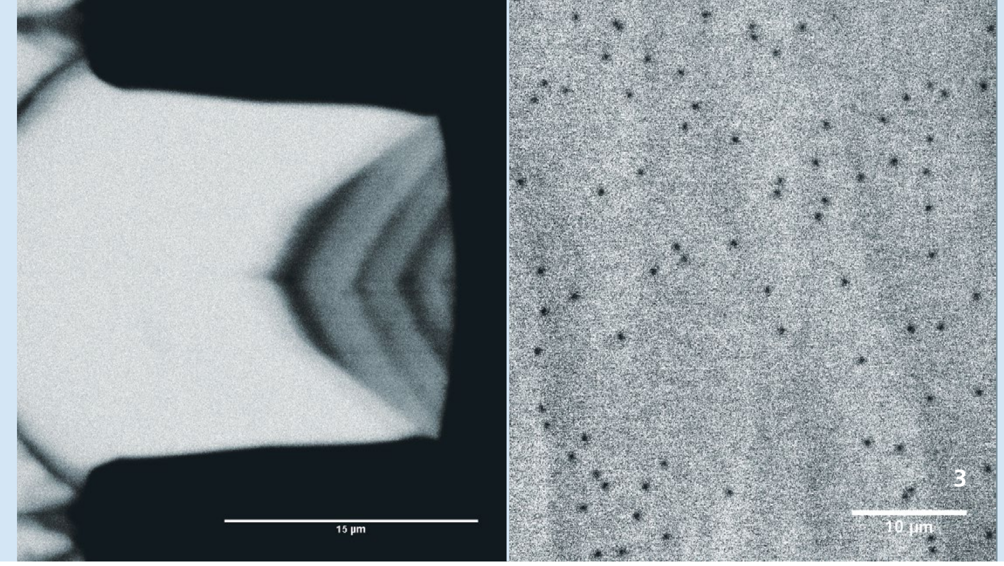
wall, we were able to reduce the contamination of the silicon ingot by metallic impurities originating from the silica crucible or the Si_3N_4 coating. Our solutions, which are marketed by our industrial partners, have proven to increase the wafer yield by 4% per ingot.

In the field of Czochralski grown silicon, we won the young researcher award of the DGKK e.V. for finding the causes of the so-called structure loss during crystal pulling of heavily n-type silicon. These findings allowed us to propose countermeasures that resulted in a yield improvement during the production of heavily doped silicon. For the industrial Czochralski process for photovoltaic applications, we support our industrial partner in the development of the next generation of pullers with respect to higher charge weights, higher throughput, and lower costs with a combination of numerical modeling and experimental investigations.

In the field of nitride semiconductors, we were able to grow the first AlN boule crystals with a 1-inch diameter and a length of several millimeters using the Physical Vapor Transport (PVT) method. In the future, these crystals will be used by our industrial partners as substrates for processing UV-C LEDs. In order to promote and accelerate the commercialization of nitride substrates, we started with the manufacturing of own HEMT test structures. Within a short time period, we were able to achieve 2DEG properties in our HEMT layer stack that are comparable to commercially available devices. Our investigations on AlGaN/GaN heterostructures processed by partners revealed that certain types of threading dislocations act as leakage current paths. Moreover, there is evidence that the presence of conductive interfaces has significant influence on bulk leakage, thus potentially degrading the bulk-related breakdown voltage of AlGaN/GaN HEMTs.

In the field of silicon carbide, we continued our analysis of the point defects that limit the minority carrier lifetime in bipolar SiC power devices, and we achieved significant progress in lifetime enhancement using post-epi processes. We have found that the minority carrier lifetime measured in our epilayers clearly depends on the supplier of the bulk substrate and therefore on the point defects within the substrates, even when very thick epilayers have been grown. Interestingly, we have observed in most cases that the lifetime is enhanced in the area of the facet of the substrate. The causes for these experimental findings are still under investigation.

A new topic of the Materials department is the development and electrochemical analysis of alternative battery materials for the post Li battery generation. For that purpose, multivalent ion systems such as aluminum ion systems have a great potential because of their reliable and cost-efficient availability. Especially the high density of the capacity of Al ion systems, which is four times higher than for Li ion systems, gives a strong motivation for our activities. We have started to synthesize suitable cathode materials and to analyze the electrochemical performance in half and full cells with newly developed electrolytes to validate these alternative storage materials.



INNOVATIVE RELIABLE NITRIDE-BASED POWER DEVICES AND APPLICATIONS

AlGaN/GaN devices have great potential as the next generation of power devices, outperforming Si and competitive with even SiC devices in applications such as power factor correction (PFC), motor control, photovoltaic (PV) inverters, electric vehicles (EV), hybrid electric vehicles (HEV), battery chargers, etc.

However, there are still factors that limit their widespread adoption in the market. The cost and reliability of the – mostly – fabricated transistors play a crucial role and still have to be improved.

The drawback of GaN-on-Si is that the heteroepitaxy requires advanced strain engineering techniques through the growth of multilayer stacks. This results in a large number of crystal defects (mainly threading dislocations), in the order of ~10E9 cm^{-3}. Therefore, any power device with a current rating of >10 A will have >10E6 defects in the device area. It is yet not clear how these defects will impact the long-term reliability of power devices, which is a major concern for wide-spread market adoption.

For this reason, a currently running project funded by the European Union under the name InRel-NPower (http://www.inrel-npower.eu/) addresses the impact of GaN material quality, in combination with the device layout, in view of long-term reliability. The project aims to study reliability in depth and develop a qualification strategy, specifically addressing the impact of dislocations and other structural disturbances inside the materials on the long-term device reliability.

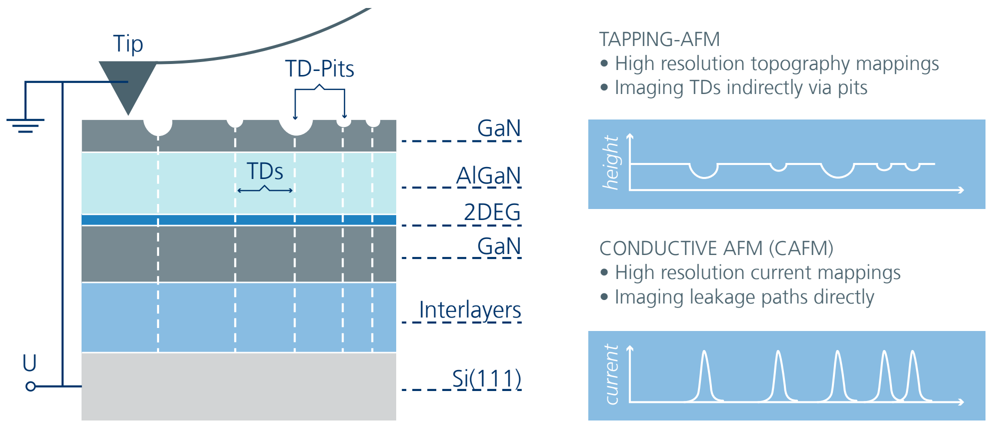
The Materials department develops new analytical concepts for the direct visualization of electrically active and potentially harmful dislocations. The dislocations are correlated with the electrical behavior of a device, using a sophisticated and thoroughly elaborated stepwise process to analyze devices structurally as well as electrically at as many stages as possible during device processing. It is, however, extremely challenging to perform this type of electrical and structural analysis at the same place during processing in order to enable direct local correlations.

Picture 4 (next page) shows one principle analysis scheme for the direct correlation of structural disturbances with their electrical conductivity measured by different atomic force microscopy (AFM) techniques, namely tapping mode AFM and conductive AFM (CAFM). This measurement scheme makes it possible to locate the places of threading dislocations (TD) on the surface of an epitaxial layer GaN present in a high electron mobility transistor (HEMT). At the same place, the current flow between the AFM tip and the back of the structure can be measured.

3 *Left: CL picture showing an impurity variation on the side walls of a V-defect in a GaN layer.*
Right: Panchromatic CL image showing the distribution of dislocations as dark spots.
© Fraunhofer IISB

MATERIALS

Innovative Reliable Nitride-based Power Devices and Applications



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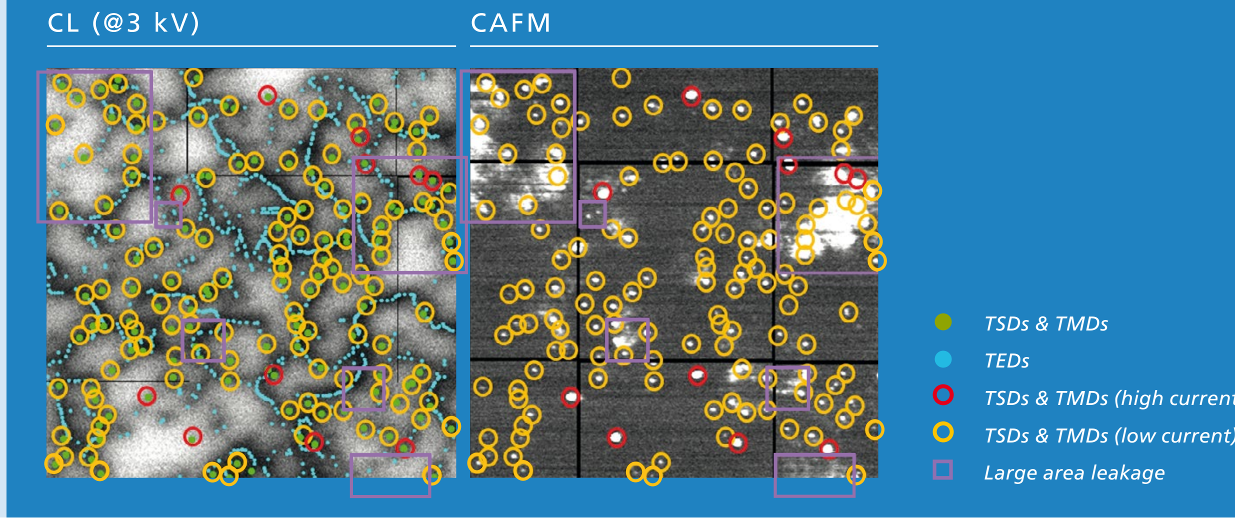
Another technology to image the distribution of structural disturbances or dislocations is cathodoluminescence (CL) imaging with a scanning electron microscope. This can reveal the dislocations as dark spots due to their action as non-radiative recombination centers.

Moreover, CL imaging offers the possibility to visualize local dopant variations, for example, which could be an additional reason for malfunction of a device. Picture 3 (previous page) exemplarily depicts a panchromatic image of an epitaxial layer of GaN on silicon and the dark spots that are generated due to the non-radiative recombination action of the dislocations. It can be seen that the dislocations may be arranged in lines or clusters, which are potentially more harmful for a device than an isolated dislocation. On the left-hand side, picture 3 shows the cross-section of a so-called V-pit that developed on the surface of a GaN layer. The grayscale variations of the contrast are a result of impurity variations on the rhombohedral faces of the sidewalls of the V-pit.

In such areas, a more detailed analysis is carried out with AFM and CL imaging at the same place. The conspicuous location can be investigated further, and a conclusion can be drawn regarding the reliability of the devices.

A direct correlation of a CL with an AFM investigation is demonstrated in picture 5. It can be seen that the different types of dislocations have different electrical activity. For example, threading screw or mixed dislocations with screw component dislocations (TSD, TMD) are clearly visible as vertical leakage paths through the structure, whereas edge dislocations (TED) are not visible to the same extent as electrically active ones. The nature of the larger areas with high vertical leakage is still unclear and is under further investigation as a task within the project.



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The InRel-NPower project aims to demonstrate new device concepts with increased robustness and reliability, which will be realized, evaluated, and tested thoroughly. This will demonstrate how it is possible to overcome the known limitations of GaN on silicon technology, such as, e.g., vertical leakage, trapping phenomena, and/or the breakdown of lateral HEMTs.

IISB offers a unique correlation between issues observed in the material microstructure and the electrical performance of a device. This makes the Materials department and the Nitrides group in particular a key partner in the project.

4 *Analysis scheme of different AFM measurements for the direct local correlation of structural and electrical disturbances in epitaxial GaN layers for HEMT epistacks.*
© Fraunhofer IISB

5 *Direct correlation of the same area investigated by CL imaging and CAFM. This sophisticated local correlation enables the visualization of (in this case) vertical leakage paths with structural issues present in a HEMT structure.*
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TECHNOLOGY AND MANUFACTURING

2

1

Technology and manufacturing at Fraunhofer IISB mean above all research, development, and prototype manufacturing in the field of power electronic devices on silicon (Si) as well as on 4H-silicon carbide (SiC).

In particular to meet the requirements of our external and internal customers better, the service sector is set up in a separate organizational unit called π-Fab. π-Fab is intended for the fabrication of custom-tailored prototype electron devices, mainly for power electronic application, and it is ISO 9001:2015 certificated for this.

For this purpose, IISB and the Chair of Electron Devices of the University of Erlangen-Nuremberg operate joint clean room facilities of 1500 m² (primarily class 10) with CMOS-compatible equipment. This allows the implementation of important process steps on silicon wafers with diameters of up to 200 mm and on SiC wafers with diameters of up to 150 mm. An industrial CMOS process transferred to IISB and constantly adapted for research and development purposes is used as a reference and as the basis for developing advanced process technologies. The main activities focus on the fields of Si power semiconductors, passives, and silicon carbide electronics.

IISB has increased its commitment especially to SiC by implementing new equipment and processes to meet special and additional requirements for SiC power device processing. Most of the FMD (Forschungsfabrik Mikroelektronik Deutschland – "Research Fab Microelectronics Germany") investments of the Technology and Manufacturing department are dedicated to the change in wafer size on SiC from 100 mm to 150 mm. This above all concerns the etching and refilling of deep trenches and the high-temperature processing of SiC. Furthermore, the FMD investment allows us to broaden our process portfolio by providing backside grinding and polishing for SiC wafer thinning and providing laser annealing for backside ohmic contact formation on the front side of already processed wafers. As a result, industrially competitive low ohmic contact can be provided.

All of this allows the department to strengthen its competence in manufacturing high-voltage power devices. By now, IISB has developed its resources and expertise to the point where it can perform nearly all manufacturing steps on SiC substrates according to an industrial standard. The devices currently under development include diodes and merged pin diodes in the voltage ranges from 1.2 kV up to 4.5 kV, as well as MOSFET devices such as vertical or lateral DMOS. A trench technology for vertical diodes and MOSFET as well as sensor and high-temperature CMOS devices are in progress.

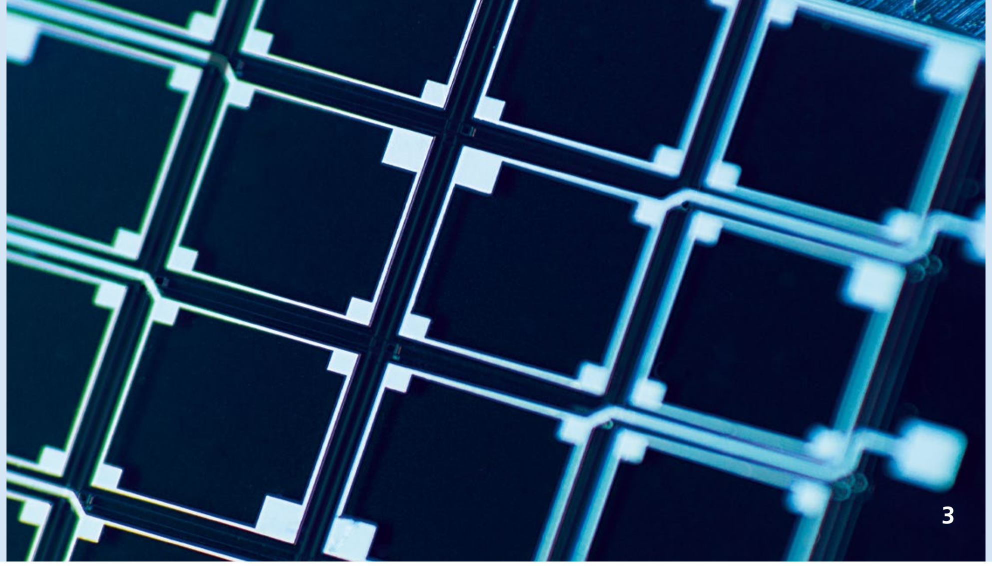
For the development of novel process steps in the field of dielectrics and metallization, IISB operates advanced sputter and chemical vapor deposition tools on the basis of ALD that are used for the deposition of high-k and metallic layers.

1 *Embedded into IISB's 'Technology & Manufacturing' and in close collaboration with our very own in-house brand 'π-Fab' Fraunhofer IISB offers R&D Services for Silicon Carbide ranging from material development and prototype devices to module assembly and mechatronic systems. © Fraunhofer IISB*

2 *Dr. Anton Bauer, head of the Technology and Manufacturing department. © K. Fuchs / Fraunhofer IISB*

TECHNOLOGY AND MANUFACTURING

UV-Detector Manufacturing



3 *Picture of an integrated 4x4-SiC-UV-Sensorarray. © Fraunhofer IISB*

Furthermore, special activities focus on ion implantation technologies. At IISB, implantation tools with acceleration voltages ranging from a few eV up to 800 keV are available. Special implantations for CMOS as well as for power semi-conductors have been established (for example, commercial tools have been modified to be able to implant several wafer diameters and manifold elements at elevated temperatures).

The physical and electrical characterization of process steps and device structures is of the utmost importance for the manufacturing of semiconductor devices. Important steps in this respect are the determination of the topography, doping profile, and further physical and chemical parameters, as well as FIB investigations, energy-dispersive X-ray analysis, and AFM surface characterization of layers. A specific competence of the department is the combination of several methods for failure analysis during the processing of semiconductor devices and tracing the causes of failure. The spectrum for electrical characterization has been further increased (e.g., lifetime measurements and high-voltage measurements especially for SiC).

Furthermore, from nanotechnology to printable macro-electronics, the Technology and Manufacturing department is your contact for the realization and characterization of single process steps up to prototype devices. Based on comprehensive clean-room facilities, further activities are becoming more and more relevant. An example of such current activities is low-temperature deposition of inorganic materials using printing techniques. The emerging markets for such products are control units and specific sensors based on inorganic materials. The field of thin-film systems ranges from materials to device exploration to the development of TOLAE (thin, organic, and large-area electronics) applications. Based on a carefully targeted selection from solution processing/printing, spray coating, or vapor deposition of inorganic layers, the devices are optimized for their respective environment. Printed electrolyte sensors integrated with read-out and data handling electronics allow physical strain to be monitored in wearable sports trackers and can also be utilized in the chemical industry, water quality assessment, or several agricultural tasks. Capacitive and temperature sensing in combination with high performance TFTs enable the realization of smart integrated thin-film systems.

Another focal area of the department's work is the processing of structures in the range of a few nanometers as well as the repair and analysis of electronic device prototypes by means of focused ion beam (FIB) techniques and electron beams. In addition to that, UV nano-imprint lithography, a cost-effective fabrication technique that allows the transfer of nano-sized features to photoresist without the use of advanced optical lithography by applying small rigid stamps and, most importantly, by applying large-area (up to 150 mm) flexible stamps too, is now well established.

A core competence of the Semiconductor Manufacturing Equipment and Methods groups is multidisciplinary research and development for manufacturers of equipment, materials, and semiconductor devices. The decisive factor for this is the expertise in process development, metrology, analytics, software, simulation, and device integration combined to develop tailor-made solutions together with customers. For this, Dr.Production® was established, which meets the challenges of "Industrie 4.0" for manufacturing with innovative methods. Dr.Production® provides software solutions for intelligent analysis of product data at the customer site and develops algorithms to make your machine intelligent.

