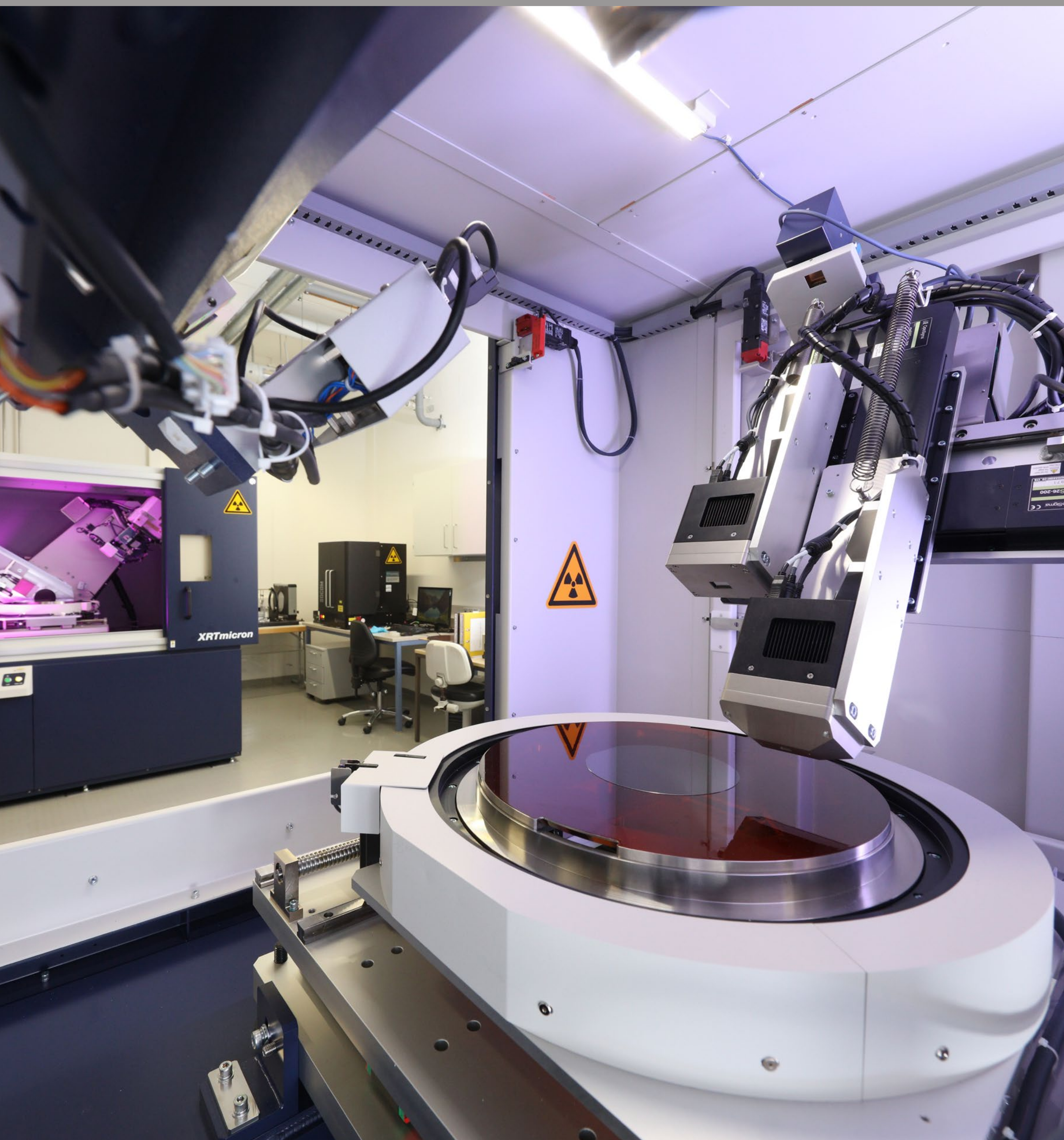
Fraunhofer IISB

FRAUNHOFER INSTITUTE FOR INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB



Fraunhofer Institute for Integrated Systems and Device Technology IISB Annual Report 2021

ANNUAL REPORT 2021

Imprint

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Cover Photo:
Unique for a research institution: Fraunhofer IISB operates a 200 mm capable AIXTRON Epitaxial Planetary Reactor. The system, which is located in one of Fraunhofer IISB's clean rooms, is used to deposit epitaxial layers on 150 mm and 200 mm substrates, especially silicon carbide.
© Kurt Fuchs / Fraunhofer IISB

Backside Photo:
In the Center of Expertise for X-ray Topography at Fraunhofer IISB, crystallographic defects on wafer scale, non-destructively, with high measurement speed and highest spatial resolution are investigated using different types of XRTmicron systems made by Rigaku Corporation.
© Kurt Fuchs / Fraunhofer IISB

ACHIEVEMENTS AND RESULTS

ANNUAL REPORT 2021

FRAUNHOFER INSTITUTE FOR

INTEGRATED SYSTEMS AND DEVICE TECHNOLOGY IISB

Director:
Prof. Dr.-Ing. Jörg Schulze

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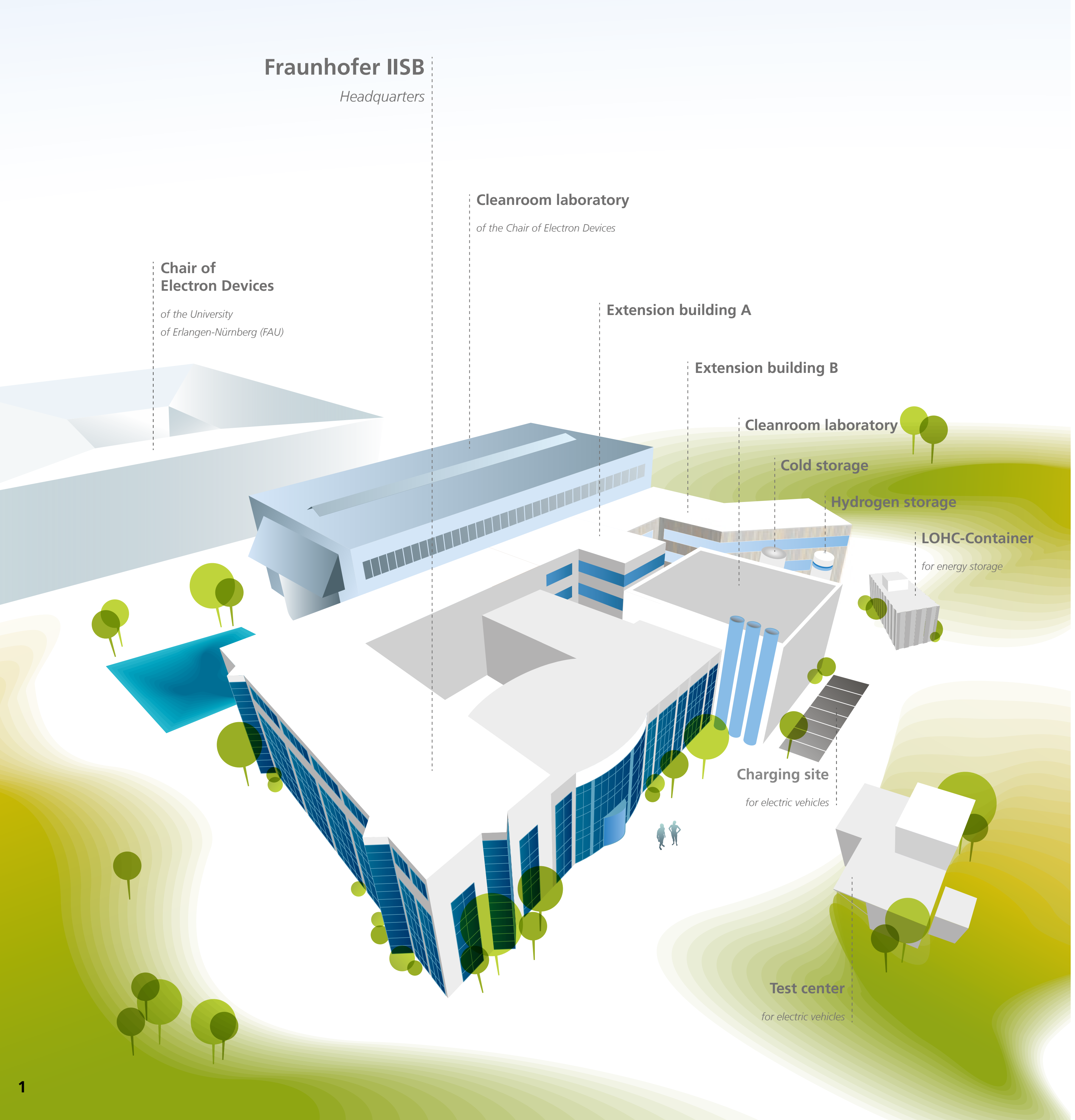
Web: www.iisb.fraunhofer.de

PREFACE



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Still under the impression of ongoing challenges and constraints in global crises that affect us all, 2021 turned out to be a once again very successful year for Fraunhofer IISB, with new topics, possibilities, and prospects. In this sense, I am very happy to address my first annual report preface to you as the new director of this fascinating research institute.

Fraunhofer IISB of course will continue to be the outstanding competence center for intelligent power electronic systems and technologies in Europe. We will expand our real-world lab for energy technology as well as our unique development and transfer platform for silicon carbide materials and devices. Based on accomplished pioneering work, we will increasingly pursue other wide-bandgap systems such as aluminum nitride and gallium oxide and proceed in our promising activities in silicon carbide-based quantum technologies. Thus, we are developing the IISB into the European center of knowledge for (ultra-)wide-bandgap power semiconductor materials and technologies in close cooperation with our partners. This also includes the strategic collaboration with companies within our well-proven framework of joint labs, e.g., on silicon carbide epitaxy or X-ray topography.