The IISB analysis laboratory for micro- and nanotechnology with various chemical, physical-chemical, and physical test methods is essential for a conclusive and comprehensible assessment. Two working groups at Fraunhofer IISB contribute their expertise in advanced process control, manufacturing science, productivity, contamination control, and yield control aspects to the ENIAC project "EPPL", which aims to combine research, development, and innovation to demonstrate the market readiness of power semiconductor devices fabricated in leading European 300 mm pilot lines.

UV-DETECTOR MANUFACTURING

Besides enabling efficient power electronics, the wide bandgap material silicon carbide (SiC) also offers excellent properties for integrated semiconductor sensor devices. One very prominent example is the visible-blind detection of ultraviolet light.

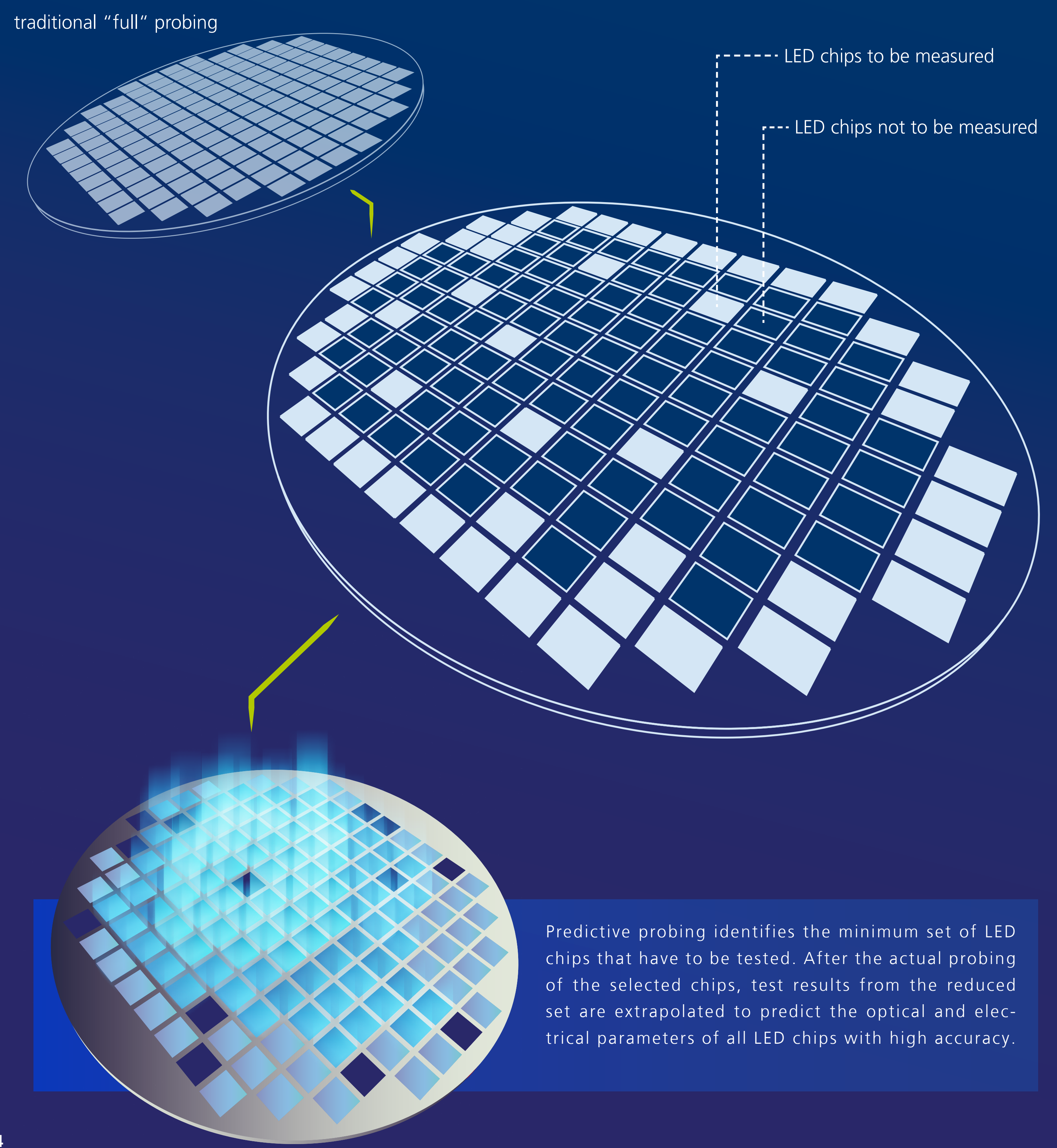
The main related material properties are the bandgap and the intrinsic carrier concentration. The bandgap of 3.26 eV in the case of the 4H polytype leads to per-se visible-blind devices without additional optical filters because photons with a wavelength of 380 nm and above are barely absorbed. Furthermore, a very low noise level and dark current can be achieved due to the low intrinsic carrier concentration.

However, the manufacturing of SiC semiconductor devices is challenging, because the well-established silicon semiconductor technology can only be partially adopted for SiC due to the strong chemical bonds in this material. In detail, doping by diffusion for instance is more or less impossible. For the production of defined p-n junctions, epitaxial growth and subsequent dry etching are used for conventional SiC UV detectors. This process sequence leads to non-planar devices and several design constraints for advanced device architectures.

Another possibility for the creation of p-n junctions is production by ion implantation. In this case, very high temperature (1600-1900 °C) annealing is required. Furthermore, ion implantation and annealing are usually accompanied by a higher defect density, which influences both carrier

TECHNOLOGY AND MANUFACTURING

The Art of Predictive Probing



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mobility and carrier lifetime. On the other hand, however, ion implantation allows a significantly higher process flexibility and the production of fully planar, monolithically integrated UV-detector devices.

Within recent years, a better understanding of the defect creation due to ion implantation and annealing has led to significant advances in SiC technology. At IISB and LEB, ion implantation and epitaxy for the creation of p-n junctions for advanced UV detectors have been compared to each other. The influence on the spectral responsivity was investigated in depth for the first time, including studies concerning the temperature behavior.

As a result, in 2017 a huge number of UV detectors were manufactured using ion implantation for the creation of p-n junctions. Furthermore, analytical and numerical device models were used to optimize the spectral responsivity. This optimization includes an improvement in the overall spectral responsivity and tuning of the highest sensitivity for a selected wavelength range. Finally, the ion implantation technology for the creation of the p-n junction has led to the first prototypes of monolithically integrated selective UV-detector arrays.

THE ART OF PREDICTIVE PROBING - HOW TO PREDICT THE PERFORMANCE OF THOUSANDS OF DEVICES BY TESTING JUST A FEW

The challenge: Quality control for premium products

Quality control plays a crucial role in the manufacturing of premium products. Measures for quality control are implemented, on the one hand, right after crucial process steps to ensure single process quality. On the other hand, the application of sophisticated test procedures during final testing guarantees a high quality of the final product – with regard to not only principle functionality (good-or-bad decision) but also concerning functional parameters and behavior. In semiconductor manufacturing and related industries, such final tests or probing mechanisms reveal the speed of a processor or memory chip, or the actual brightness of an LED. The results are then utilized to sort devices according to their performance and characteristics, or, in the worst case, to discard a product.

In previous years, we reported about the development and application of novel measurement techniques to control quality along the manufacturing chain. We also reported about techniques

4 *The concept of predictive probing.*
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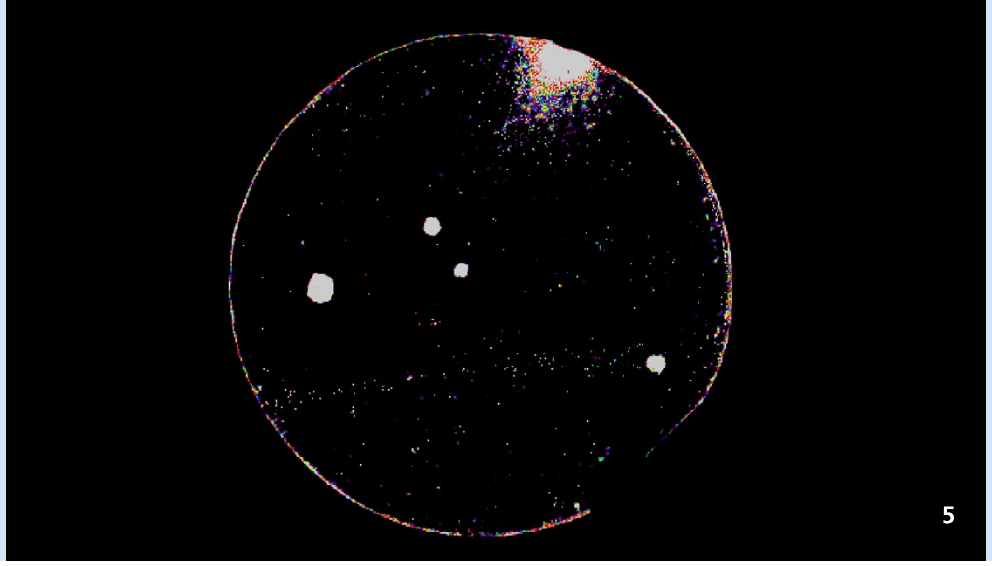
TECHNOLOGY AND MANUFACTURING

The Art of Predictive Probing



such as "virtual metrology" that utilize data collected from upstream processes and measurement steps as the basis for a highly accurate prediction of single measurement results without actual physical measurement.

We have now taken this data-driven approach to the next level: Together with an industry partner, we have developed the concept of "predictive probing" and demonstrated it in LED manufacturing.

The use case: LED manufacturing

The manufacturing of an LED chip consists of several process steps carried out on sapphire wafers – including epitaxy to create the optically active layers, doping to achieve certain electrical properties, metallization to generate contacts, or layer formation to guide the emitted light. Throughout the manufacturing process, measurements are carried out to characterize certain process steps and to control the quality of the emerging device. Towards the end, great effort is made to probe every single LED chip: In dedicated probing equipment, ultra-thin needles are used to contact an LED and measure its brightness, color, and electrical properties. With thousands of LED chips to be tested per wafer, this is a time-consuming step – and an expensive one: Up to half of the cost of the final LED is consumed by this probing step.

It is obvious that reducing the amount of required testing is of great interest but poses an enormous challenge: Omitting a certain fraction of LED chips on a wafer from probing saves time, but optical and electrical parameters from these omitted LEDs are still needed! Furthermore, defective LED chips have to be reliably detected.

The concept: Predictive probing

The concept of predictive probing follows two objectives:

1. Identify the LED chips that have to be probed.
2. Reconstruct the optical and electrical parameters from the LED chips that were not probed This includes the detection of defective LED chips.

To achieve these objectives, predictive probing relies on long-term and short-term historical data: A basic identification of chips to be probed is derived from historical probing data from different wafers and products, revealing typical areas of uncertainty on a wafer. This basic identification is amended by utilizing measurement data collected during the processing of the very wafer that is ready for probing. This upstream metrology data includes particle measurements, ultrasonic measurements, or photoluminescence measurements.

A set of machine learning algorithms take this data and identify the LED chips that have to be probed. A convolutional neural network that identifies areas with potentially defective chips to enhance the probing density supports these algorithms. After the reduced set of LED chips are run through the probing machine, the second part of the predictive probing program takes the optical and electrical parameters from the measured chips and calculates the characteristics of the non-measured ones.

The result: Accurate prediction based on 7% of tested devices

During the development and demonstration of predictive probing, a large amount of data was collected, several generations of algorithms were developed, and the architecture of an appropriate neural network was developed. Finally, it is now possible to omit the measurement of 93% (!) of LED chips on a wafer, which leads to a drastic decrease in overall measurement time and cost, and still predict the brightness, color, and electrical parameters of all LEDs – with an accuracy that fulfils the specification of the manufacturing partner.

Finally, the concept of predictive probing was demonstrated to work great in the specific domain of LED manufacturing. Furthermore, the principles of the approach and the knowhow gained during the development can be transferred and applied to other applications and industries where predictive probing can significantly lower the cost and effort in quality control.

5 *View of the fully convolutional neural network on the LED wafer, identifying areas with potential LED failure.*
© Fraunhofer IISB

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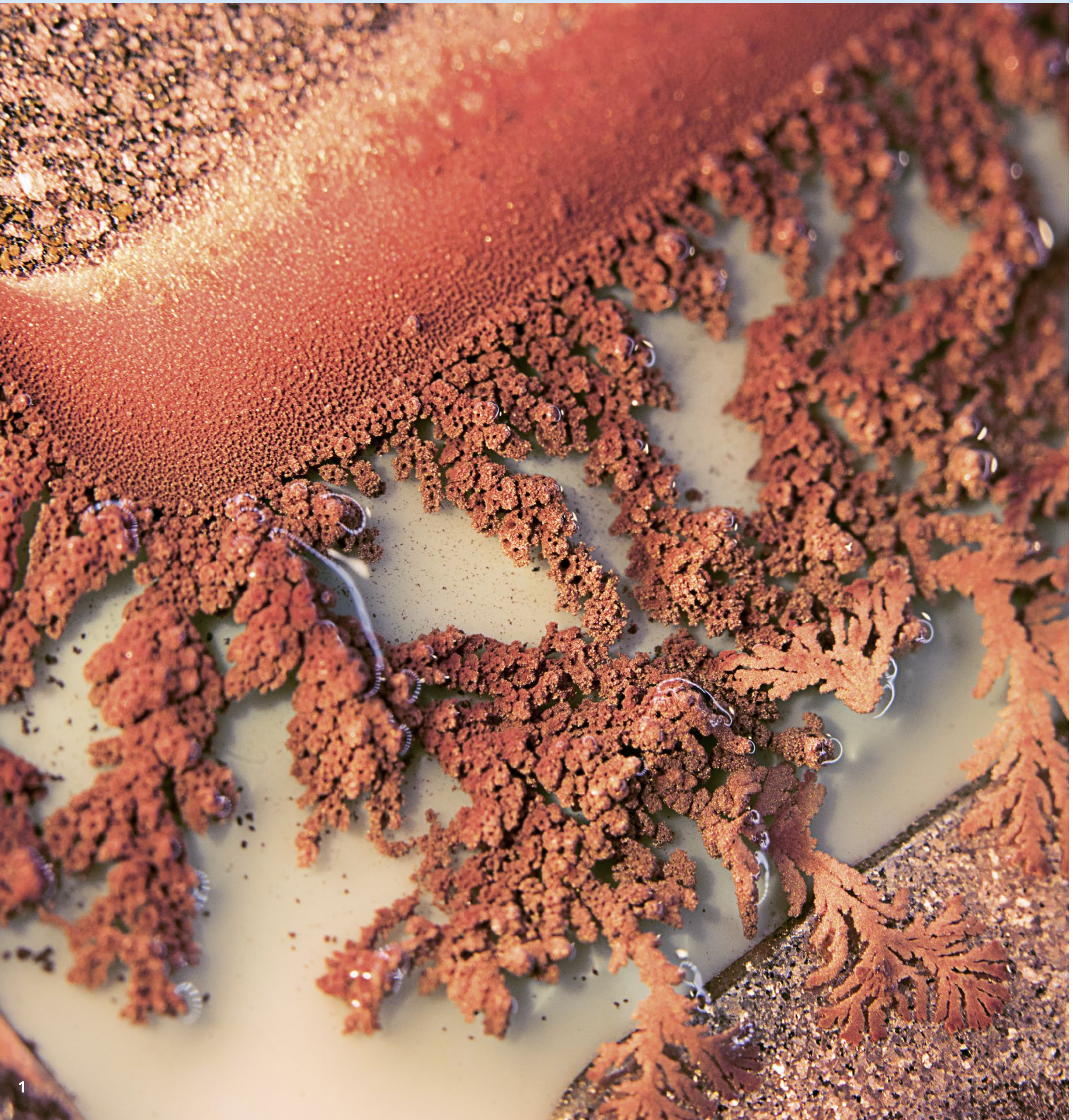
DEVICES, TEST AND RELIABILITY

2



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The Devices, Test and Reliability department acts as a bridge between the Semiconductor Technology business unit, which is focused on materials and processes, and the application-oriented Power Electronics business unit. The fields of research include design and fabrication aspects of active and passive devices, packaging technology and concepts, as well as electrical characterization, lifetime testing, modelling, and reliability.

The development of silicon carbide devices is steadily progressing. In 2017, trench JBS diodes were developed that yielded a very competitive 1.5 V forward voltage drop for 600 V / 5 A devices. Moreover, the fabrication technology for 1200 V SiC VDMOS transistors was further improved and high yields are now obtained. The integration density of these transistors is around 8 mΩcm^2.

Additionally, Fraunhofer IISB has joined forces with the National Institute for Nanomaterials Technology in Pohang, Republic of Korea, to develop and enhance fabrication capabilities for 150 mm SiC devices. This 5-year project – which is funded by the National Research Foundation of Korea – seeks to improve to and demonstrate a high manufacturing yield and trench MOS power transistors as well as to establish manufacturing technologies for superjunction SiC devices. A close collaboration between both institutions and significant exchange of staff will establish the basis for subsequent joint R&D activities in Korea and Germany.

An internal research project dedicated to the fabrication of high-temperature-capable electronics based on 4H-SiC has achieved a new milestone. A baseline technology for SiC CMOS has been established using basic devices and simple circuits. First movers using this technology have been successfully recruited, and an initial multi-project wafer run using this baseline technology will be carried out on 100 mm wafers in 2018.

For the monolithic integration of capacitors and snubbers for implementation with fast-switching SiC- or GaN-based power modules, the design of 1200 V capacitors has been completed and fabrication has been started.

In the field of packaging, a new research field has moved into the spotlight. This is electrochemical corrosion and its prevention for power electronic subassemblies and systems.

New, publicly funded research projects have been allocated. One of these is “Isogap”, part of the German Federal Ministry of Education and Research (BMBF) funding measure “Internationalization of Excellence Clusters” in a cooperation with Japan in the area of “Next Generation Power Electronics – Wide Bandgap Power Semiconductor Devices and System Integration” (CLINT-WPE). The project will be coordinated by the power electronics cluster within ECPE e.V. The aim is to understand the failure mechanisms of multidimensional failure causes and to investigate cost-ef-

1 *Copper dendrites bridging an insulation gap resp. corrosion trace on a ceramic circuit carrier.*
© Fraunhofer IISB

2 *Andreas Schletz, head of the Devices and Reliability department.*
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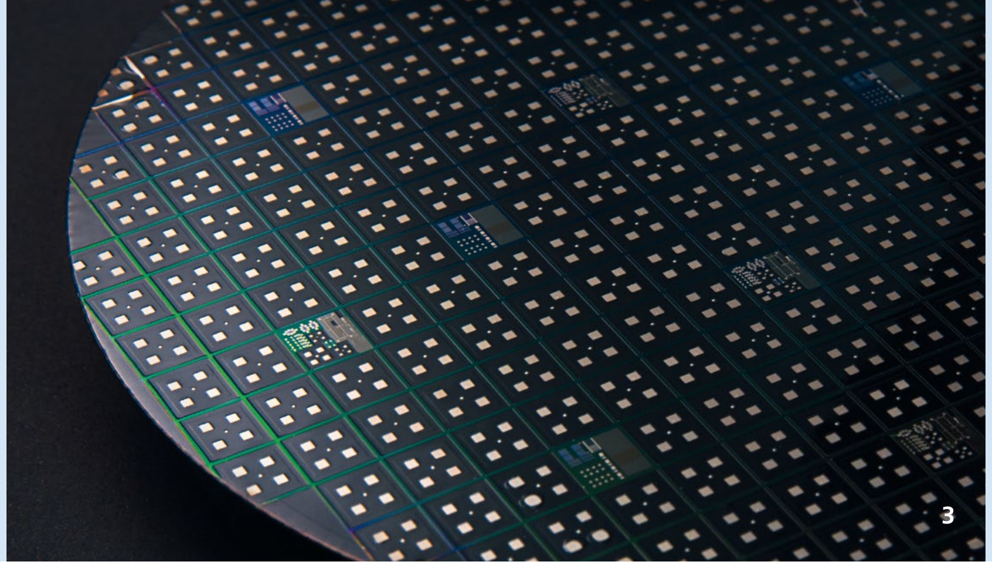
DEVICES, TEST AND RELIABILITY

High-Voltage Low-Resistance Power MOSFET



3 *100 mm SiC wafer with 1.2 kV SiC Power MOSFETs. © Fraunhofer IISB*

fective countermeasures. The focus is on an optimized material stack based on high-performance polymers for power electronic modules.