Although almost forgotten against the backdrop of the COVID pandemic, the striving for climate neutrality keeps being one of the biggest tasks of both humanity and science. Fraunhofer wants to prominently move forward here, and the IISB can profoundly contribute with its huge experience in complex energy systems comprising a multitude of diverse, smartly interacting components. This is underlined, among others, by our extended activities in hydrogen systems, considerable progress in aluminum-ion batteries, intelligent operational strategies in sector-coupled energy systems, or the completion of the Fraunhofer flagship project Towards Zero Power Electronics (ZEPOWEL), with the IISB having developed extremely efficient power converters based on wide-bandgap devices.

Starting here in September, I was handed over a very stable, flourishing, and renowned institute. I would like to thank Prof. Martin März, who took the lead as acting director for three years, and the whole IISB team for their great work and the warm welcome. I also thank our partners in industry and all our funding authorities, especially the Bavarian Ministry of Economic Affairs, Regional Development and Energy as well as the German Federal Ministry of Education and Research for their lasting support.

Now, I warmly encourage you to read more about the latest work of Fraunhofer IISB presented in this annual report. Let yourselves be inspired!

Sincerely yours,
Prof. Dr. Jörg Schulze (Erlangen, January 2021)

1 *Schematic overview of the Fraunhofer IISB headquarters in Erlangen. © Anja Grabinger / Fraunhofer IISB*

2 *Prof. Dr.-Ing. Jörg Schulze, director of Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

TABLE OF CONTENTS

AT A GLANCE

Profile
History
Advisory Bord 2021

PROFILE

Intelligent Power Electronic Systems and Technologies - according to this motto, the Fraunhofer Institute for Integrated Systems and Device Technology IISB conducts applied research and development for the benefit of industry and society. With scientific expertise and comprehensive systems know-how, the IISB supports customers and partners worldwide in transferring current research results into competitive products, for example for electric vehicles, aviation, production, and energy supply.

The institute consolidates its activities in the two major business areas of Power Electronic Systems and Semiconductors. In doing so, it comprehensively covers the entire value chain from basic materials to semiconductor device, process, and module technologies to complete electronics and energy systems. As a unique European competence center for the semiconductor material silicon carbide (SiC), the IISB is a pioneer in the development of highly efficient power electronics even for the most extreme requirements. With its solutions, the IISB repeatedly sets benchmarks in energy efficiency and performance. By integrating intelligent data-based functionalities, new use cases are continuously emerging.

The IISB currently employs about 300 people. Its headquarters are in Erlangen, with additional branches at the Energie Campus Nürnberg (EnCN) and the Fraunhofer Technology Center High Performance Materials (THM) in Freiberg. In joint projects and associations, the IISB collaborates with numerous national and international partners.

HISTORY

Fraunhofer IISB, rooted in the Nuremberg metropolitan region, 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 affiliate institute IIS-A, today's Fraunhofer Institute for Integrated Circuits IIS. In 2003, the IIS and the IISB became completely independent from each other.

From 1985 until 2008, Prof. Heiner Ryssel headed the IISB, from 2008 to 2018, Prof. Lothar Frey, and between 2018 and 2021 Prof. Martin März. Since September 1, 2021, Prof. Jörg Schulze is the institute's director. The Institute has always fostered a close scientific relationship with the University of Erlangen-Nürnberg (FAU). In 2015, together with the IIS and the FAU, "Leistungszentrum Elektroniksysteme" (LZE) was founded.

ADVISORY BORD 2021

Dr. Stefan Kampmann (Chairman of the Advisory Board)
Voith Group

Dr. Helmut Gassel
Infineon Technologies

Prof. Dr. Ulrike Grossner
ETH Zürich, Professur für Leistungshalbleiter

Dr. Christina Hack
Brose Fahrzeugteile

Thomas Harder
European Center for Power Electronics (ECPE)

Prof. Dr. Joachim Hornegger
Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

Dr. Gabriel Kittler
X-Fab Global Services

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

Dr. Andreas Mühe
PVA TePla

Dr. Martin Schrems
i-conel

Dr. Thomas Stockmeier
ams AG

Ltd. MR Dr. Stefan Wimbauer
Bavarian Ministry of Economic Affairs, Regional Development and Energy

AT A GLANCE

Organizational Chart 2021
Operating Budget
Staff Development

ORGANIZATIONAL CHART 2021

DIRECTOR
J. Schulze

STRAT. INITIATIVES
B. Fischer

STRAT. MARKETING
S. Flack

ADMINISTRATION
H. Hermes

INFRASTRUCTURE
N. Kandziora

IT
G. Ardelean

DIVISION SEMICONDUCTOR TECHNOLOGY
J. Schulze

DIVISION POWER ELECTRONICS
M. März

MATERIALS – J. Friedrich
- SILICON & SPECIAL MATERIALS – C. Reimann
- SILICON CARBIDE & RELATED MATERIALS – P. Berwian
- NITRIDE MATERIALS – E. Meißner
- BATTERY MATERIALS – U. Wunderwald
- SPECTROSCOPY & TEST DEVICES – F. Beyer
- EQUIPMENT & DEFECT SIMULATION – C. Kranert

MODELING & ARTIFICIAL INTELLIGENCE – J. Lorenz
- TCAD – P. Pichler, E. Bär
- LITHOGRAPHY & OPTICS – A. Erdmann
- AI-AUGMENTED SIMULATION – A. Roßkopf

SEMICONDUCTOR DEVICES – A. Schletz, T. Erlbacher
- SiC CIRCUITS & CHARACTERIZATION – M. Rommel
- DEVICE DEVELOPMENT – T. Erlbacher
- PRODUCTION MANAGEMENT – M. Kocher
- PROCESS DEVELOPMENT – O. Rusch
- DEPOSITION & PATTERNING – S. Oertel, V. Häublein
- IMPLANTATION & HOT PROCESSES – V. Häublein
- CLEANROOM INFRASTRUCTURE – T. Dirnecker (act.)

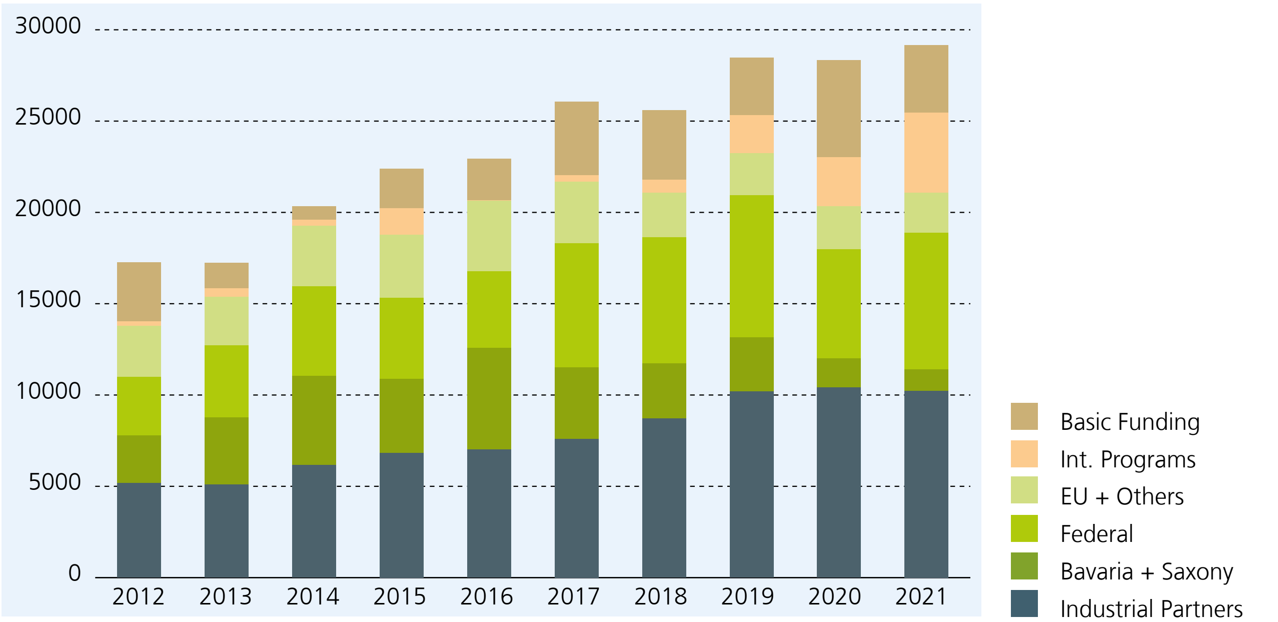
HYBRID INTEGRATION – A. Schletz
- ADVANCED POWER MODULES – H. Rauh
- FUNCTIONAL MATERIAL SYSTEMS – M. Jank
- TEST & RELIABILITY – J. Leib

VEHICLE ELECTRONICS – B. Eckardt
- DRIVES & MECHATRONICS – M. Hofmann
- AC/DC CONVERTERS – S. Zeltner
- DC/DC CONVERTERS – S. Matlok
- RF POWER ELECTRONICS & EMC – S. Ditze
- GRID INTERFACES – S. Endres
- AVIATION ELECTRONICS – F. Hilpert
- MEDIUM VOLTAGE ELECTRONICS – T. Heckel

INTELLIGENT ENERGY SYSTEMS – V. Lorentz
- INDUSTRIAL POWER ELECTRONICS – M. Billmann
- BATTERY SYSTEMS – R. Schwarz, M. Wenger
- DC GRIDS – B. Wunder
- ENERGY TECHNOLOGIES – R. Öchsner
- DATA ANALYTICS – M. Schellenberger