Another project funded under this research program is "SiC DCBreaker", which starts this year. This focuses on the development of solid-state circuit breakers based on SiC JFETs. With the 150 mm SiC processing technology for MOSFETs and JFETs, monolithic integration of multiple devices in a single chip (in this case 2 JFETs) will enable enhanced performance with discrete solutions. This remains one of the institute's cutting-edge device types in development. These monolithically integrated devices are self-triggering, resettable electronic fuses that detect an externally defined overcurrent.

A third project, ZuLeSelf, sponsored by the Federal Ministry of Education and Research will start in 2018. ZuLeSelf will support the new research area with condition monitoring and modelling.

The successful work of the past was also continued, especially on the topic of silver sintering die attach technology. In particular, the pressureless sintering of top-side chip contacts was developed. Successful tests were conducted. Power electronics packaging now has an additional easy-to-process, double-sided sintered chip contact with an attractive tooling cost.

The new clean room for new packaging concepts and technologies is now in operation. All tools have been installed and set up. The complete packaging line from storage, printing, die bonding, soldering and sintering, encapsulation, and testing is now clustered in a high-quality packaging lab. Thanks to the new project "Research Fab Microelectronics Germany" (FMD), sponsored by the Federal Ministry of Education and Research, additional hardware will be installed that allows new research to be well equipped for the future. The packaging group is active in the FMD topic "Heterointegration".

The research activities concerning testing and reliability were strengthened by continued material characterization for the next generation of lifetime modelling for power electronics. Besides the bond line of semiconductor devices, other materials are moving into focus. The characterization is accompanied by statistical evaluation that gives a better understanding of some lifetime test results, especially at high temperature. A new publically funded research project, "SiCool", was allocated in 2017, and will be supported by the Federal Ministry of Education and Research. The aim is to develop a physics-of-failure-based lifetime model in conjunction with state-of-the art failure in time (FIT) modelling for power and signal electronics located on the same circuit board.

The testing of ceramic capacitors was further expanded. The devices will play a big role in the future of power electronic filters and DC links thanks to their high energy and power densities and their ability for high-temperature usage. Test methods were intensified to characterize the capacitors in terms of electrical parameters, especially under high voltage and temperature. The next target is power cycling of power capacitors, in which a small working group is now active. Similar to the packaging group, the FMD project provides additional hardware for the test and reliability area. The new equipment will make it possible to move forward into the future. The testing and reliability group is active in the FMD topic "Design, Test and Reliability".

In addition to these new publicly funded projects, there were a huge number of joint industrial projects in all research fields. The topics ranged from assistance and consulting to large feasibility studies and process and technology developments for devices, packaging, and testing. The applied research within the department is financed by an industrial budget contribution of well above forty percent. This perfectly achieves the Fraunhofer target.

Many thanks to all colleagues for their great support during difficult times and the excellent work that has led to success and makes the institute ready for the future.

HIGH-VOLTAGE LOW-RESISTANCE POWER MOSFET

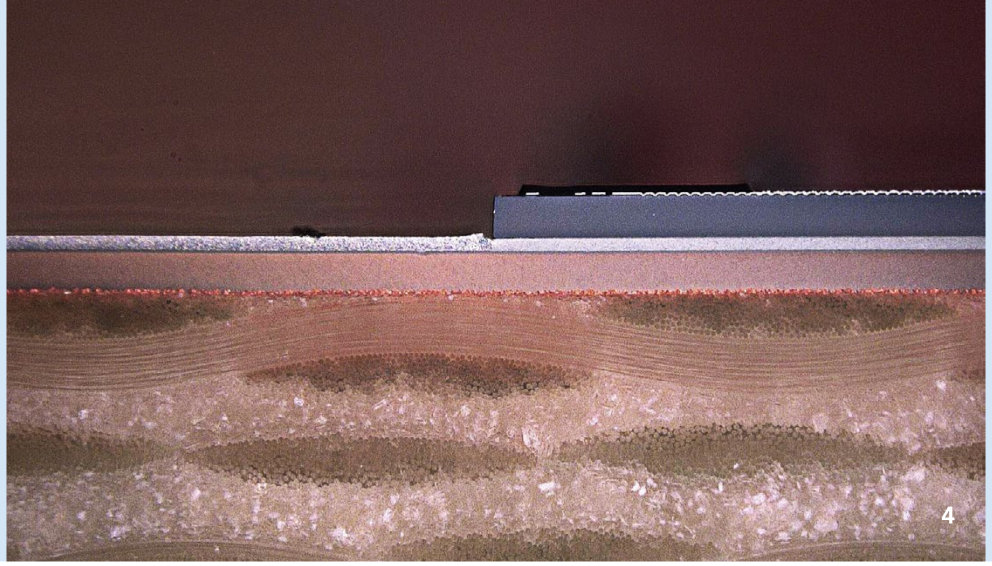
The metal oxide field effect transistor (MOSFET) is a semiconductor device class whose electrical current conduction is controlled by a voltage applied to the gate electrode. Since its first realization in the late 1950s, silicon MOSFET has been widely used in a variety of electronic applications. In power electronics, MOSFET acts as a switch whose voltage drop during the conduction state has to be as low as possible in order to achieve a highly efficient power conversion.

Silicon carbide (SiC) technology significantly extends the limits of power devices owing to the outstanding physical properties of the semiconductor material. While conventional silicon power MOSFETs block voltages below 1 kV and exhibit an on-state resistance of several hundred mΩ, the 1.2 kV and 1.7 kV SiC power MOSFETs with an on-state resistance well below 100 mΩ have recently been commercialized on the market.

Fraunhofer IISB develops designs and technology for silicon carbide unipolar devices in a voltage range from 1.2 kV to 4.5 kV. In recent years, one of the core activities of the "Devices & Reliability" department has been developments dedicated to 1.2 kV silicon carbide power MOSFETs. The goal of high-voltage blocking capability and specific on-state resistance below 10 mΩcm^2 has been recently achieved for the 3rd generation of our devices. Those devices are fully operational and reliable at temperatures up to 150 °C. Excellent electrical parameters of transistors are the result of an optimized integrated circuit design and constant advances in SiC technology in-house at Fraunhofer IISB. The processing technology and design use processes and concepts

DEVICES, TEST AND RELIABILITY

Lifetime on Printed Circuit Boards – A Step Towards Low-Cost Power Electronics



free of third party IP. Our design is based both on numerical device simulation and an analytical approach. It has evolved into its mature form due to the extensive experience of our project teams. The key developments in silicon carbide processing that contribute to the performance of devices include gate oxidation, ion implantation, and contact formation.

In the near future, an even further reduction of the on-state resistance of SiC power MOSFET is expected, due to new investments in the silicon carbide process line at Fraunhofer IISB, e.g., equipment dedicated to wafer thinning and laser annealing. The 1.2 kV SiC power MOSFET is a starting point for devices with higher voltage ratings. A 3.3 kV transistor has already been successfully implemented, and key items for the improvement of its electrical parameters have been identified. Optimization of that device, a higher cell integration, and the development of a SiC Trench MOSFET are the goals of our department for the years 2018 – 2019.

LIFETIME ON PRINTED CIRCUIT BOARDS – A STEP TOWARDS LOW-COST POWER ELECTRONICS

Cost saving is a strong driver in power electronics. Today, electronic components are soldered or glued onto PCBs. These techniques are state of the art and available at low cost. They are well suited for signal electronics in the general temperature range.

Power semiconductor components, though, can become relatively hot. Their dominant cost factor is the chip size. A smaller size will lead to a higher absolute temperature and a higher temperature swing under similar side conditions. Especially the latter will reduce the lifetime. In this domain, expensive inorganic-based insulated substrates such as direct bonded copper are used. These materials are designed for high temperatures and high temperature swings. Silver sintering is an emerging alternative to high-temperature soldering for semiconductor die bonding on ceramic circuit boards. The lifetime and reliability of such assemblies has already been proven for decades and is still the focus of attention.

The drawback of this technology is the high cost. Furthermore, it is only applicable with certain noble surface materials. Most of the traditional surface-mounted devices do not have a suitable metallization. Preparing these components for sintering would take unacceptably long.

In order to overcome these drawbacks and stay cost effective, the use of printed circuit boards (PCB) is an option if thermally heavily stressed components such as power semiconductors are attached with a valid technology.

For this reason, selective silver sintering was developed at the institute. The process consists of two steps. First, uncritical components such as non-sinterable components are mounted on the PCB using the previously mentioned low-cost standard joining technologies such as soldering or adhesives. In a second step, critical components that generate significant power losses and thus reach higher temperatures are sintered to the PCB.

Selective sintering involves a special sinter process flow. Instead of printing the sinter paste directly onto the substrate, the material is printed and dried on a carrier. A die placer is then used to position the bare die chips onto the sinter layer, with a specific applied pressure, temperature, and time. The sinter material tacks to the rear side of the bare die and is lifted from the carrier together with the chip. After that, the chip is sintered on the PCB using a specific temperature, pressure, and time to achieve a high-quality bond line without damaging the PCB.

To evaluate the performance of the new unusual material combination, active power cycling tests were carried out. During this test, the samples are alternatingly heated and cooled. Heating is achieved by conduction losses in the device. The devices are cooled down by a cold plate. Different thermal expansion coefficients and the overall temperature-dependent material parameters of the different material layers lead to mechanical stress that activates microscopic damage processes. During cycling tests, this damage accumulates and finally leads to the end of life of the setup.

In a first step, the samples were aged by long cycles with a 30 s cycle time in order to increase the stress on the sinter layer bonding. A demanding temperature swing of 110 K at a constant heating current was chosen to quickly reveal the weaknesses of the new technology. After 168,000 cycles – which is a lot – the first run was aborted as no failures or signs of degradation were observed. More than 100,000 additional cycles were added with much harsher testing conditions. In the end, a 150 K temperature swing was applied to accelerate the aging as much as possible, exceeding all limits, especially the glass transition temperature of the organic material. During all additional test runs, no failures or degradation of the samples were encountered.

The power cycling tests yield a surprisingly high lifetime. Therefore, selective silver sintering on printed circuit boards is a promising new approach for thermally stressed bare-die power electronic devices in addition to signal electronics. It is an auspicious solution for cost-effective power electronic systems!

4 *Power semiconductor device sintered on printed circuit board after power cycling test.*
© Fraunhofer IISB

DEVICES, TEST AND RELIABILITY

Corrosion Inside the Power Module

5 *ECM on a ceramic circuit carrier in between two metal conductors. © Fraunhofer IISB*

CORROSION INSIDE THE POWER MODULE

Electrochemical Migration (ECM) – One Form of Corrosion in Electronics

Electrochemical migration, a form of corrosion, is a moisture-related malfunction that reduces the reliability and lifetime of electronic assemblies and is often responsible for climate-related failures. Electrochemical migration is recognizable as tree-like structures growing, for example, in insulation gaps between metal pads, as can be seen in picture 5.

As a cause of damage, however, electrochemical migration is often not detectable or only with great effort. If only small dendrites occur, which are not capable of carrying the current, they will immediately burn off again. As evidence, the affected circuits would have to be returned from the field and examined by scanning electron microscopy for ECM traces. In cases where ECM is not recognized as the cause of failure, it can be found together with software errors and leakage current effects as an unspecified malfunction.

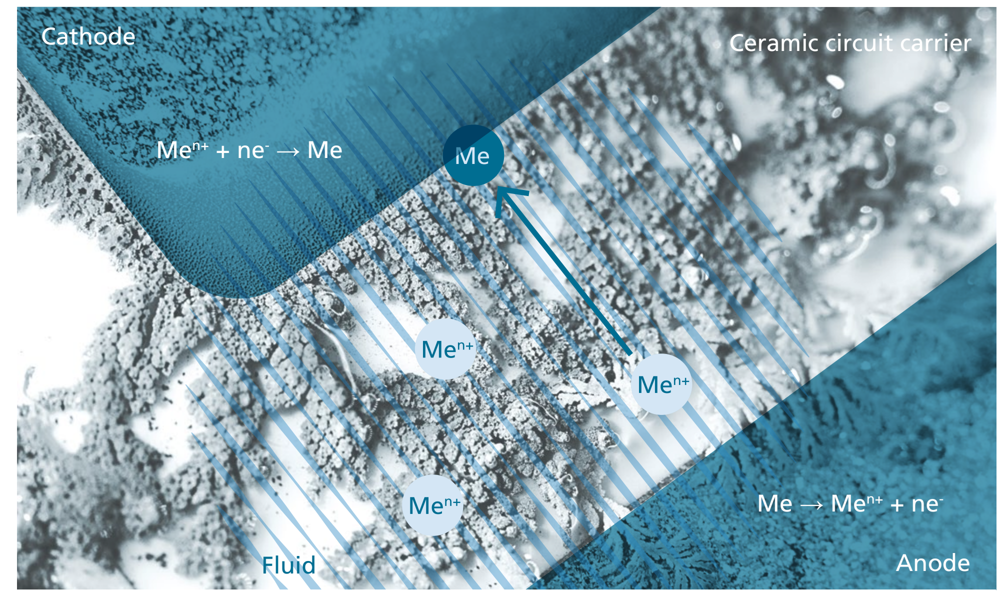
However, when stable, current-carrying dendrites result, temperatures of a few hundred degrees can quickly occur. If the circuit does not have an appropriate fuse and shutdown, these temperatures can lead to fire. Since this destroys the circuit, in many cases it remains speculative whether the cause of the fire is due to electrochemical migration or voltage breakdowns.

Mechanism of ECM

ECM occurs immediately in electronic packages if there is a gap due to delaminated insulating potting material, metals and metal combinations that tend to corrode, humidity and a sufficient voltage load. Given these conditions, metal ions dissolve and the positive metal ions migrate from the anode to the cathode, where the ions are captured. In this way dendrites grow from the cathode to the anode (see picture 6).

Increasing Requirements and Applications under Extreme Environmental Conditions

Due to steadily increasing requirements in terms of higher packaging densities or miniaturization, the problem of electrochemical corrosion is coming more and more to the fore. Furthermore, the demand for using power electronic modules under extreme environmental conditions is rising. Examples of such applications are inverters in wind turbines, especially offshore ones, or photovoltaic systems. Power electronics installed in trains, for example, need to withstand fast climate changes when driving through a tunnel. This also applies to automotive and telecommunications industries, which serve a worldwide sales market and must ensure the functionality of the elec-



5 *Copper dendrites bridging an insulation gap resp. corrosion trace on a ceramic circuit carrier. © Fraunhofer IISB*

6 *Schematic view of the electrochemical migration process on ceramic circuit carrier. © Fraunhofer IISB*

tronic components in different climate zones, with high temperature fluctuations and extreme humidity. Most extreme environmental conditions are to be found in the field of aerospace with extreme climate changes, radiation, and mechanical stress. Under the mentioned conditions, condensation resulting from a temperature drop can lead to moisture in the module, for example.

Corrosion Research and Corrosion Testing at Fraunhofer IISB

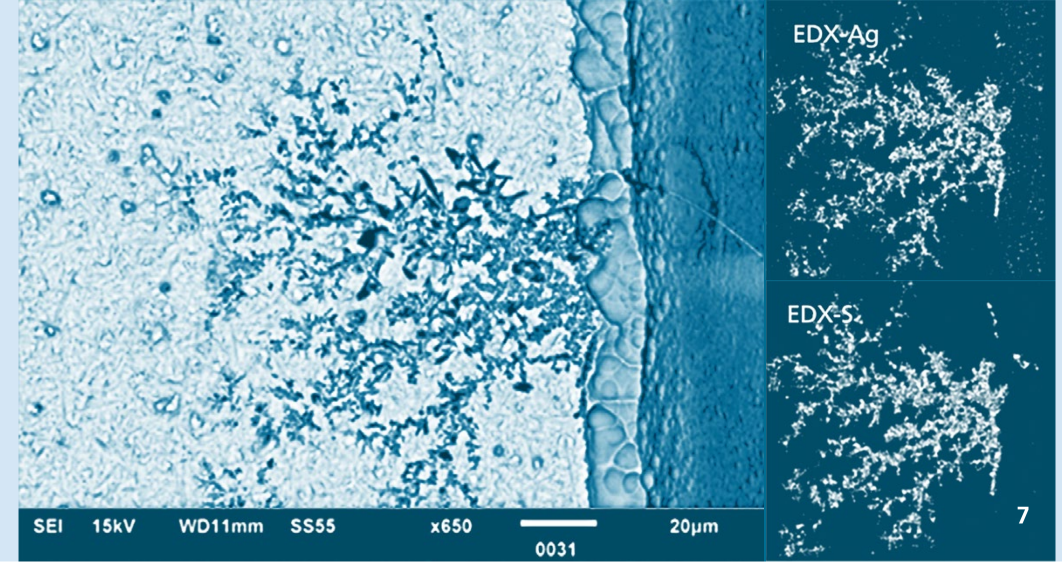
Corrosion and corrosion protection are being researched at Fraunhofer IISB. Various environmental tests, for example, damp heat tests, temperature shock tests, and corrosive gas tests are conducted. Within the investment program of the German Federal Ministry for Education and Research (BMBF) for microelectronic research, which is called the "Research Fab Microelectronics Germany" (FMD), new equipment and systems are procured. These include a new temperature shock chamber with a wider temperature range and a higher maximum temperature; a corrosive gas test chamber with a higher possible temperature, humidity, and gas concentration; a HAST (highly accelerated stress test) system, also referred to as pressure cooker, for accelerated testing with high humidity, high temperature and air pressure, and a salt spray test chamber.

Damage Analysis

To get to the dendrites, the decapsulation of mold compounds as well as silicone gel is often necessary. Cross-sectioning by sawing, grinding, polishing, or femto-laser curing can also be helpful

DEVICES, TEST AND RELIABILITY

Corrosion Inside the Power Module



in some cases. Damage analysis includes, for example, microscopic examinations to determine the presence or absence of dendrites. Moreover, scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) are used to get information about the elements that are involved in dendrite formation as well as the element distribution and quantity.

As coating is probably the most important corrosion protection for the module, analysis methods for the characterization of the coating material are also very important. They can be used for the process development of new coatings, for the comparison of coatings, and for the comparison of the characteristics of a coating before and after environmental testing to determine their resistance to, and lifetime within, certain environmental influences. Characterizing methods for coatings are, for example, tests to evaluate the adhesion of coatings, such as the scratch test. Furthermore, laser interferometry is conducted for the analysis of the coating thickness and the coating quality. Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) can be used to get information about different properties, such as the melting point, melting range, heat capacity, and so on.

Further analyzing methods include Fourier-transform infrared spectroscopy (FTIR), focused ion beam (FIB), high-speed cutting by plasma, radiography/computer tomography, partial discharge measurement, and comparative tracking index.

Corrosion Protection

As corrosion or rather corrosion resistance is not purely a material property but a system characteristic, the module concept must be considered as a whole. Corrosion behavior and corrosion resistance equally depend on three spheres of influence – the metal, the environment, and the design of the technical system, ranging from the microscopic surface quality and the material combination to the overall concept.