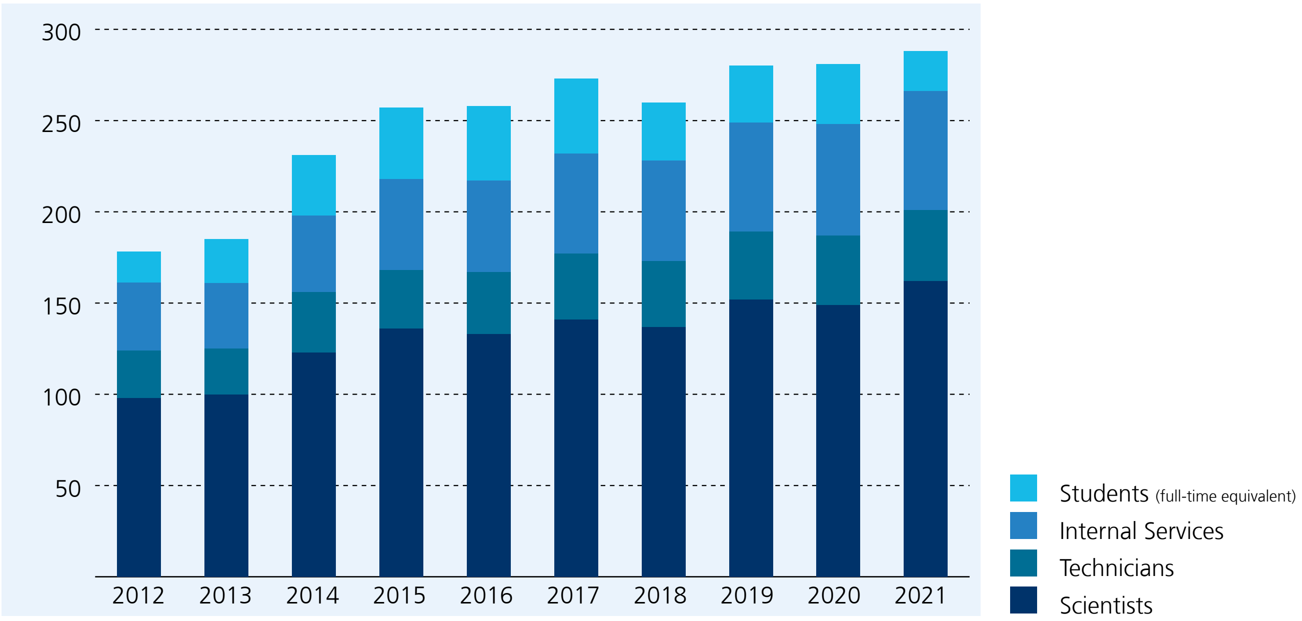
OPERATING BUDGET

28.32 Mio. € in 2021



STAFF DEVELOPMENT

281 Employees in 2021



THE POWER ELECTRONICS INSTITUTE

Division Semiconductor Technology
Modeling & Artificial Intelligence
Materials

DIVISION SEMICONDUCTOR TECHNOLOGY

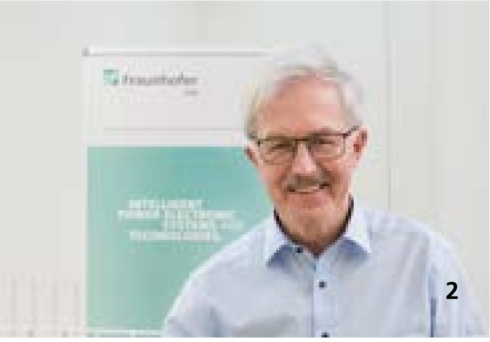
„With its comprehensive competencies, flexibility, and unique infrastructure, Fraunhofer IISB is the technology and transfer platform no. 1 for silicon carbide devices in Europe. Additionally reinforcing our pioneering activities on, e.g., aluminum nitride in a strong and collaborative R&D network, we are developing our institute into the European knowledge hub for (ultra-)wide-bandgap power semiconductor materials and technologies."

Prof. Jörg Schulze

Fraunhofer IISB is the designated competence center and direct contact point for semiconductor materials and technologies for power electronics within Fraunhofer and the Research Fab Microelectronics Germany (FMD). The industry-compatible silicon carbide technology line and prototyping fab of the IISB are unique in Europe, providing easy access especially for small and medium-sized enterprises that depend on such key technologies for generating competitive products. Activities at the institute range from the development of crystalline and other functional materials, device and processing technologies on silicon and silicon carbide to heterogeneous integration, packaging and innovative power modules. This is supported by test and reliability studies, manufacturing optimization, and extensive capabilities in characterization as well as modeling and artificial intelligence. The spectrum comprises not only high-voltage or high-temperature power electronic devices and circuits but also sensors, thin-film, and even silicon carbide based quantum technologies. The technology developments of the IISB benefit from our deep understanding of applications and systems.

1 *Prof. Dr.-Ing. Jörg Schulze, director of Fraunhofer IISB, head of Semiconductor Technology division and Chair of Electron Devices. © Kurt Fuchs / Fraunhofer IISB*

MODELING & ARTIFICIAL INTELLIGENCE



"Nowadays, simulation is indispensable for the development of microelectronics, nanoelectronics, and power electronics. The work of our department is based on physical understanding and on the application of artificial intelligence, and ranges from equipment and processes to devices, circuits and electronic systems."

Dr. Jürgen Lorenz

The department continues to combine the development of simulation capabilities with their application to technological challenges within the institute or with external partners: Application knowledge is essential to guide tool development in terms of priorities and relevant effects. Our expertise in the capabilities and limitations of the physical models and algorithms used is fundamental to the efficient and reliable application of simulation.