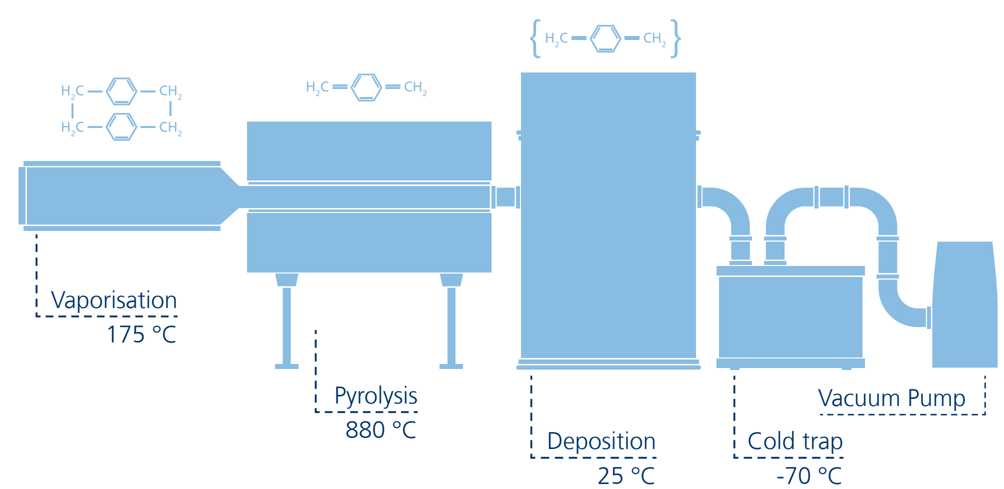
The most obvious measure is to prevent humidity in the module as well as delamination of the coating material. If this cannot be inhibited, it has to be at least delayed. Metal, solder, or other residuals from the production process have to be avoided in or around the insulation gaps. The metals and metal combinations used have to be well chosen, and it is possible to use metallic coatings to prevent corrosion.

The adhesion of the potting has to be long-lasting, at least ensured by an appropriate surface quality of the interface. To achieve this, bonding agents can be used. Polymeric coatings of the metallization (for example polyimide or Parylene) are insulating and can prevent the diffusion of humidity. The whole case of the module can be encapsulated by adhesives and sealed with additional polymer materials to avoid any humidity in the module. Other possibilities are using potting materials with corrosion inhibitors, semipermeable membranes on the interface to the environment, or even hermetic housings with a dry interior.

Parylene Coating

An innovative process for the permanent sealing of electronic assemblies and components is Parylene. In this technique, a transparent polymer film is applied to the substrate in a vacuum by condensation from the gas phase. Picture 8 shows the single steps of the Parylene coating.

The Parylene coating promises resistance to acids and alkalis as well as protection against moisture and dust. Due to the gaseous deposition, the Parylene is able to coat areas and structures which are not or only insufficiently coatable with liquid-based processes. Examples for such areas are sharp edges or tops or narrow and deep gaps. A Parylene coating system is also procured within the investment program FMD of the BMBF.



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7 *Left side: SEM picture of dendrite, right side: EDX element maps of sulfur and silver*
© Fraunhofer IISB

8 *Parylene coating process*
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VEHICLE ELECTRONICS

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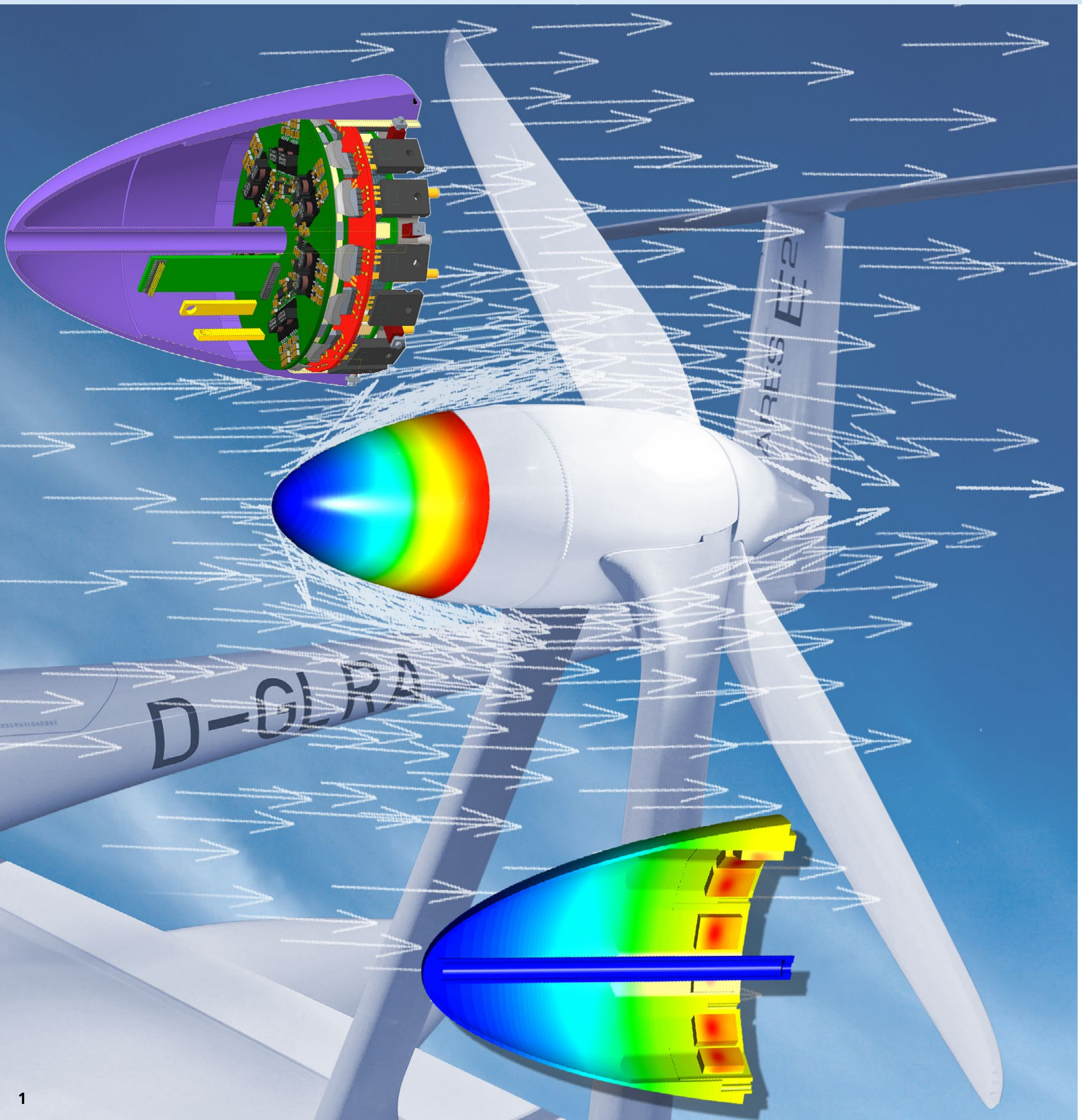

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The research and development of new power electronic solutions for electric, hybrid, or fuel cell vehicles is an ongoing challenge. Even though the focus of public interest and the funding of research projects are moving to autonomous driving applications, the electric power train is the key to environmentally friendly mobility. This is true for passenger cars, and even more for future public transport, light and heavy trucks, as well as for small and regional aircraft.

To keep up with the demand for new power electronic solutions, the Vehicle Electronics department has expanded its activities with the two new groups “Grid Interface” and “Aviation Electronics”.

The “Grid Interface” group is focusing on all kinds of vehicle on-board chargers, developing and realizing highly efficient charging solutions. The “Aviation Electronics” group will tackle the challenges of power electronic solutions for more electric aircraft and electric propulsion systems in the future.

The SiC and GaN semiconductors that are now available make it possible to realize new power electronic concepts that are more compact and efficient. An interesting example is a single-stage charger using SiC MOSFETs that was developed in the publicly funded research project “Luftstrom”. The developed and evaluated concept makes it possible to realize the on-board charger of an electrically powered vehicle with fewer components, in a smaller size, and with a higher efficiency than conventional two- or three-stage charger solutions.

In addition to automotive applications, we are using these new power semiconductors to develop a fully air-cooled aircraft drive inverter for an electrically powered aircraft in the framework of the European-funded project “AutoDrive”. The challenge is to reduce the losses to a minimum in order to make cooling possible entirely through the smooth surface.

The automotive vehicle department is still growing because of the demand for automotive solutions and new applications. We are now 50 engineers and technicians.

Sincere thanks to all colleagues for their extraordinary work, to all our partners from industry and politics for their support, and to the institute and the Fraunhofer Society for giving us these great opportunities.

1 *Thermal design and multi-physics system simulation of an highly efficient and integrated full-SiC drive inverter for aircraft applications. The system comes without a conventional cooling system, using only surrounding laminar air flow and thermal capacity of the NACA-airfoil system housing for cooling means. Top: Mechatronic design of the redundant 2x3-phase inverter SiC powerstage. Center: Aircraft system integration on the Lange Research Aviation “Antares E^2” and transient thermal airflow simulation. Bottom: Holistic simulation down to component level with qualitative temperature distribution.*
© Fraunhofer IISB

2 *Dr. Bernd Eckardt, head of the Vehicle Electronics department.*
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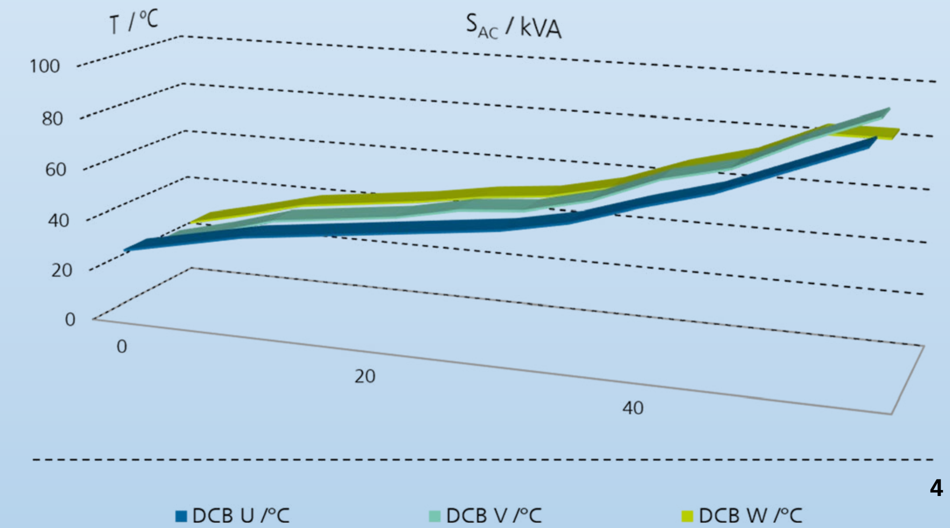
VEHICLE ELECTRONICS

Air-cooled 40 kW SiC Inverter for Automotive Applications



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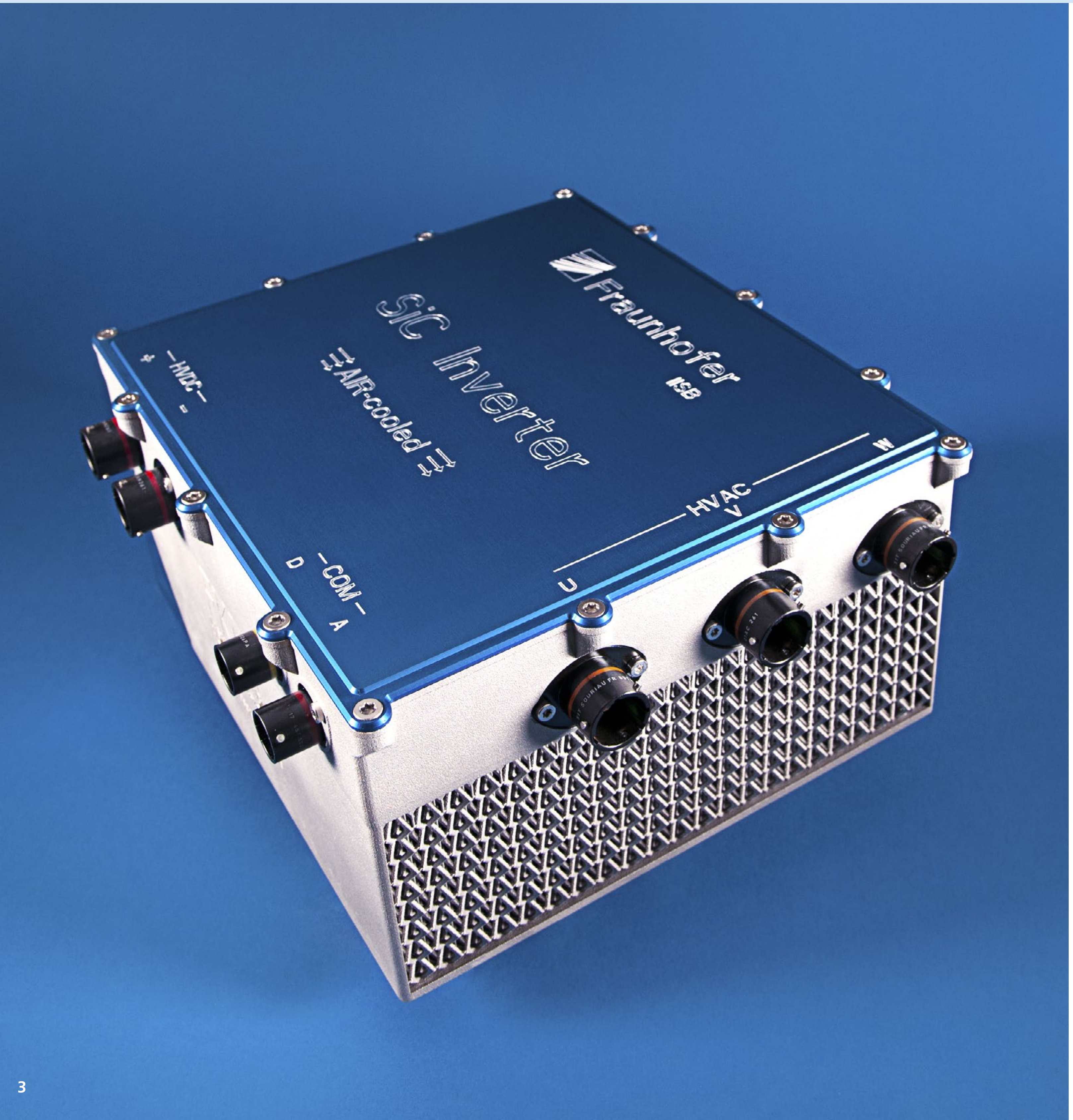

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AIR-COOLED 40 KW SIC INVERTER FOR AUTOMOTIVE APPLICATIONS

Semiconductors based on silicon carbide (SiC) enable power electronic systems – such as DC / DC converters, chargers, and drive inverters – with the highest power density, efficiency, and switching frequency. This is mainly due to the significantly reduced switching and conduction losses of SiC transistors compared to state-of-the-art silicon-based IGBTs and MOSFETs.

In the field of automotive traction inverters for electric and hybrid vehicles, the class of 1200 V SiC MOSFETs is of particular interest for drives with nominal voltages in the range of up to 850 V. Achievable switching frequencies of more than 30 kHz support the current trend regarding the use of high-speed drives as well as motors with single-tooth windings and low phase inductivities. In addition to realizable system power densities of more than 50 kW / l for water-cooled systems, the increased drive cycle efficiencies of SiC inverters are of particular interest.

By reducing system losses by up to 50%, even air-cooled SiC-based drive inverters with a higher power density can be realized for special applications and requirements. At Fraunhofer IISB, an air-cooled, modular and compact three-phase 850 V inverter for automotive applications with a continuous output power of 40 kW and a peak power of 100 kW was designed and realized (see picture 3). Using four parallel 1200 V SiC MOSFETs per switch, the system can provide a maximum phase current of 100 Arms. Despite the reduced cooling performance of air, the system could be realized with an overall volume of only 5.3 liters.

Due to possible switching frequencies up to 100 kHz, the SiC inverter is suitable for machines and applications with the highest electric frequencies, such as high-speed traction motors, compressors, and electric turbochargers. High frequency harmonics, modulated on top of the fundamental sinusoidal phase current, are also possible to avoid or create acoustic stimulation within the electric machine.

Design of the air-cooled inverter

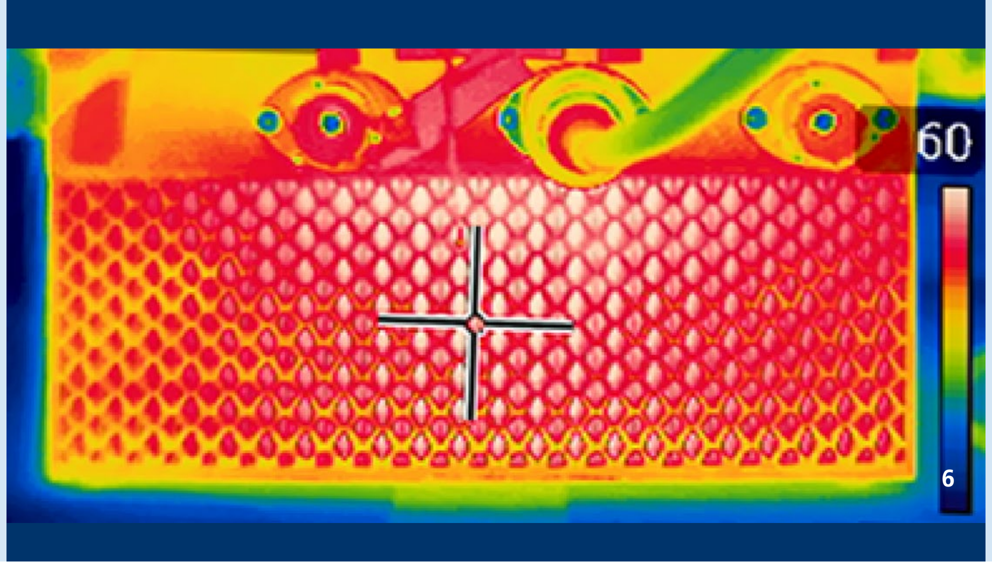
The heat-sink structure is directly integrated in the inverter housing and combines an optimized heat dissipation, low weight, and good manufacturability. The DCB-based power modules are directly placed on the heat sink, eliminating additional thermal resistances. A direct metal laser sintering (DMLS) process is used with AlSi10Mg powder to produce the housing.

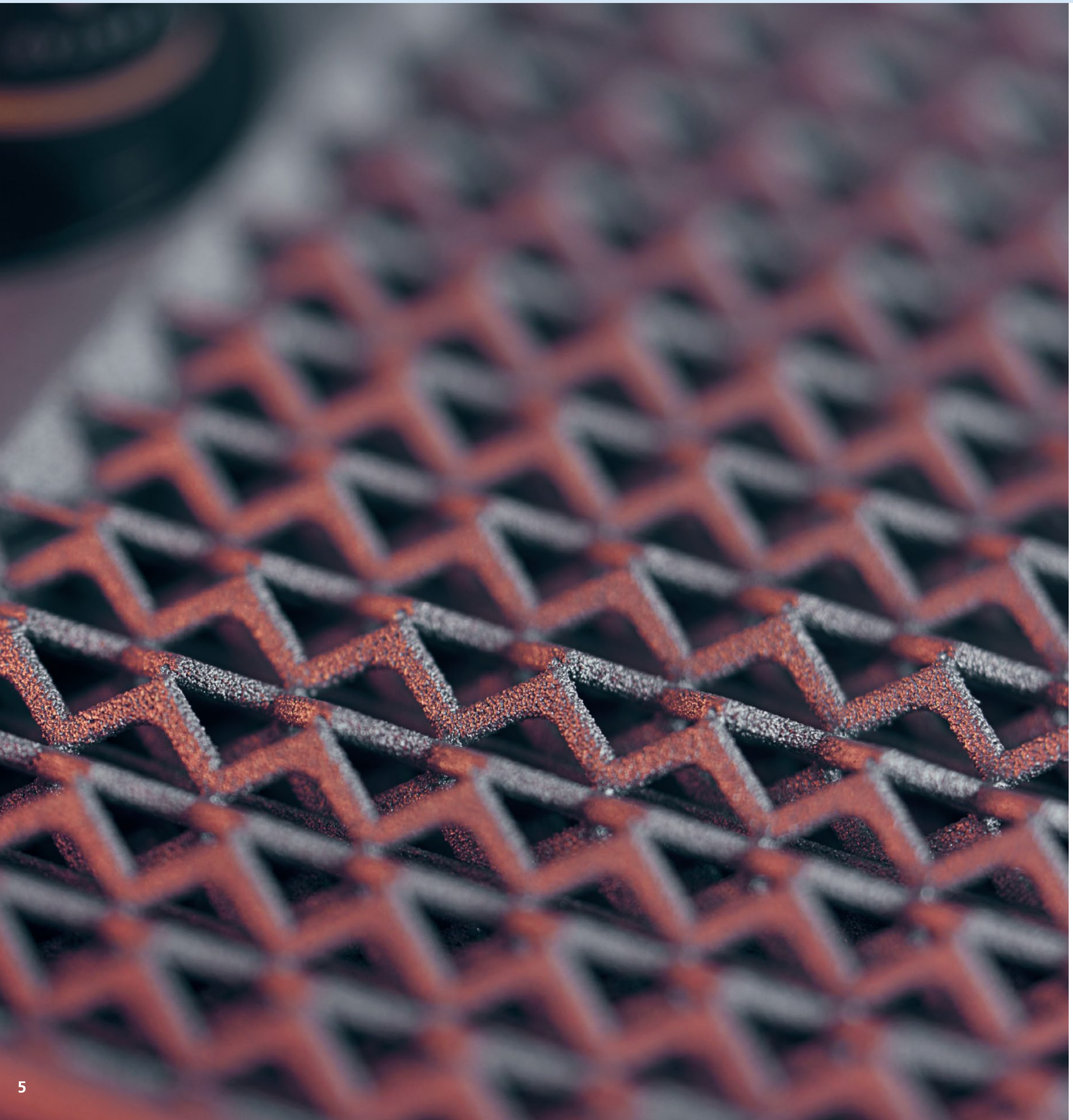
3 *Air-cooled silicon carbide inverter for automotive and aircraft application.* *© Fraunhofer IISB*

4 *Power-module temperature rise over continuous apparent output power (f_{sw} = 70 kHz)* *© Fraunhofer IISB*

VEHICLE ELECTRONICS

Air-cooled 40 kW SiC Inverter for Automotive Applications





A subsequent heat treatment of the material increases the thermal conductivity to a level close to common aluminum alloys. Three fans provide a temperature- and load-dependent forced-air cooling of the SiC inverter.

To realize the highest switching speeds and reduced switching losses, a low-inductance commutation cell design of the SiC inverter is crucial. Despite the use of half-bridge power modules with classical aluminum bond wire and DCB technology, a commutation inductance between the power module and the DC-link capacitor of less than 12 nH was achieved in the SiC inverter.

3D FEM field simulation was carried out to visualize and optimize the transient current paths within the power module. A low inductive coupling between the power paths and signal paths was also achieved, leading to a reliable module behavior. The central DC-link capacitor of the inverter is connected to the modules using a high-current PCB with 105-µm-thick copper layers. Additional ceramic pulse capacitors are optionally placed directly above the DC connections of the power module. With this module design, a voltage overshoot of less than 200 V during switch-off is measured even at switching speeds of 40 V / ns.

Thermal characterization of the system

The air-cooled inverter system has been electrically and thermally characterized. Picture 4 (previous page) shows the power-module temperature rise over the continuous apparent output power at 70 kHz switching frequency. The measurement was carried out at room temperature, and the three phases show a symmetrical thermal behavior.

At a continuous apparent output power of 40 kW, a temperature of 65 °C is measured within the power modules; the SiC-MOSFET chip temperature is ~20 K higher. The air temperature rises from the inlet to the outlet by approx. 15 K at maximum fan speed.

5 *3D-sintered cooling structure of air-cooled SiC-inverter.*
© Fraunhofer IISB

6 *Thermographic image of cooling structure during high power test.*
© Fraunhofer IISB

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ENERGY ELECTRONICS

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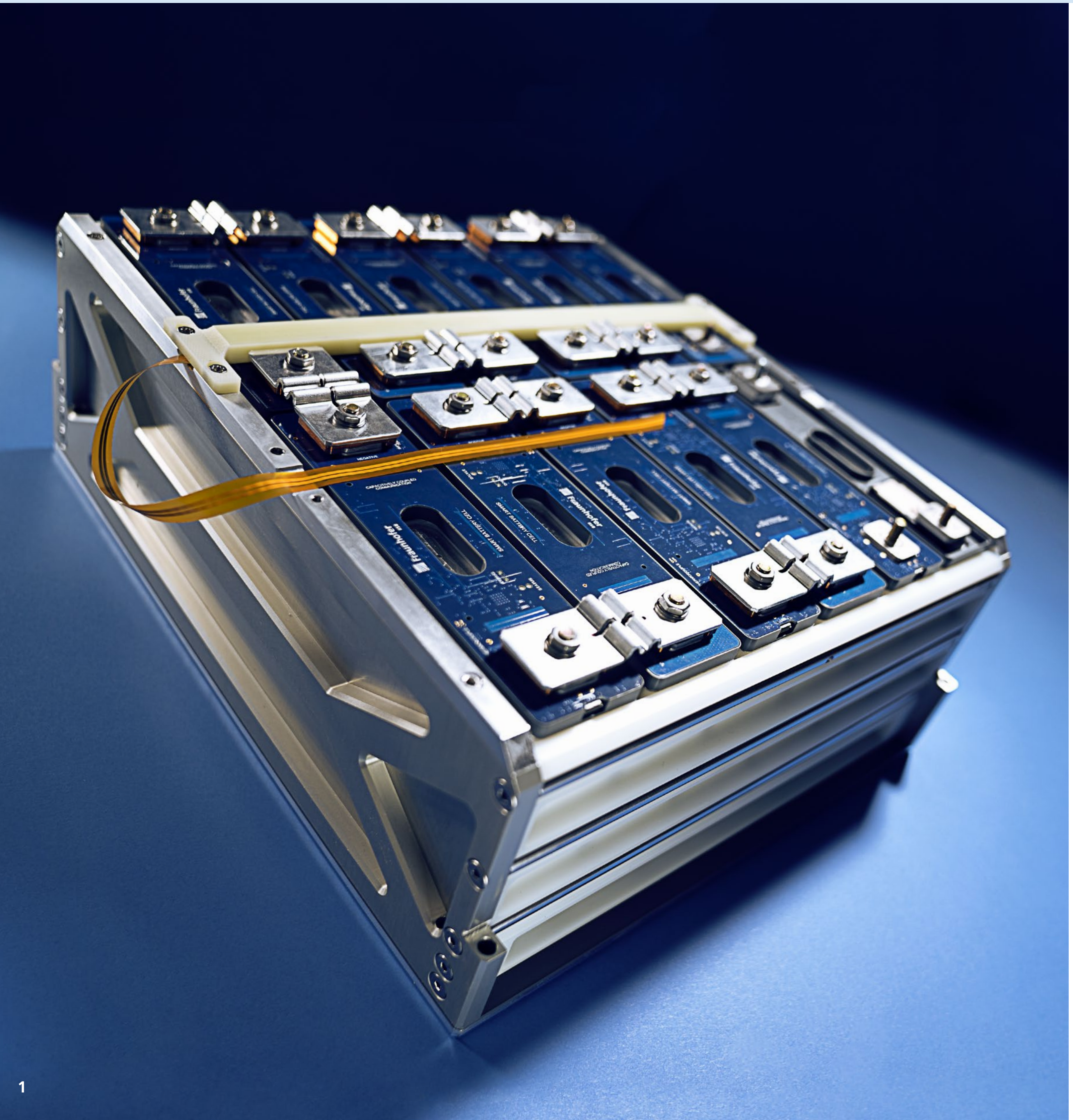

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The research focus of the "Energy Electronics" department is on electrical energy systems and the different kinds of power electronics necessary for this purpose. The target applications cover the entire power range from a few watts up to gigawatts. The department is organized in four working groups, with a total of about 40 researchers. A staff with long-term experience in industrial projects allows us to successfully support our customers in solving power electronic application problems. In addition, the close cooperation with the Chair of Energy Electronics at the University of Erlangen-Nuremberg provides us with access to the latest basic research results and an attractive pool of students.

A highlight in 2017 was the IEEE International Conference on DC Micro Grids (ICDCM) in Nuremberg. Mr. Bernd Wunder, head of the "DC Grids" group and a representative of the IISB for DC topics on boards such as VDE / DKE, IEC, eMerge Alliance, and IEEE Smart Grid, was successful in bringing the second ICDCM conference to Nuremberg after its launch in Atlanta in 2015. As the technical chairman of the conference, he was responsible for the technical program as well as for the local organization. With two hundred attendees from all over the world (75% international), the conference exceeded our expectations by far. The conference included 84 papers and presentations. Three keynotes were given by Prof. Rik DeDoncker (RWTH Aachen), Prof. Martin Maerz (University of Erlangen-Nuremberg), and Prof. Pavol Bauer (TU Delft). Three tutorials in advance of the conference completed the very appealing program. The presentations showed the latest results from research in the areas of power converters, grid protection, and control of DC grids in the low and medium voltage range – and also addressed the entire range of possible applications, whether in the field of renewable energy systems, in private and commercial buildings, in industrial production facilities, or in mobile applications such as railway systems or ships.

A second highlight in 2017 was the spin-off founded by our student and ex IISB colleague, Mr. Chacon. His company CEUS offers smart Li-ion battery storage solutions for office and outdoor applications. When using desk-sharing workplaces, for example, a local energy supply can decouple the workplace from the infrastructure. This offers possibilities for new room design concepts and can considerably reduce the costs for the building infrastructure at the same time. The integration of power electronics and battery storage opens up many new functionalities and applications that we would like to develop. Cooperation with CEUS could be an interesting path for commercial exploitation.

Apart from these highlights, an impressive number of industrial projects were successfully completed. We also had 33 supervised bachelor's and master's theses, 15 scientific publications, and more than 35 lectures. In addition to our very well received monthly colloquium on power electronics, two seminars were organized for and in cooperation with the Bavarian cluster "Power Electronics". Sincere thanks to all colleagues in the department for their extraordinary dedication, to all our supporters from industry, politics, and Fraunhofer, and to the entire staff of the IISB.

1 *Smart Lithium-ion battery cells with contactless data communication interface. © Fraunhofer IISB*

2 *Prof. Martin März, head of the Energy Electronics department. © K. Fuchs / Fraunhofer IISB*

ENERGY ELECTRONICS

Smart Battery Cells with Sensorless Temperature Estimation

SMART BATTERY CELLS WITH SENSORLESS TEMPERATURE ESTIMATION

Despite all of the recent advances in the field of lithium ion batteries, the battery still requires close monitoring in order to guarantee safe and reliable operation. However, traditional battery monitoring relying on cell voltage measurement and a few punctual temperature measurements can only give a general picture of the battery states. By integrating sensors, actuators, and intelligence into the battery cell itself, it is possible to create a smart battery cell that is not only able to monitor itself but also makes it possible to gain a new quality of information that was not accessible with traditional means of battery monitoring. In the national project MiBZ funded by the German Federal Ministry of Education and Research (BMBF) and the European project 3Ccar (funded equally by the BMBF and the European Commission in the ECSEL program), it was possible to demonstrate the implementation of this novel kind of approach.

In order to guarantee safe and reliable battery system operation, it is necessary to stay within a certain safe operating area (SOA) at all time. To compensate for the inaccuracies of current battery monitoring systems, the battery performance is artificially limited. These margins not only increase the battery size but also its cost. Especially in an electric vehicle, where the battery system accounts for a large part of the costs, it is of interest to use the battery to its full potential. Smart battery cells are able to provide exact knowledge about the battery state, which is a way to reduce performance and safety margins without sacrificing safety or lifetime. In fact, the information acquired by smart battery cells in a system can help to increase safety. Smart battery cells in combination with wireless data transmission, cloud-based data storage, and machine learning pave the way for innovative concepts such as predictive maintenance and fleet management, offering actual added value and enhanced user experience. All these topics are currently in development at the Fraunhofer IISB in the frame of the foxBMS® open research and development platform for battery management systems (BMS).

Sensorless Temperature Estimation

To ensure safe operation of lithium batteries – especially in high-energy and power applications – battery cell temperature monitoring is mandatory. In conventional systems, an external temperature sensor is placed on the surface of a few cells in each battery module. This method is not very appropriate because only the external battery temperature can be measured, which is delayed by the thermal capacity of the battery cell, especially for bigger battery cells (i.e., around 100 Ah). As customers demand higher ranges for their electric vehicles, battery systems as well as the individual battery cells are increasing in energy capacity, physical size, and power capability.

When a thermistor is placed on the outside of a cell, the accuracy and the dynamics of the cell temperature measurement, especially for detecting peaks or overload, is mainly influenced by the thermal capacity and conductivity of the electrode stack and housing. Temperature sensors used in automotive applications, where high reliability and low costs are demanded, are commonly based on thermistors. The advantages of thermistor-type temperature sensors are a simple and robust sensor design, easy application, and packaging. The main drawback of using thermistors for battery monitoring is their placement on the outer surface of the battery housing (for prismatic cells) or pouch. This drawback leads to greater safety margins between the usable temperature range of the battery system defined by the OEM in the specific application and the safe operating area defined by the battery cell manufacturer.

3 *Smart cell with sensorless temperature estimation.* *© Fraunhofer IISB*

The sensorless temperature estimation circuit implemented in the smart battery cell uses a galvanostatic (i.e., current) single frequency excitation in the low ampere range for a few milliseconds and measures the voltage response of the battery cell. This specific voltage response is given by the battery cell impedance and shows a strong temperature dependency at the selected excitation frequency. By using advanced filtering techniques, the developed algorithm is able to estimate the inner cell temperature with ± 1 K deviation, even under load conditions. Furthermore, the developed circuit is able to measure and estimate the equivalent cell temperature with a rate of 1 Hz to provide an accurate temperature estimation at all times.

Using the sensorless temperature estimation technique in automotive applications increases the measurement dynamics, and the inner temperature of the battery cell can be estimated. In consequence, the safety margins can be reduced in favor of an increased operating area of the battery without any higher safety risks, thus increasing both the driving range and driving dynamics.

Capacitively Coupled Communication Interface

A smart battery cell requires an advanced communication interface in order to transfer the generated data from the cells to higher level vehicle control units such as the battery management system (BMS) or even further, enabling a myriad of cloud-based services. This way, every battery cell becomes a participant in the Cognitive Power Electronic 4.0® (CPE4.0) network. Due to the large number of battery cells commonly used in electric vehicle battery systems, wires and connectors to hook up all the smart battery cells represent a reliability challenge. Therefore, a contactless communication interface based on capacitive coupling has been developed as part of the MiBZ project. A differential flat conductor pair is brought in close proximity to the appropriate coupling areas on the smart cell in order to establish the connection. This set-up can easily be realized as part of the battery module housing, thereby reducing the assembly effort while production costs for the module housing practically stay the same.

ENERGY ELECTRONICS

Modular Medium-Voltage Hardware-in-the-Loop Testbench

5

4

MODULAR MEDIUM-VOLTAGE HARDWARE-IN-THE-LOOP TESTBENCH

Power hardware-in-the-loop (PHiL) for medium-voltage applications

The public power supply system is changing towards a system dominated by power electronics. Power electronic systems are already used along the whole energy supply chain, beginning with generation by photovoltaic or wind power, continuing through the transmission system, and all the way to the consumer. New upcoming technologies and decreasing prices will intensify this development and will lead to a system with fewer rotating machines that have a significant role for the whole system stability. With the decreasing number of rotating machines, power electronic systems will need to take over ancillary services in the electrical grid to ensure system stability. This change will especially affect the medium and lower voltage levels. The newly developed and integrated power electronic devices for this voltage range will therefore confront new challenges regarding their stability requirements. The Modular Medium Voltage Hardware in the Loop Test Bench fills this gap between the development of new power electronic devices and their commissioning. Apart from relying only on simulation results that are carried out during the development, devices can be tested with realistic currents and voltages and can therefore be stressed under challenging conditions within the test bench. Especially irregular grid states and fault conditions that need to be avoided by all means in the power transmission system can be applied to devices and prove their reliable functionality.

Modular multilevel converters as supply grid simulators

Modular multilevel converters (MMC) offer a high number of output voltage levels and a high effective switching frequency. Therefore, the very accurate emulation of the supply grid voltages as well as the simulation of disturbances in the supply grid voltages are possible. The test environment is very flexible through the use of an MMC in the test bed, as the MMC consists of many identical submodules that can be arranged in a flexible way. The maximum voltage of the converter can be increased by connecting more submodules in series, and the current capability of the converter can be increased by connecting arms of the MMC in parallel. It is also possible to build more than one converter with the submodules, in order to meet different test demands.

Modular medium-voltage hardware-in-the-loop testbench @ Fraunhofer IISB

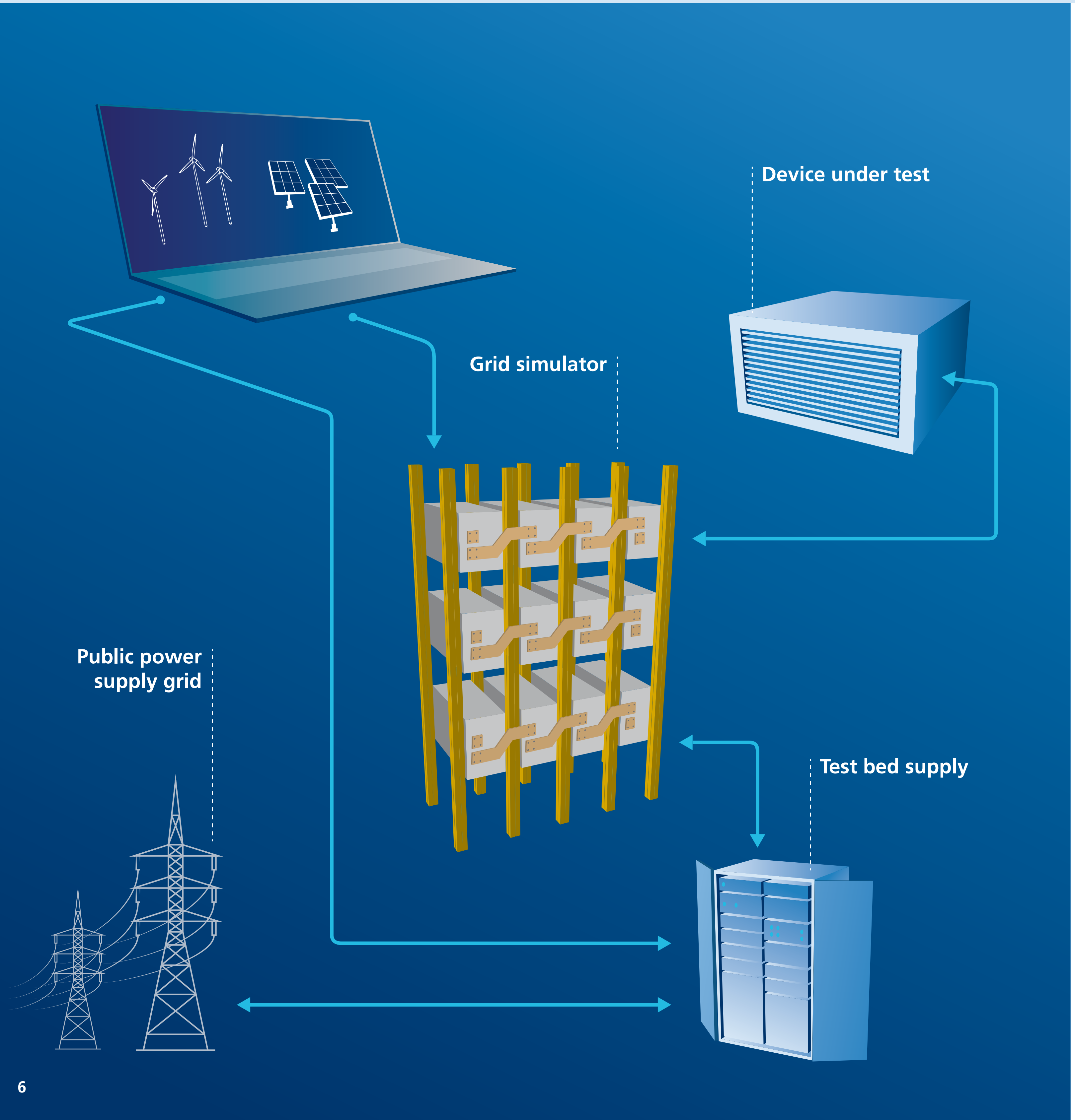
The test bed is designed to achieve maximum flexibility. Therefore, it will be possible to test different types of converters with realistic currents and voltages. The test environment

4 *Grid simulator test setup with a three phase modular multilevel converter using 1.2 kV IGBT modules.*
© K. Fuchs / Fraunhofer IISB

5 *Modular multilevel converter cells with high current interconnects.*
© K. Fuchs / Fraunhofer IISB

ENERGY ELECTRONICS

Modular Medium-Voltage Hardware-in-the-Loop Testbench



(picture 6) will consist of the grid simulator and a robust test field supply, consisting of transformers with a regulated secondary voltage and 12-pulse rectifiers. The grid simulator is reconfigurable, as its power stage is based on cell-based MMC systems. Possible devices under test are, for example, active filters, active front ends, or inverters for photovoltaic or wind power generation. In addition to the simulation of supply grids, it is also possible to emulate machines (generators or motors) for testing motor inverters or cycloconverters.