Our work benefits from decades of experience in Technology Computer-Aided Design TCAD and a broad cooperation with highly qualified partners all over Europe, among others in European projects coordinated by us. This solid foundation also allows us to embark on new simulation approaches such as physics-informed artificial intelligence or new promising application areas such as supporting the development of quantum computing or its use for optimization tasks. Among others, the department supports the development of silicon carbide devices at the IISB, the development and application of quantum computing in the Munich Quantum Valley initiative, and the industrial development of EUV lithography at the European level.

2 *Dr.-Ing. Jürgen Lorenz, head of Modeling & Artificial Intelligence department. © Amelie Schardt / Fraunhofer IISB*

MATERIALS

"The R&D activities of the IISB cover the complete value chain for complex and intelligent electronic systems, from basic materials to devices and modules all the way to complete systems for application in mobility and energy technologies, with power electronics being a consistent backbone of the institute."

Dr. Jochen Friedrich

We support material, device and equipment manufacturers as well as their suppliers with scientific-technological solutions in the field of production and characterization of crystals, epitaxial layers, and devices. We improve the material quality and reduce the production cost. We identify defects harmful for device performance and reliability and look for solutions to avoid them. We develop technologies for new materials, and tailor the material properties for new applications.

Our focus is on semiconductors for power electronics, communication electronics, sensors & detectors, and quantum technologies. Our strategy is to optimize manufacturing processes through a combination of experimental process analysis, tailored characterization techniques and numerical modeling. For that purpose, we have a well-suited infrastructure consisting of R&D furnaces and epitaxial reactors, state-of-the-art metrology tools for investigating the physical, chemical, electrical and structural material properties, and powerful simulation programs for heat and mass transport calculations.

3 *Dr.-Ing. Jochen Friedrich, head of Materials department. © Amelie Schardt / Fraunhofer IISB*

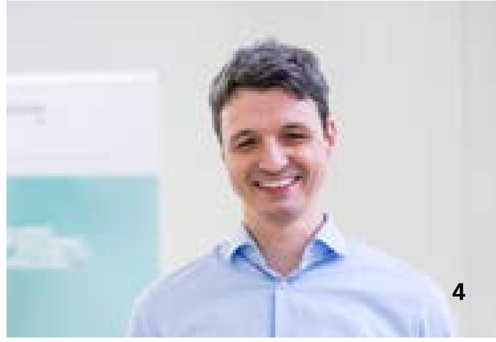
THE POWER ELECTRONICS INSTITUTE

Semiconductor Devices
Hybrid Integration

SEMICONDUCTOR DEVICES

"We are bridging the gap from material to application – with silicon carbide as the semiconductor material for the future. The IISB has deep know-how in design, process development and processing. Extensive tools and highly qualified staff make the IISB unique worldwide in the fields of SiC power, SiC sensor and SiC CMOS devices."

Dr. Tobias Erlbacher



4 *Priv.-Doz. Dr.-Ing. Tobias Erlbacher, head of Semiconductor Devices department.*
© Amelie Schardt / Fraunhofer IISB

The Semiconductor Devices department is focused on three main topics: device design, process development and manufacturing. Our aim is to help our customers to proof new design concepts with the clear option to produce a small series production afterwards. The prototype devices make it possible to prove the robustness of concepts and processes as well as to test their reliability and application conditions in order to achieve market acceptance. Especially small and medium-sized companies gain access to semiconductor technology. The IISB closes the gap from single samples up to the volume of industrially operated foundries. Our department addresses versatile markets like power, sensors, and CMOS.

The semiconductor material took a big step toward silicon carbide (SiC) in terms of wafer starts. Silicon (Si) still plays a role at the IISB and will be continued. One highlight is the new development towards higher temperatures around 300 °C. The department started developments for high temperature CMOS on SiC. Applications for this technology include integrated circuits beyond silicon for extremely harsh environments, including high temperatures and radiation levels with low leakage. Additionally, the technology can be tailored to obtain specialized optical SiC devices. Examples are power module integrated gate drives or signal conditioning for sensors in high temperature environment. Our goal is to have a reliable offering on the europractice platform starting with an early access prototype. In addition, the package contains compact models and application notes for a design kit.

For small volume production, our customers need a robust technology together with predictable lead times. The project SiC4KMU (within Leistungszentrum Elektroniksysteme LZE) has been started to address this need especially for small and medium-sized companies. Our 150 mm SiC and Si pilot line covered by our brand "π-fab" has now reached a higher level of technological readiness, which will be further raised in the future. Our manufacturing execution system was developed into a professional tool, that enables cooperation within the Forschungsfabrik Mikroelektronik Deutschland (FMD) community. Together with our process development for SiC we are now able to predict fab out dates, enabling on-time manufacturing.

HYBRID INTEGRATION

„Hybrid Integration acts as a bridge between the Semiconductor Technology and the application-oriented Power Electronics divisions. Sensor, signal and power electronics packaging is our focus. Concepts, technologies, testing and reliability modeling are our perfectly vertically integrated know-how."

Andreas Schletz

5 *Andreas Schletz, head of Hybrid Integration department.*
© Amelie Schardt / Fraunhofer IISB

In 2021, there was a bigger restructuring in our department that affected all working groups. The new lineup sharpens the thematic orientation of the groups and addresses promising future research goals and customer-oriented services. In order to visualize the changed topics, the name of the department was changed from "Devices and Reliability" to "Hybrid Integration".

The new working group "Innovative Power Modules" headed by Dr. Hubert Rauh now focuses on packaging concepts. That covers power modules with high switching performance as well as high current capability, enabled by enhanced electrical, thermal as well as thermo-mechanical design. The powerful packaging lab offers prototyping at high technology readiness levels up to small volume manufacturing for system demonstrators. The excellent link to the in-house power electronic system departments keeps research on track for application. On the other hand, the internal customer has good access to customized solutions.

The next big topic will be packaging concepts for cryogenic power electronics. We welcome Dr. Michael Jank, who heads the new working group "Functional Material Systems". He and his team were formerly located in the "Technology and Manufacturing" department and have now joined our department. This transition supports their current research topics "smart sensors" and "thin-film technologies" by giving them direct access to and responsibility for the corresponding hybrid interconnection and packaging technologies. From now on, the work field is completed by power electronic packaging technologies. This includes all activities on corrosion and coating topics and the joint labs with SST Palomar for soldering and Boschman for sintering processes. Dr. Jank is also deputy head of the department and responsible for scientific excellence.

Furthermore, we are pleased that Dr. Jürgen Leib has taken over the "Test and Reliability" working group, which was previously managed by Andreas Schletz on a temporary basis. The research topics will continue to be power electronic testing, especially automotive qualification as well as the thermo-mechanic lifetime simulation. The latter had a big breakthrough in predicting test parameters to save expensive test time through a digital twin approach. This will be an important focus in the future.

THE POWER ELECTRONICS INSTITUTE

Division Power Electronic Systems
Vehicle Electronics
Intelligent Energy Systems

DIVISION POWER ELECTRONIC SYSTEMS

„Sustainability in energy supply and mobility is a key in meeting the imminent environmental and economic challenges our society is facing. Innovative solutions require fresh thinking, leaving beaten tracks, and a comprehensive view of the overall system. This is exactly the mission and motivation behind the research work at Fraunhofer IISB on intelligent power electronics and energy systems."

Prof. Martin März

6 *Prof. Dr.-Ing. Martin März, head of Power Electronic Systems division and Chair of Power Electronics. © Amelie Schardt / Fraunhofer IISB*

Looking back on 2021, some impactful research developments can be identified, such as the "more electric" or "all-electric" approach in aircraft technology. This electrification requires groundbreaking innovations in power electronics, especially with regard to safety, robustness, availability, service life, weight and power density.

We have also expanded our research activities in the area of DC grids to develop energy management and protection components in such grids. A third important field of research is cognitive power electronics, i.e., power converters that are able to generate maximum information about their environment – whether it is monitoring the stability of grids or the condition of systems and machines.

VEHICLE ELECTRONICS

„For advanced next-generation electric mobility, wide-bandgap semiconductors are the enabling technology. Smaller, more efficient power electronics and drives are the key for new mobility applications. By this, mobility will be the lead application for wide-bandgap semiconductors in the coming years."

Dr. Bernd Eckardt

7 *Dr.-Ing. Bernd Eckardt, head of Vehicle Electronics department. © Anja Grabinger / Fraunhofer IISB*

The focus of the vehicle electronics department is to bring new semiconductor technologies, advanced power electronic concepts and control strategies into mobile applications. To achieve this, the Vehicle Electronics department has a wide range of know-how, gathered in more than 20 years of continuous development.

We are realizing advanced power modules with very low parasitic inductance and completely new cooling solutions and many parallel SiC or GaN devices to tackle the challenge of high-power applications up to megawatt scale. These modules are integrated into advanced mechatronic solutions for small size, low weight, and high mechanical robustness to provide the most advanced technology for the bench or test vehicle integration. The prototype systems with outstanding power density and efficiency enable our partners to develop and evaluate the next generations of powertrains for passenger cars, trucks, ships, and trains.

The extremely increased power densities allow complete new powertrains, like on full electric aircrafts with new challenging requirements. To cover all these applications, power electronic solutions of 1 kW up to 10 MW and up to 20 kV can be tested at the power electronic labs and test benches of the department.

INTELLIGENT ENERGY SYSTEMS

„Our department develops and integrates innovative hardware and software solutions for the digitalization of electrical energy storage and conversion. We address mobile applications like automotive, airborne and waterborne as well as stationary applications in industry and renewables."

Dr. Vincent Lorentz

8 *Dr.-Ing. Vincent Lorentz, head of Intelligent Energy Systems department. © Anja Grabinger / Fraunhofer IISB*

The Intelligent Energy Systems department at Fraunhofer IISB develops advanced technologies and electronic solutions for the digitalization of energy storage and power conversion systems in mobile and stationary applications, thus building our Cognitive Power Electronics (CPE) ecosystem that covers the entire power range from a few milliwatts up to several gigawatts.