6 *Schematic overview of the test bench for medium-voltage hardware-in-the-loop tests.*
© Fraunhofer IISB

Full-bridge submodules with 1200 V IGBT modules and film capacitors (CSM=5.5 mF) are used in the MMC system. The maximum apparent power of the system is $S_{AC,max}$ = 10 MVA and the maximum AC voltage is $V_{AC,max}$ = 20 kV. As the system should be very flexible, the electrical connections between the submodules can be modified easily. The control hardware, which is a system on a chip, is very powerful. Therefore, it is possible to use automatic code generation; thus, the control code running on the control system is easily changeable and adaptable to different test scenarios. The communication between the control hardware and the submodules is carried out on a high-speed fiber communication system. There are two possibilities for the auxiliary power supply: from the DC link capacitor with a wide-range power supply and from the public supply grid with a highly isolated power supply.

In order to speed up the subsequent commissioning of the modular medium-voltage hardware-in-the loop testbench in Erlangen, a pretest is set up at the Energy Campus Nuremberg (EnCN) in cooperation with the Chair of Energy Electronics (LEE) of Friedrich-Alexander-Universität Erlangen-Nürnberg. The test system consists of twelve submodules that are interconnected as a three-phase system with four submodules per phase (see picture 4 and 5, previous page).

Within this pretest, all significant power electronic systems, the cooling system, as well as the communication and control systems are stressed under realistic conditions. The commissioning of the test system shows the successful integration of all parts together and provides important measurement results for the following technical work. Due to the modularity, the existing down-scaled test system offers a wide scope of additional test scenarios and is already used to support industrial customers in special measurement tasks. With the next step, all parts are scaled up for commissioning in the modular medium-voltage hardware-in-the-loop testbench at IISB in Erangen to provide a flexible and reliable test environment for future power electronic systems that will play an essential role for the stability of the public power supply system.

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ENERGY TECHNIQUES

Long-term Energy Storage System based on Hydrogen Technology

1

2

LONG-TERM ENERGY STORAGE SYSTEM BASED ON HYDROGEN TECHNOLOGY

A globally unique system for the compact storage of huge amounts of energy is set up at Fraunhofer IISB in Erlangen and integrated in a modern direct current grid. In the framework of the joint initiative Leistungszentrum Elektroniksysteme LZE, it is investigated how such energy storage systems can contribute to a safe and clean energy supply of industrial plants and larger building complexes.

Entering the white steel container at Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen, it can get a little tight. The interior is packed with technology that enables the storage and release of electrical energy based on a liquid hydrogen carrier.

Energy inside a container

"The goal was to place all components of the process in a 20 ft container," explains Johannes Geiling. He works as research assistant at Fraunhofer IISB and is responsible for the setup of the process part of the new energy storage system. The plant is set up in the framework of the LZE and is intended to set benchmarks for the long-term storage of huge amounts of energy – by requiring extremely less space.

The basic concept of the storage system is to use excess energy, e. g., from a local photovoltaic plant, to produce hydrogen und to store this hydrogen safely and compactly within an organic carrier – even for longer periods up to seasonal storage. For the later use, the hydrogen can be released from the carrier and converted into electrical energy by using a fuel cell.

With the installed components, 25 kilowatts of electrical power can be stored and released from the storage system. The used fuel cell system is based on the low-temperature PEM technology (PEM: Proton Exchange Membrane). The PEM technology makes it possible to set the fuel cell from the off state to standby within a few minutes. Fast availability, for example, is important for covering load peaks at industrial plants at a later time.

Liquid organic hydrogen carrier

The carrier material used for the hydrogen storage is known as LOHC (liquid organic hydrogen carrier) in technical language. The researchers in Erlangen see a great potential in the use of

1 *Employees of Fraunhofer IISB are discussing the compact setup of the process part of the innovative energy storage system.*
© K. Fuchs / Fraunhofer IISB

2 *Inside the process compartment, the electrolyser (left), fuel cell (center) and oneReactor (right) and the related auxiliary units are placed.*
© K. Fuchs / Fraunhofer IISB

ENERGY TECHNIQUES

Long-term Energy Storage System based on Hydrogen Technology

LOHC technology, in which the Institute of Chemical Reaction Engineering (CRT) at the University of Erlangen-Nürnberg has a lot of expertise.

During a chemical reaction, huge amounts of electrolytically produced hydrogen are bound on the carrier molecule. The reaction product, which contains the hydrogen, can be stored safely under common ambient conditions for pressure and temperature. Only under defined conditions inside a chemical reactor can the hydrogen be released from the carrier. Regarding the requirements for storage and transport, the carrier can be compared to common diesel, which means a big advantage compared to other hydrogen storage technologies, which usually need high pressure or very low temperatures.

In addition, the carrier material is widely used in industrial processes as thermal oil in heating and cooling processes. Applied as LOHC, the carrier material enables the repeated storage and release of energy in a cycle process. In contrast to fossil fuels, the LOHC is not consumed during the process but can be repeatedly loaded and unloaded with hydrogen.

Modular and scalable

About 300 liters of LOHC can be stored inside the container in Erlangen, which corresponds to an energy amount of nearly 600 kilowatt hours stored in the hydrogen. This is enough to cover the electricity demand of smaller industrial plants for a few hours. Via additional tank containers, the stored amount of energy can be increased by several magnitudes. Therefore, even larger industrial plants, data centers, or hospitals can be supplied over longer time periods.

With the new demonstration system, the researchers in Erlangen want to answer several questions: How can LOHC-based energy storage systems deal with fluctuating energy generation profiles? How can the compact setup be realized within a single container? And how can such a system be efficiently integrated in industrial energy systems? At Fraunhofer IISB, the system is connected to the local direct current (DC) grid. Local DC grids enable a more efficient operation of the whole electrical system due to the avoidance of conversion losses between direct current and alternating current.

Interdisciplinary cooperation

Because of the extreme compactness of the container system, a large variety of customized solutions was necessary. "Only through interdisciplinary cooperation can our research project be managed successfully," explains deputy project manager Michael Steinberger. The electrical engineer has become a specialist in fuel cells over the last years and is also responsible for the control system in the container.

For the conception of the control system, Steinberger received valuable support from communication experts at the Fraunhofer Institute for Integrated Circuits IIS.

However, deep knowledge of chemical processes is also necessary. For example, the chemical reactor for the release of hydrogen stored in LOHC is a development of the Institute of Chemical Reaction Engineering at the University of Erlangen-Nürnberg, which is a project partner within the framework of the Leistungszentrum Elektroniksysteme LZE.

A higher degree of self-sufficiency

The research activities on the globally unique energy storage system are leading to important knowledge of how such systems can be integrated in local energy systems. "An important focus of our work is to find the best operational strategy for the storage system," says IISB researcher Johannes Geiling. With the right operational strategy, the LOHC-based energy storage system will enable the extensive integration of renewable energy sources while ensuring security of supply in industrial plants, larger building complexes, or quarters, and thereby increase the degree of energy self-sufficiency.

3 *Inside the electrical compartment, highly efficient power electronics for the integration within the direct current microgrid of the institute is installed.*
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EVENTS

Special Exhibit "KRISTALLE!" in the Museum for Industrial Culture

1

SPECIAL EXHIBIT "KRISTALLE!" IN THE MUSEUM FOR INDUSTRIAL CULTURE IN NUREMBERG, GERMANY

1 *The special exhibition "CRYSTALS! - Key materials for the 21st century" was created by Fraunhofer IISB in cooperation with the Museum for Industrial Culture in Nuremberg. © K. Fuchs / Fraunhofer IISB*

The special exhibit "KRISTALLE! - Schlüsselmaterialien für das 21. Jahrhundert" ("CRYSTALS! - Key materials for the 21st century") was ceremoniously opened to the public on February 22 in the Museum for Industrial Culture in Nuremberg. Around 150 guests from science, industry, politics, art, and the museum scene as well as friends of the institution accepted the invitation of the museum and Fraunhofer IISB to the opening reception and enjoyed the unique atmosphere in the halls of the former screw factory in the eastern part of Nuremberg. The exhibit was held at the Museum of Industrial Culture until April 30, 2017 and supplemented the touring exhibition INNOspaceExpo "ALL.täglich!" ("EVERY.day") of the German Aerospace Center (DLR), which was shown at the same time.

In the historic Museumsstraße, Ingrid Bierer, the director of museums of the city of Nuremberg, and her colleague Dr. Gabriele Moritz, the deputy head of service and head of the "Cultural History Museums" department, started the formal part of the evening event. In their welcome address, they briefly introduced the two exhibits and summarized the historical development of the museum.

Afterwards, Dr. Franziska Zeitler, head of the "Innovation and new markets" department at DLR Space Administration, focused on the innovation and transfer potential of space travel and space research. She also discussed the wide variety of activities at DLR and gave insights into the history of the DLR touring exhibit "ALL.täglich!".

Dr. Jochen Friedrich, head of the Materials department at the Fraunhofer IISB in Erlangen then gave a talk presenting the concept and contents of the special exhibit "KRISTALLE!". Starting from people's millennia-old fascination with natural minerals and precious gemstones, the materials scientist presented the world of technical crystals in an easily understandable form and also explained the theory and practice of crystalline materials to the audience. Using illustrative examples, he demonstrated the great importance of artificially produced crystals for technology and everyday life and covered the spectrum up to scientific crystal pulling experiments in outer space. Dr. Friedrich ended by giving a short overview of the special historical significance of the Franconia region as a cradle of modern microelectronics. This created a successful transition to the following tour of the exhibit.

In the exhibition hall, the Fraunhofer IISB team led by Dr. Jochen Friedrich and the second organizer of the exhibition, Dr. Christian Reimann, director of the Silicon group at IISB, were available

EVENTS

2017 IEEE International Conference on DC Microgrids (ICDCM)

3

2

to the audience for technical questions. The “KRISTALLE!” exhibit is a further milestone in the longstanding cooperation of the regional Fraunhofer institutes with the Museum of Industrial Culture.

COMEBACK WITH EFFICIENCY – LOCAL DC SYSTEMS ENRICH THE ENERGY SUPPLY

2017 IEEE International Conference on DC Microgrids (ICDCM)

As supplements to the usual alternate current system, local direct current systems offer a variety of possibilities for making the energy supply more efficient and more reliable. The technical progress in this field has been enormous in the past years, and the topic is booming. From June 27 to 29, the 2nd IEEE International Conference on DC Microgrids ICDCM met in Nuremberg, Germany. Around 200 experts discussed current developments and applications in the field of direct current technology.

In the energy system of the future, customer generation of electricity – through photovoltaic systems, for example – as well as the associated on-site storage and own use of electrical energy will be a matter of course. In contrast to the established integrated grid, which is based on alternating current, solar cells and electrical stores supply direct current. Many electrical consumers and most electronic devices also work internally with direct current, so that lossy conversion processes between direct current (DC) and alternating current (AC) have been unavoidable up to now.

Historically, alternating current became established as the standard after the co-called “War of Currents” at the end of the 19th century. Due to the rapid development of power electronics based on semiconductors in the past decades, however, it has been possible to more than compensate for the technological disadvantages of direct current and create new advantages. Now local direct current systems, also called DC microgrids, allow the direct connection of producers, storage facilities, and consumers. In addition to an efficiency increase of 5 - 10%, this approach also allows material savings of up to 30%. Direct current systems are thus experiencing a renaissance, and the topic has been gaining momentum recently.

As a European center of energy technology and power electronics, the metropolitan region of Nuremberg has especially been able to profit from the latest developments. Against this background, it is all the more gratifying that the recently started IEEE International Conference on DC

2 *The organizers of the crystal exhibition at the Museum of Industrial Culture (from left to right): Dr. Jochen Friedrich, Head of the Materials Department at Fraunhofer IISB in Erlangen, Dr. Christian Reimann, Head of the Silicon Group at Fraunhofer IISB, and Matthias Murko, Director of the Museum of Industrial Culture in Nuremberg.*
© K. Fuchs / Fraunhofer IISB

3 *In addition to the exhibition, experiments were offered specially for children and youth under the title “Crystals! Grow them Yourself”.*
© K. Fuchs / Fraunhofer IISB

EVENTS

2017 IEEE International Conference on DC Microgrids (ICDCM)

Microgrids 2017 was held in Nuremberg. At the 2nd IEEE ICDCM 2017 the around 200 experts from research and industry met to discuss network technology, storage, and security of supply in private and industrial buildings, aircraft, ships, and trains.

The director of the technical program committee of the ICDCM 2017 was Bernd Wunder, the group director for DC networks at the Fraunhofer IISB in Erlangen. He greatly contributed to organizing the conference in Nuremberg and has also worked in international standardization bodies (IEEE, IEC, DKE) on the standardization of DC technology.

Bernd Wunder sees great potential in direct current technology: "Local direct current systems can use their advantages on various voltage levels. For example, in the range up to 48 volts, it is possible to eliminate the many bulky and inefficient power supply units that power office applications and IT equipment such as laptops, screens, or servers. At 380 volts, direct current systems for LED-based lighting systems or cooling systems are interesting. The medium voltage range up to 20 kV – also a focus at the ICDCM this year – is also becoming more and more important. An ideal application field for direct current systems is self-sufficient networks, such as isolated solutions on ships or in remote settlements in developing countries that are not yet connected to a public power grid and use self-produced solar energy. This also reduces the dependence on transmission over long distances and complex distribution networks."

Fraunhofer IISB has been doing research in the area of local direct current systems for many years, especially on the required power electronics, and has followed the development from the very beginning. The institute deals with special direct-current protection devices or highly efficient DC management systems, among others. The possibilities of digitization are also increasingly used to link different systems and components: "Cognitive Power Electronics 4.0" has intelligent information technology and extensive sensors to make detailed statements about the condition of the power grid and ensure stability, reliability, and supply quality at all times. With the increasing number of regenerative and decentralized energy generators, today's distribution networks are also subject to great loads. New intelligent grid structures in connection with electrochemical energy stores already make it possible to intercept negative effects – for example, from an over- or undersupply – in the local networks and thus relieve the integrated grid. However, the integration in a common network is very complex and there is relatively little experience with practical operation. For this reason, the linkage of direct current systems with organic hydrogen stores, which can also absorb large amounts of energy and adjust seasonal fluctuations, is therefore one of the things being studied at the "Leistungszentrum Elektroniksysteme LZE" ("Center of Excellence for Electronic Systems"), a joint initiative of the Erlangen Fraunhofer institutes IIS and IISB and the University of Erlangen-Nuremberg.

4 *The participants of the 2017 IEEE International Conference on DC Microgrids (ICDCM) organized by Fraunhofer IISB in Nuremberg.*
© Stefanie Rei / Fraunhofer IISB

4

EVENTS

Bavarian Starting Signal for the Research Fab Microelectronics Germany (FMD)

6

5

REALLY STRONG TOGETHER – BAVARIAN STARTING SIGNAL FOR THE RESEARCH FAB MICROELECTRONICS GERMANY

On July 13, 2017, the Bavarian locations of the "Forschungsfabrik Mikroelektronik Deutschland, FMD" ("Research Fab Microelectronics Germany") were officially opened at the Fraunhofer IISB in Erlangen. Stefan Müller, Member of Parliament and Parliamentary State Secretary of the Federal Ministry for Education and Research, was the guest of honor and presented sponsorship certificates to the Fraunhofer Institutes IIS, IISB, and EMFT. The objective of the research fab is to ensure the sustainability of German microelectronics research, develop new areas, and give industry direct access to a large, powerful research platform.

The European semiconductor and electronics industry faces the challenge of global competition and expanding its leading position in many areas despite a dynamic market development, rapidly increasing innovation speeds, and the technical as well as social upheavals from digitization. To support this effort, eleven institutes of the Fraunhofer Microelectronics Group, together with two institutes of the Leibniz Association, are organizing a multi-location research factory for micro- and nanoelectronics in a nationwide consortium. The aim is to offer customers from large-scale industry, small and medium-sized companies, as well as universities the entire value-added chain for micro- and nanoelectronics from a single source. The German Federal Ministry for Education and Research (BMBF) supports the necessary investments for this nationwide in the next four years with around 280 million euros for Fraunhofer and 70 million euros for Leibniz.

The FMD will unite the research and development distributed among the individual institutes in one joint technology pool extending across locations. The closely cooperating consortium of the FMD with around 3900 employees forms a research unit of international standing.

BMBF State Secretary Stefan Müller gave the official starting signal for the Bavarian representatives in the FMD at Fraunhofer IISB in Erlangen. These include the Fraunhofer Institute for Integrated Circuits IIS and for Integrated Systems and Device Technology IISB in Erlangen, Nuremberg, and Fürth, and the Fraunhofer Research Institution for Microsystems and Solid State Technologies EMFT in Munich. 59.5 million euros of the total funding go to the Bavarian locations of the three institutes with a total of around 1200 employees.

"Our microelectronics research ensures future-proof jobs in the digital age: The microelectronics industry is investing in Germany again. For this to continue, we are creating the prerequisites

5 *Prof. Lothar Frey (left), Director of Fraunhofer IISB, receives the official funding decision for investments at Fraunhofer IISB within the FMD from Stefan Müller (right), Parliamentary State Secretary at the German Federal Ministry of Education and Research.*
© K. Fuchs / Fraunhofer IISB

6 *Stephanie Zötl (right) explains the new laboratory facilities at the IISB to the guests of honor at the event.*
© K. Fuchs / Fraunhofer IISB

7

today for the microelectronics technologies of tomorrow with the research fab – here in Bavaria and throughout Germany," explains Stefan Müller, who, after presenting the sponsoring certificates, ceremoniously unveiled the signs that honor IIS, IISB, and EMFT as members of the Research Fab Microelectronics.

On the occasion of the opening ceremony in Erlangen, the three institutes explained the offers and possibilities of the FMD as well as their respective technological focuses and contributions in the research fab. These especially include the areas of information and communication technology, power electronics, circuit design, sensor technology, materials research, and reliability tests. They address the economically important application areas of energy technology, automotive, aerospace, industry 4.0, and digitization.

After the official project start for the FMD at the beginning of April, the partners will intensively deal with the construction of the new laboratory facilities as well as with the implementation of the unique cooperation network. At the end of 2020, the extensive investment measures should be entirely complete and the infrastructure of the research fab should be completely ready for operation.

"As a result of the new possibilities of the FMD, the research institutions can raise their profile further by building on their specific strengths. This also intensifies the development of future topics such as quantum technology, the processing of extremely large data quantities, or the FMD vision "Towards Zero Power" for electronics with extremely low power consumption. This guarantees the influence of German microelectronics research over the long term," concluded the directors of the three Fraunhofer Institutes in agreement.

The Forschungsfabrik Mikroelektronik Deutschland, FMD is supported by the German Federal Ministry for Education and Research (BMBF).

DRIVE-E ACADEMY 2017

Driven by the future

54 young junior scientists immersed themselves in electrical mobility for a week and four excellent student papers were each honored with a DRIVE-E study prize.

The topic of electromobility is as relevant as ever – and innovative concepts are in demand. With the presentation of the DRIVE-E study prizes on October 12, 2017 at the Porsche Museum

7 *Prof. Lothar Frey, Director of Fraunhofer IISB, Prof. Christoph Kutter, Director of Fraunhofer EMFT, Josef Sauerer, Head of Smart Sensing and Electronics at Fraunhofer IIS, and Stefan Müller, Parliamentary State Secretary at the German Federal Ministry of Education and Research, during the tour of the Fraunhofer IISB laboratory for construction and connection technology (from left to right).*
© K. Fuchs / Fraunhofer IISB

EVENTS

DRIVE-E Academy 2017

9

8

in Stuttgart, the German Federal Ministry for Education and Research (BMBF) and the Fraunhofer-Gesellschaft honored four award winners for their excellent theses on topics in electrical mobility with prize money of up to 6000 euros.

The annually held DRIVE-E Academy offers students at all German colleges the possibility of gaining an exclusive insight into the theory and practice of electrical mobility. The dedication of the University of Stuttgart, the local university partner, as well as the companies visited in the region contributed very significantly to the success.

Four innovative ideas for electromobility

The first prize in the category of master's theses went to Bavaria. The thesis of Alexander Rupp from the Technical University of Munich dealt with solid state batteries in which the usual liquid electrolyte is replaced with a solid electrolyte. In the category of project or bachelor's theses, the first place also involved solid state batteries. Célestine Singer, another student at the Technical University of Munich, investigated whether and how existing technology chains for oxide ceramics can be used for the production of solid state batteries.

Second place in the category of master's theses was awarded to the paper of Verena Müller from the University of Erlangen-Nuremberg, which developed solutions for an especially economical process in which lithium-ion batteries are charged for the first time and prepared for further use. The jury was also excited about the thesis of Oliver Fuhr from TU Dortmund University, which won the second prize in the category of project or bachelor's theses. He dealt with the question of how solar systems and vehicles can communicate with each other to enable remote charging.

About the DRIVE-E program

DRIVE-E was jointly initiated in 2009 by the German Federal Ministry for Education and Research (BMBF) and the Fraunhofer-Gesellschaft. With the DRIVE-E study prize, the BMBF and the Fraunhofer-Gesellschaft honor excellent, innovative student theses on electrical mobility. Graduates of and students at German advanced technical colleges, universities, and other institutions of higher learning can apply with their scientific papers.

Numerous students from throughout Germany had applied for the eighth edition of the popular young scientist program of the BMBF and the Fraunhofer-Gesellschaft. After a successful start on Monday and Tuesday at the EVS30, the world-renowned conference for electrical mobility, the Academy program took place during the following three days, above all at the Research Institute of Automotive Engineering and Vehicle Engines at the University of Stuttgart. The young scientists got to know innovative start-ups in the area of electrical mobility and had stimulating discussions

8 *At the DRIVE-E Academy 2017, the Formula Student Electric Team of the University of Stuttgart (Greenteam Uni Stuttgart) also presented themselves at the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS). © Uli Regenscheit / DRIVE-E*

9 *Participants of the DRIVE-E Academy 2017 at a workshop on vehicle electronics. © Uli Regenscheit / DRIVE-E*

10

with the speakers. In addition, automotive manufacturers and suppliers from the region, such as Daimler, Bosch, and Schaeffler, gave unique insights into their innovative mobility concepts for the future. The students got a taste of practical work during an informative excursion to the "Active Research Environment for the Next Generation of Automobiles (ARENA2036)" and at an electrical driving event at Daimler.

In short: The DRIVE-E Academy offers a unique mixture of theory and practice.

DGKK AWARD FOR YOUNG SCIENTIST LUDWIG STOCKMEIER FROM FRAUNHOFER THM IN FREIBERG

Increasing yield in the production of highly doped silicon crystals for economical power supply units and efficient motor controllers

To minimize electrical switching losses and thereby lower the energy consumption of power supply units or electrical motors, silicon crystals with a very low electrical resistance are needed. However, crystal defects frequently appear in such cases that reduce the production yield and thus increase manufacturing costs. Qualified engineer Ludwig Stockmeier from the Fraunhofer Technology Center for Semiconductor Materials THM in Freiberg, Germany has now discovered that certain instabilities in the growth process cause these defects to occur in silicon crystals. For his scientific and technical work on identifying the reason for these defects, Mr. Stockmeier was presented with the 2017 DGKK award for young scientists. The knowledge that he has acquired can be used to implement measures to prevent the development of crystal defects in industrial production.

Power-electronic components for energy supply, automotive, and industrial electronics significantly contribute to energy efficiency and CO_2 reduction. Particularly for applications at low to medium power and medium to high frequencies, so-called PowerMOS components are used – for example, in switching power supplies, robots, automobile electronics, or for driving motors. In these vertical component structures, silicon crystals with a very low electrical resistance – up to 0.001 Ωcm – are needed to minimize switching losses in the forward direction.

The electrical resistance is achieved by a targeted addition of phosphorus or arsenic to the 1500 °C hot silicon melt, from which silicon crystals are produced according to the so-called

10 Driving event at Daimler AG in Stuttgart during the DRIVE-E Academy 2017.
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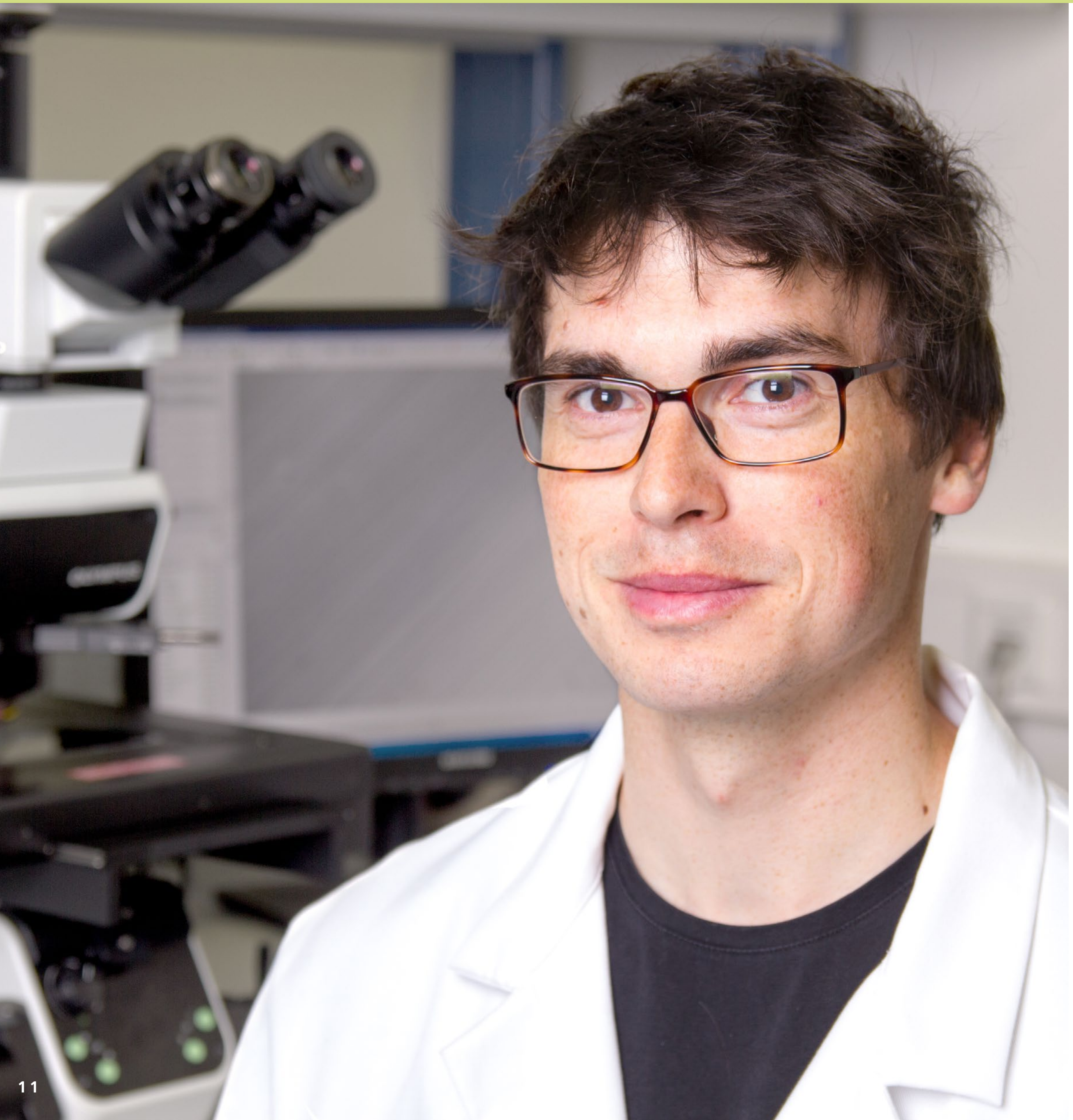
EVENTS

DGKK Award for Young Scientist Ludwig Stockmeier from Fraunhofer THM



11

Czochralski method. However, the required high amounts of phosphorus or arsenic frequently cause crystal defects to occur in the form of dislocations during the manufacturing process. As a result of these crystal defects, the monocrystalline structure of the silicon is lost, which reduces the crystal yield. However, it was not yet known precisely why these crystal defects occur much more frequently in the production of silicon crystals that are highly doped with arsenic or phosphorus than with material that is normally or highly doped with boron.

Qualified engineer Ludwig Stockmeier from Fraunhofer THM in Freiberg has now investigated in detail the cause of dislocations when highly doped silicon crystals are grown according to the Czochralski method. Mr. Stockmeier has been able to determine when dislocations occur by analyzing the process data from crystal pulling experiments carried out by the project partner Siltronic AG and using X-ray investigations of the crystals.

After the time and place of the dislocation occurrence had been determined, the cause of the dislocation occurrence still had to be found. For this purpose, Ludwig Stockmeier studied the incorporation of phosphorus and arsenic in the silicon crystal on the microscopic level. He was able to show that the stresses caused by the concentration fluctuations in normally doped silicon are low. The same holds true for material that is highly doped with boron. For this reason, the temperature fluctuations that always occur when silicon crystals are produced according to the Czochralski method do not cause dislocations in these two cases. However, material that is highly doped with phosphorus or arsenic has much higher mechanical stresses, and dislocations that form due to an unstable growth process caused by the temperature fluctuations can easily spread. Stockmeier was therefore able to conclusively indicate the probability of dislocation depending on the doping.

With the knowledge attained by Ludwig Stockmeier, the industry can now develop and implement technological measures to minimized the occurrence of dislocations when growing silicon highly doped with arsenic or phosphorus and thus increase the crystal yield.

This scientific achievement was honored with the Young Scientist Award from the German Society for Crystal Growth and Crystal Growing (DGKK).

Ludwig Stockmeier carried out his work in the framework of the "PowerOnSi" project, which was supported by the State Ministry for Sciences and Art of Saxony, in the framework of the ECSEL project "PowerBase". ECSEL stands for Electronic Components and Systems for European Leadership, a private-public partnership program that is an important component of the Europe 2020 initiative of the EU Commission.

11 *DGKK Young Scientist Award winner Ludwig Stockmeier from Fraunhofer THM at his laboratory workplace. Stockmeier received the Young Scientist Award of the German Society for Crystal Growth and Crystal Pulling for his work on increasing the yield in the production of highly doped silicon crystals.*
© Fraunhofer IISB

EVENTS

Die Lange Nacht der Wissenschaften 2017

DIE LANGE NACHT DER WISSENSCHAFTEN 2017

Electronics development from the basic material to a complete system – Fraunhofer IISB at „Die Lange Nacht der Wissenschaften" („The Long Night of the Sciences")

Whether highly efficient drive electronics for electric vehicles or energy-saving systems for the intelligent distribution of electrical energy in buildings and state-of-the-art power grids – the Fraunhofer Institute for Integrated Systems and Device Technology IISB presented exciting developments during "Die Lange Nacht der Wissenschaften" ("The Long Night of the Sciences") on October 21, 2017. The institute researches all steps in the development of complex electronics systems from the basic material to complete system solutions.

Highlights at the main location of the institute in Erlangen were, for example, a tour of the test center for electric vehicles or the "Electrotainment" talk on megavolts and kiloamperes. Visitors were able to dive into the fascinating world of crystals or learn about how the power consumption of companies can be reduced through comprehensive monitoring.

The popular tour of the large cleanroom laboratory of the University of Erlangen-Nuremberg provided a journey through the world of chips and transistors. Researchers also showed how functional electronics can be printed economically and explained the high reliability demands of electronics for power supply and e-mobility. Simulation experts explained how the nanoelectronics of tomorrow are already being created on computers today.

The electric motorcycle "ElMo" built by students could also be seen in action on an obstacle course in the inner courtyard. A new energy store container packed full of hydrogen technology could also be seen for the first time. The "Leistungszentrum Elektroniksysteme LZE" ("Center of Excellence for Electronic Systems") presented itself as well.

The location of the Fraunhofer IISB at the Energie Campus Nürnberg (former AEG site) provided information about power-electronic systems for electric power grids of the future with experiments and demonstrations.

In the direct vicinity, the new Chair for Energy Electronics (LEE) of Prof. Martin März (deputy institute director of the IISB) presented itself with demonstrations and talks on the topic of decentralized power supply.

12 *A regular highlight of the Long Night is the experimental lecture "Electrotainment at the IISB". © K. Fuchs / Fraunhofer IISB*

13 *The Bavarian energy research project SEEDs also presented itself at the Long Night of Science. © Erik Teuber*

EVENTS

Award for IISB Researcher Alicia Zörner
Roofing Ceremony for the Second IISB Building Extension

14 *Award winner Alicia Zörner in her laboratory at Fraunhofer IISB.*
© Fraunhofer IISB

AWARD FOR IISB RESEARCHER ALICIA ZÖRNER

Alicia Zörner, an employee of the Thin Film Systems group of the IISB, received the "Best Student Paper Award" for her work at the "10th International Conference on Biomedical Electronics and Devices (BIODEVICES / BIOSTEC)", which was held from February 21 to 23 in Porto, Portugal.

In her scientific paper "Determination of the Selectivity of Printed Wearable Sweat Sensors", Alicia Zörner and her co-authors from Fraunhofer IISB and Fraunhofer IIS dealt with the characterization and control of sensors that can be used in clothing to analyze human sweat. These sensors can be used, for example, to determine body-related parameters during athletic activities that athletes can use to optimize their training.

The results of this paper show that the sensors can help to reliably warn against the overloading of muscles during sports activities, despite the presence of very different interference parameters in sweat. The papers are part of the pilot project "Low-power electronics for sports and fitness applications" in the "Leistungszentrum Elektroniksysteme LZE" ("Center of Excellence for Electronic Systems").

ROOFING CEREMONY

FOR THE SECOND IISB BUILDING EXTENSION

After an initial building extension was opened in 2012, the second extension takes into account the continuous and successful development at the main location in Erlangen. The institute currently has more than 250 employees as well as numerous university students. The urgently needed space for laboratory facilities and offices is being created in the 4000-square-meter area of the building extension, half of which is usable space.

The building will be primarily used for the subjects of power electronics and energy supply. It contains among other things a medium-voltage hall with a new kind of mains simulator in a multilevel converter topology as well as several laboratory systems for the Bavarian energy research project SEEDs. The building of the IISB serves as a demonstration and test platform for this project. The building extension furthermore accommodates the crystal growing laboratories in which researchers will develop semiconductor materials. Moving is planned for summer 2018.

EVENTS

15th Fraunhofer IISB Lithography Simulation Workshop
Award for IISB Microtechnologist Alexandra Diez

15TH FRAUNHOFER IISB LITHOGRAPHY SIMULATION WORKSHOP

From September 21 to 23, 2017, the 15th Fraunhofer IISB Lithography Simulation Workshop was held in Behringersmühle near Ebermannstadt, Germany. As in the past years, renowned scientists from America, Asia, and Europe were enlisted as speakers.

The around 40 workshop participants from leading industrial companies and research institutions uniformly praised the wide spectrum of topics and the high scientific level of the workshop.

The focus of the workshop this year was on methods for creating structure sizes of less than 10 nm for future nanoelectronic circuits. The methods for this range from lithography using extreme ultraviolet light (EUV lithography) to direct writing to special alternative lithography techniques. This year's opening lecture, which is traditionally held on the first evening of the workshop, dealt with the use of Fourier ptychography to increase the resolution of microscopes.

The numerous multidisciplinary expert discussions were loosened up by, among other things, a hike followed by a medieval banquet at Rabeneck Castle.

AWARD FOR IISB MICROTECHNOLOGIST

Alexandra Diez, who completed her training as a microtechnologist at the IISB in 2017, was honored by the „IHK" („Chamber of Commerce and Industry", CCI) for Nuremberg and Central Franconia for her excellent exam results and as the best microtechnology trainee in 2016 / 2017.

At a ceremony in the „IHK-Akademie" in Nuremberg on November 9, IHK president Dirk von Vopelius honored 58 young management assistants and skilled workers who graduated in 2017 with excellent results: They completed the training in their professions or specialties at the top of their classes with an overall grade of "very good". A total of 9137 examinees took part in the IHK final exams in Central Franconia in winter 2016 / 2017 and in summer 2017.

Alexandra Diez now works in the Technology and Manufacturing department of the IISB and will start further training as a technician next year. The IISB has been training microtechnologists very successfully and in close cooperation with the University of Erlangen-Nuremberg since 1999.

15 *Topping-out ceremony for the second extension of the IISB on June 27.*
© K. Fuchs / Fraunhofer IISB

16 *Alexandra Diez, who completed her training as a microtechnologist at the IISB in 2017, was honored by the Nuremberg Chamber of Commerce and Industry (CCI) for her excellent exam results and as the best microtechnology trainee in 2016 / 2017.*
© K. Fuchs / IHK Nürnberg

NAMES AND DATA

GUEST SCIENTISTS

Boteng, Y.
November 7, 2017 - January 10, 2018
China
Tianjin Universität
Modellierung von Defektentstehung in 4H-SiC

Chen, W.
August 10, 2017 - September 9, 2017
China
College of Electronics Engineering
Chongqqing University of Posts and Telecommunications

Ouennoughi, Z.
June - July 2017
Algeria
Université Ferhat Abbas Sétif 1
Investigation of current conduction mechanisms in SiO_2 gate dielectrics on 4H-SiC

Purgat, P.
October 16, 2017 - March 3, 2018
Niederlande
Uni Delft
Modular Power Electronic Transformers for LVDC Distribution Grids

Qiang, W.
January 13 - 31, 2017
China
Shanghai Institute of Microsystem and Information Technology
Chinese Academy of Sciences

Xingzhao, C.
September 9, 2017 - Oktober 10, 2017
China
Tianjin Universität
Einfluss der Al-Konzentration auf die Eigenschaften von 4H-SiC-Kondensatoren

PATENTS (GRANTED IN 2017)

Berberich, S.; Maerz, M.:
Schaltungselement und Verfahren zum Sichern einer Lastschaltung
EP 1 751 797 B1 / DE 50 2005 015 607.2

Berberich, S.; Lorentz, V.; Maerz, M.:
Vorrichtung und Verfahren zum Erfassen eines Stromes in einer Spule
DE 10 2008 044 634 B4

Brunner, D.; Maerz, M.; Schimanek, E.; Schletz, A.:
Leistungselektronikanordnung
DE 50 2007 015 759.7

Burenkov, A.:
Strahlungsquelle und Verfahren zu deren Betrieb
EP 2 956 974 B1 / DE 50 2014 00 40 89.8 / FR 50 2014 00 40 89.8 / GB 50 2014 00 40 89.8 / US 9812642B2

Endres, S.; Zeltner, S.:
Leistungselektronische Schaltung und System mit derselben
DE 50 2014 003 757.9 / EP 2 959 584 B1 / FR EP 2 959 584 B1 / GB EP 2 959 584 B1

Erlbacher, T.; Hürner, A.:
Monolithisch integrierter Halbleiterschalter, insbesondere Leistungstrennschalter
DE 10 2016 207 859 B3

Fischer, R.; Rauh, H.; Vogler, T.:
Radnabenantriebssystem mit integriertem Kühlsystem
DE 10 2011 081 511 B4

Roth, A.; Schletz, A.:
Verfahren zur Erhöhung der thermo-mechanischen Beständigkeit eines Metall-Keramik-Substrats
DE 10 2010 024 520 B4

NAMES AND DATA

PARTICIPATION IN COMMITTEES

Bauer, A.
- Koordinator der ITG-Fachgruppe 8.1.2 und der VDE/VDI-GMM-Fachgruppe 1.2.4 "Heißprozesse und RTP"

Erdmann, A.
- Conference Chair of SPIE Optical Microlithography Conference at SPIE Advanced Lithography Symposium, San Jose, USA, February, 2017
- Member of Editorial Board of Advanced Optical Technologies (De Gruyter journal)
- Program Co-Chair of European Mask and Lithography conference (EMLC), Dresden, GER, June, 2017
- Member of Program Committee of 3rd International DSA Symposium, Chicago, USA, September, 2017

Erlbacher, T.
- Leitung der VDE-GMM Fachgruppe 1.3.2 „Gesamtprozesse für Leistungselektronische Bauelemente"

Friedrich, J.
- Co-Chair of DGKK-Arbeitrskreis "Herstellung und Charakterisierung massiver Halbleiter"
- Counciler in the Executive Committee of the International Organization of Crystal Growth (IOCG)
- Advisory Committee of International Workshop on Crystalline Silicon for Solar Cells
- Advisory Committee of International Workshop on Crystal Growth Technology
- Advisory Committee of 6th European Conference on Crystal Growth
- Reviewer for Journal of Crystal Growth, Applied Physical Letters

Häublein, V.
- Koordinator der ITG-Fachgruppe 8.1.1 und der VDE/VDI-GMM-Fachgruppe 1.2.2 "Ionenimplantation"

Jank, M.
- Associate Editor des Open Access Journals Frontiers in Materials – Translational Materials Science, Frontiers Media S.A.
- VDE/VDI-GMM-Fachgruppe 1.3.3 "Materialien für Nichtflüchtige Speicher"
- Mitglied des Exzellenzclusters EXC315/2 "Engineering of Advanced Materials" der FAU Erlangen-Nürnberg
- Principal Investigator im DFG-Graduiertenkolleg, In situ Microscopy with Electrons, X-rays and Scanning Probes (GRK 1796)
- Mitglied des DFG-Schwerpunktprogramms High Frequency Flexible Bendable Electronics for Wireless Communication Systems (FFlexCom, SPP 1796)
- Arbeitskreis "Printed Electronics Franken"

Kallinger, B.
- Reviewer for physica status solidi – A Journal of Crystal Growth, Materials Science in Semiconductor Processing

Lorenz, J.
- Member of the Steering Committee of the SISPAD series of conferences
- Member of the Program Committee, SISPAD 2017, Kamakura, JPN, September 7 - 9, 2017
- Member of the Technical Program Comittee, ESSDERC 2017, Leuven, BEL, September 14 -17, 2017
- Member of the PENTA Technical Expert Group

Meissner, E.
- Reviewer for Journal of Crystal Growth and Materials Chemistry and Physics, Physica Status Solidi Rapid Research Letters, The Journal of Supercritical Fluids
- Expert Panel Member for the Research Council of Norway

Pfeffer, M.
- Member of the "Factory Integration International Focus Team" (FI IFTs) of the "IEEE International Roadmap for Devices and Systems (IRDS)"
- Member of the "Yield Enhancement International Focus Team" (YE IFTs) of the "IEEE International Roadmap for Devices and Systems (IRDS)"
- Member of Semicon Europe Semiconductor Technology Programs Committee (STC)

Pichler, P.
- Executive Committee of GADEST 2017, Lopota Resort, Georgia, October 1 - 6, 2017
- Scientific Committee of FOR3NANO, Helskinki, FIN, June 28 - 30, 2017

Puls, P.
- Jury-Mitglied für Forschung auf der Konferenz „Innovationsforum Nachhaltige Energiesysteme"

Reimann, C.
- Reviewer for Journal of Crystal Growth, Crystal Research and Technology, Progress in Photovoltaics: Research and Applications, and Journal of Photovoltaics

Roeder, G.
- Koordinator der VDE/VDI-GMM-Fachgruppe 1.2.3 "Abscheide- und Ätzverfahren"

Rommel, M.
- Koordinator der VDE/VDI-GMM-Fachgruppe 1.2.6 "Prozesskontrolle, Inspektion & Analytik"
- International Program Committee der Konferenz MNE 2017 (43rd International Conference on Micro&Nano Engineering 2017)

NAMES AND DATA

CONTINUATION: PARTICIPATION IN COMMITTEES

Schellenberger, M.
- Mitglied im Programmkommitee der europäischen APCM-Konferenz
- Leiter der europäischen SEMI PCS-Taskforce

Schletz, A.
- Reviewer for Microelectronics Reliability Journal
- Member of the ZVEI APG-AK HTE+LE Core Group "Qualifikation von Film-Kondensatoren"

Trempa, M.
- Reviewer for Journal of Crystal Growth

CONFERENCES, WORKSHOPS, FAIRS, AND EXHIBITIONS

5th International Conference Advanced E-Motor Technology 2017
Berlin, GER, February 14 - 16, 2017

6th jDGKK Seminar
Freiburg, GER, March 7 - 8, 2017

7th International Symposium on Development Methodology
Wiesbaden, GER, November 14 - 15, 2017

7th jDGKK Meeting
Freiburg, GER, March 10, 2017

7. ETG-Fachtagung Bauelemente der Leistungselektronik und ihre Anwendungen
Bad Nauheim, GER, April 6 - 7, 2017

VIII International Scientific Colloquium on Modelling for Materials Processing
Riga, Latvia, September 21 - 22, 2017

15th Fraunhofer IISB Lithography Simulation Workshop
Behringersmühle, GER, September 21 - 23, 2017

16. Nutzertreffen der GMM-VDE/VDI-Fachgruppe 1.2.6 "Prozesskontrolle, Inspektion und Analytik"
Munich, GER, March 16, 2017

20. Workshop der GMM-VDE/VDI-Fachgruppe 1.2.3 „Abscheide- und Ätzverfahren"
Erlangen, GER, December 13, 2017

35. CADFEM ANSYS Simulation Conference 2017
Koblenz, GER, November 15 - 17, 2017

41. Nutzertreffen der GMM-VDE/VDI-Fachgruppe 1.2.4 „Heißprozesse und RTP"
Erfurt, GER, March 29, 2017

42. Nutzertreffen der GMM-VDE/VDI-Fachgruppe 1.2.4 „Heißprozesse und RTP"
Itzehoe, GER, November 8, 2017

57. Nutzertreffen der GMM-VDE/VDI-Fachgruppe 1.2.2 „Ionenimplantation"
Erfurt, GER, March 30, 2017

58. Nutzertreffen der GMM-VDE/VDI-Fachgruppe 1.2.2 „Ionenimplantation"
Itzehoe, GER, November 9, 2017

232nd ECS Meeting, The Electrochemical Society
National Harbor, USA, October 1 - 5, 2017

ad3pa 2017, International Workshop on Advanced 3D Patterning
Dresden, GER, October 5 - 6, 2017

ADTC 2017, European Nanoelectronics Applications, Design & Technology Conference and edaWorkshop
Dresden, GER, May 8 - 10, 2017

Anwenderforum Leistungshalbleiter
Munich, GER, Novemberg 7 - 8, 2017

AIChe Annual Meeting 2017
Minneapolis, USA, October 29 - November 3, 2017

apc|m 2017, 17th European advanced process control and manufacturing Conference
Dublin, IRL, April 10 - 12, 2017

NAMES AND DATA

CONTINUATION: CONFERENCES, WORKSHOPS, FAIRS, AND EXHIBITIONS

ASMC 2017, 28th Annual SEMI Advanced Semiconductor Manufacturing Conference
Saragota Springs, USA, May 15 - 18, 2017

BIOSTEC 2017, International Joint Conference on Biomedical Engineering Systems and Technologies
Porto, POR, February 21 - 23, 2017

CLINT-WPE Workshop Cooperation with Japan, Wide Bandgap Lead Applications & Advanced Requirements
Nuremberg, GER, March 7, 2017

CMAME 2017, 5th IEEE International Conference on Mechanical, Automotive and Materials Engineering
Guangzhou, CH, August 1 - 3, 2017

DGKK Arbeitskreis – Massivhalbleiter
Freiberg, GER, October 11 - 12, 2017

DLRK 2017, 66. Deutsche Luft- und Raumfahrtkongress
Munich, GER, September 5 - 7, 2017

ECPE Cluster-Schulung „Anwendertraining zur Wide-Bandgap-Systemintegration“
Nuremberg, GER, July 5 - 6, 2017

ECPE Cluster-Schulung „Messen, Prüfen und Charakterisieren von Leistungshalbleiter-Bauelementen“
Reutlingen, GER, November 22 - 23, 2017

ECPE Cluster-Seminar „Schaltungsträger und Substrattechnologien für die Leistungselektronik“
Nuremberg, GER, June 26 - 27, 2017

ECPE Workshop „Current Measurement for Power Electronics, Applications and in Lab Scale“
Hamburg, GER, October 17 - 18, 2017

EMRS Spring Meeting 2017, European Materials Research Society
Strasbourg, FRA, May 22 - 26, 2017

EMLC 2017, The 33rd European Mask and Lithography Conference
Dresden, GER, June 27 - 28, 2017

emv 2017, Internationale Fachmesse mit Workshops für Elektromagnetische Verträglichkeit
Stuttgart, GER, March 28 - 30, 2017

Energy Storage 2017, Cluster-Treff „Energieeffiziente Prozesse und energieoptimierte Gebäude“
Würzburg, GER, March 23, 2017

EPE’17 ECCE EUROPE, The 19th Conference on Power Electronics and Applications (and Exhibition)
Warsaw, POL, September 11 - 14, 2017

ESK5 2017, 5. Erlanger Symposium über Kristallzüchtung von Halbleitern und optischen Kristallen
Erlangen, GER, January 27, 2017

ESREF 2017, 28th European Symposium on Reliability of Electronic devices, Failure physics and analysis
Bourdeaux, FRA, September 25 - 28, 2017

EU PVSEC 2017, 33rd European PV Solar Energy Conference and Exhibition
Amsterdam, NL, September 25 - 29, 2017

FOR3NANO, Formation of 3D Nanostructures by Ion Beams
Helsinki, FIN, June 28 - 30, 2017

Freiberg Silicon Days
Freiberg, GER, June 7 - 9, 2017

Future Technologies Science Match
Dresden, GER, January 26, 2017

GSCCG-5/DKT 2017, 5th German-Swiss Conference on Crystal Growth
Freiburg, GER, March 8 - 10, 2017

ICAE 2017, International Conference on Advanced Electromaterials
Jeju, KOR, November 21 - 24, 2017

ICDCM 2017, IEEE International Conference on DC Microgrids
Nuremberg, GER, June 27 - 29, 2017

ICEAM 2017, International Congress Engineering of Advanced Materials
Erlangen, GER, October 10 - 12, 2017

ICNS 12, 12th International Conference on Nitride Semiconductors 2017
Strasbourg, FRA, July 24 - 28, 2017

ICSCRM 2017, International Conference on Silicon Carbide and Related Materials
Washington DC, USA, September 17 - 22, 2017

IEEE AFRICON 2017
Cape Town, South Africa, September 20 - 22, 2017

IEEE INTELEC 2017
Queensland, AUS, October 22 - 26, 2017

InnoPlanT.NET Netzwerktreffen „Intelligente Implantate“
Erlangen, GER, February 23, 2017

ITC 2017, 12th International Thin-Film Transistor Conference
Austin, USA, February 23, 2017

IWBNS-X, 10th International Workshop on Bulk Nitride Semiconductors
Espoo, FIN, September 18 - 22, 2017

IWCGT-7, 7th International Workshop on Crystal Growth Technology
Potsdam, GER, July 2 - 6, 2017

Joint Conference of the 7th International Symposium on Physical Sciences in Space (ISPS-7) & 25th European Low Gravity Research Association Biennial Symposium and General Assembly (ELGRA-25)
Juans-les-Pins, FRA, October 2 - 6, 2017

Karrieremesse ORTE
Freiberg, GER, January 12, 2017

Kolloquium zur Halbleitertechnologie und Leistungselektronik
Erlangen, GER, 2017

KRISTALLE! – Schlüsselmaterialien für das 21. Jahrhundert, Sonderausstellung Museum Industriekultur
Nuremberg, GER, February 21 - April 30, 2017

Lange Nacht der Wissenschaften
Erlangen, GER, October 21, 2017

LOPEC 2017, Internationale Fachmesse und Kongress für gedruckte Elektronik
München, GER, March 29 - 30, 2017

NAMES AND DATA

CONTINUATION: CONFERENCES, WORKSHOPS, FAIRS, AND EXHIBITIONS

MC 2017, Microscopy Conference
Lausanne, SUI, August 21 - 25, 2017

Nacht der Wissenschaft und Wirtschaft
Freiberg, GER, June 17, 2017

NEREID, 2nd General Workshop on NanoElectronics Roadmap for Europe: Identification and Dissemination
Athen, GRC, April 6 - 7, 2017

NIL Industrial Day 2017
Berlin, GER, May 2 - 3, 2017

Nutzertreffen der GMM-VDE/VDI-Fachgruppe 1.2.3 „Abscheide- und Ätzverfahren“
Erlangen, GER, December 12, 2017

PCIM Asia 2017, International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management
Shanghai, CH, June 27 - 29, 2017

PCIM Europe 2017, International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management
Nuremberg, GER, May 16 - 18, 2017

PRN 2017, 4th International Conference on Polymer Replication on Nanoscale
Aachen, GER, May 8-9, 2017

Productronica 2017
München, November 14.-17, 2017

P-Seminar „Kristallzüchtung“ der Bertolt-Brecht-Schule Nürnberg
Nuremberg, GER, 2017

P-Seminar Schulwettbewerb „Wer züchtet den schönsten Kristall?“ des Gymnasiums Eckental
Nuremberg, GER, 2017

Pupils’ excursion, Emil-von-Behring Gymnasium Erlangen-Spardorf
Erlangen, GER, July 24, 2017

SEMICON Europa 2017, Internationale Fachmesse für Halbleitertechnik
Munich, GER, November 14 - 17, 2017

SEMICON Taiwan 2017
Taipei, Taiwan, September 13 - 15, 2017

Sensors Day 2017
Cambridge, GB, October 20, 2017

SILICON PV 2017, 7th International Conference on Crystalline Silicon Photovoltaics
Freiburg, GER, April 3 - 5, 2017

SISPAD 2017, International Conference on Simulation of Semiconductor Processes and Devices
Kamakura, JPN, September 7 - 9, 2017

SPEC 2017, 3rd Annual Southern Hemisphere Power Electronics Conference
Puerto Varas, Chile, December 4 - 7, 2017

SPIE Advanced Lithography
San Jose, USA, February 26 - March 2, 2017

TOLAE 2017, Industrial Workshop on Thin, Organic and Large Area Electronics Technologies
Dresden, GER, October 24, 2017

UPEC 2017, 52nd International Universities Power Engineering Conference
Heraklion, GRC, August 28 - 31, 2017

WiPDA 2017, IEEE 5th Workshop on Wide Bandgap Power Devices and Applications
Albuquerque, USA, October 30 - November 1, 2017

WOST 2017, 14. Weimarer Optimierungs- und Stochastiktage
Weimar, GER, June 1 - 2, 2017

NAMES AND DATA

PUBLICATIONS

Albrecht, M.; Huerner, A.; Erlbacher, T.; Bauer, A. J.; Frey, L.:
Experimental Verification of a Self-Triggered Solid-State Circuit Breaker Based on a SiC BIFET
Materials Science Forum Vol, 897, 2017, pp. 665
DOI: 10.4028/www.scientific.net/MSF.897.665

Albrecht, M.; Huerner, A.; Erlbacher, T.; Bauer, A. J.; Frey, L.:
Monolithically Integrated Solid-State-Circuit-Breaker for High Power Applications
Materials Science Forum, Vol. 897, 2017, pp. 661 - 664
DOI: 10.4028/www.scientific.net/MSF.897.661

Bayer, C., Römelsberger, C.:
Entwicklung neuartiger Leistungsmodule, Extraktion elektrischer Parasiten bei Leistungsmodulen mit ANSYS Q3D
Proceedings of CADFEM ANSYS Simulation Conference, Koblenz, November 2017

Belitz, R.; Meisner, P.; Coeler, M.; Wunderwald, U.; Friedrich, J.; Zosel, J.; Schelter, M.; Jachalke, S.; Mehner, E.:
Waste Heat Energy Harvesting by use of $BaTiO_3$ for Pyroelectric Hydrogen Generation
Energy Harvesting and Systems: Materials, Mechanisms, Circuits and Storage, Band 4, Heft 3, 2017, pp. 107 - 113
DOI: 10.1515/ehs-2016-0009

Benedetto Di, L.; Licciardo, G. D.; Erlbacher, T.; Bauer, A. J.; Rubino, A.:
Novel Advanced Analytical Design Tool for 4H-SiC VDMOSFET Devices
Materials Science Forum Vol. 897, 2017, pp. 529 - 532
DOI: 10.4028/www.scientific.net/MSF.897.529

Biasio De, M.; Kraft, M.; Geier, E.; Goller, B.; Bergmann, Ch.; Esteve, R.; Cerezuela-Barreto, M.; Lewke, D.; Schellenberger, M.; Roesner, M.:
Raman Micro-Spectroscopy as a non-destructive key Analysis Tool in Current Power Semiconductor Manufacturing
Proceedings of SPIE Vol. 10210
DOI: 10.1117/12.2259927

Coumont, M.; Hermanns, K.; Lukaschik, A.; Griepentrog, G.; Hanson, J.:
Influence of Modulation and Voltage Balancing on Spectral Emission of the Modular Multilevel Converter
Proceedings of UPEC 2017, 52nd International Universities Power Engineering Conference, Heraklion, GRC, August 28 - 31, 2017
DOI: 10.1109/UPEC.2017.8231862

Derby, J. J.; Tao, Y.; Reimann, C.; Friedrich, J.; Jauß, T.; Sorgenfrei, T.; Cröll, A.:
A quantitative model with new scaling for silicon carbide particle engulfment during silicon crystal growth
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Hürner, A.:
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Tobisch, A.:
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Al-Naimi, A.:
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Becker, L.:
Entwicklung eines Schlickers zur Herstellung von dichten TaC-Schichten zur Beschichtung von Innenaufbauten in der AlN-Kristallzüchtung

Bodensteiner, F.:
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Cheng, C.:
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NAMES AND DATA

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Wick, D.:
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