We integrate innovative data analytic technologies into our solutions that enable smart diagnostics and monitoring functions. This works for our cutting-edge electronic power converters, our high-performance battery as well as hydrogen systems, including our disruptive open-source battery and fuel-cell management system foxBMS®.

Our research and development efforts focus on power and control electronic hardware and software algorithm as well as data processing technologies – using the latest developments in artificial intelligence – to detect anomalies in energy conversion systems and management systems targeting the transportation and energy domains.

LOCATIONS AND NETWORK

Headquarters of Fraunhofer IISB, Erlangen
Technology Center for High-Performance Materials THM, Freiberg
Cooperations

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 10,000 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, a medium-voltage application hall, an application center for DC grid technology, 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.

TECHNOLOGY CENTER FOR HIGH-PERFORMANCE MATERIALS THM, FREIBERG

Am St.-Niclas-Schacht 13, 09599 Freiberg

High-performance materials such as semiconductors and energy materials are fundamental to solving the major challenges of the future: intelligent mobility, Industry 4.0, the energy transition or the Internet of Things. Both the development of new, high-performance materials and the associated efficient manufacturing processes play a major role here, as well as a sustainable recycling economy that enables the economic recovery of valuable materials. The Fraunhofer THM is a partner of companies within the framework of industrial contracts and publicly funded projects in the production, application and recycling of semiconductor and energy materials.

Supported by the Free State of Saxony, the Fraunhofer THM is a research and transfer platform of the Fraunhofer Institute for Integrated Systems and Device Technology IISB and the Fraunhofer Institute for Ceramic Technologies and Systems IKTS. Together, semiconductor and energy materials are transferred into new applications and at the same time, future material recycling is considered and developed.

COOPERATIONS

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

- Since its foundation, the IISB has been closely cooperating with the University of Erlangen-Nürnberg (FAU), especially the Chairs of Electron Devices and Power Electronics. The joint operation of infrastructure as well as the exchange in education and training create extensive synergies.
- The IISB is in close cooperation with the Technical University TU Bergakademie Freiberg in the area of semiconductor materials.
- The IISB is a core member of the "Leistungszentrum Elektroniksysteme" (LZE, www.lze.bayern).
- The IISB is a member of the "Energie Campus Nürnberg" (EnCN, www.encn.de).
- 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 Growth Association DGKK e.V.
- The IISB is a close partner of the "Förderkreis für die Mikroelektronik e.V."
- The IISB is a member of several associations regarding hydrogen research (h2b, hy+, cluster mobility and logistics, Fraunhofer Netzwerk Wasserstoff).

Consortial Projects

- The IISB is partner of the excellence projects at the University of Erlangen-Nürnberg (www.eam.uni-erlangen.de, www.aot.uni-erlangen.de/saot/).
- The IISB is the coordinator and partner, numerous European research projects, such as MUNDFAB, a Horizon 2020 project (https://www.mundfab.eu).

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 Research Fab Microelectronics Germany (FMD, https://www.forschungsfabrik-mikroelektronik.de)
- Fraunhofer Nanotechnology Alliance (www.nano.fraunhofer.de)

1 *The THM Freiberg supports industry in the development of semiconductor and energy materials for intelligent mobility, Industry 4.0, the energy transition or the Internet of Things (IoT). The IISB part of the THM comprises 650 m^2. © Kurt Fuchs / Fraunhofer IISB*

THE UNIVERSITY OF ERLANGEN-NÜRNBERG

Chair of Electron Devices (LEB)
Chair of Power Electronics (LEE)
Academic Teaching

1 *Chair of Electron Devices of the University of Erlangen-Nürnberg: main building (left) and clean room laboratory (right). © Thomas Richter / LEB*

CHAIR OF ELECTRON DEVICES (LEB)

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

Within the framework of a cooperation agreement, the two institutions not only jointly operate the University's cleanroom facility 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. Since many years, the vocational training as a "microtechnologist" has been offered jointly by the IISB and the Chair of Electron Devices. Employees of the IISB assist in courses and internships at the University.

www.leb.tf.fau.de

CHAIR OF POWER ELECTRONICS (LEE)

The Chair of Power Electronics (German abbreviation: LEE) is headed by Prof. Martin März. It conducts research on current topics in the field of power electronics for electric power supply. Besides stationary decentralized electrical power systems, the addressed application fields also include the power-grids in vehicles, ships, railways, and airplanes. The LEE is part of the Energie Campus Nürnberg (EnCN) in the Fürther Strasse in Nuremberg, and the first chair grown out of the EnCN.

www.lee.tf.fau.de

FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

ACADEMIC TEACHING

Staff members of Fraunhofer IISB regularly give lectures at the university:

Dr. Bernd Eckardt
- Electrical Energy Storage Systems

Dr. Andreas Erdmann
- Optical Lithography

Dr. Tobias Erlbacher
- Process Integration and Device Architecture
- Integrated Circuits Technology
- Power Semiconductor Devices

Dr. Michael Jank
- Nanoelectronics
- Printed Electronics

Dr. Jürgen Lorenz
- Process and Device Simulation

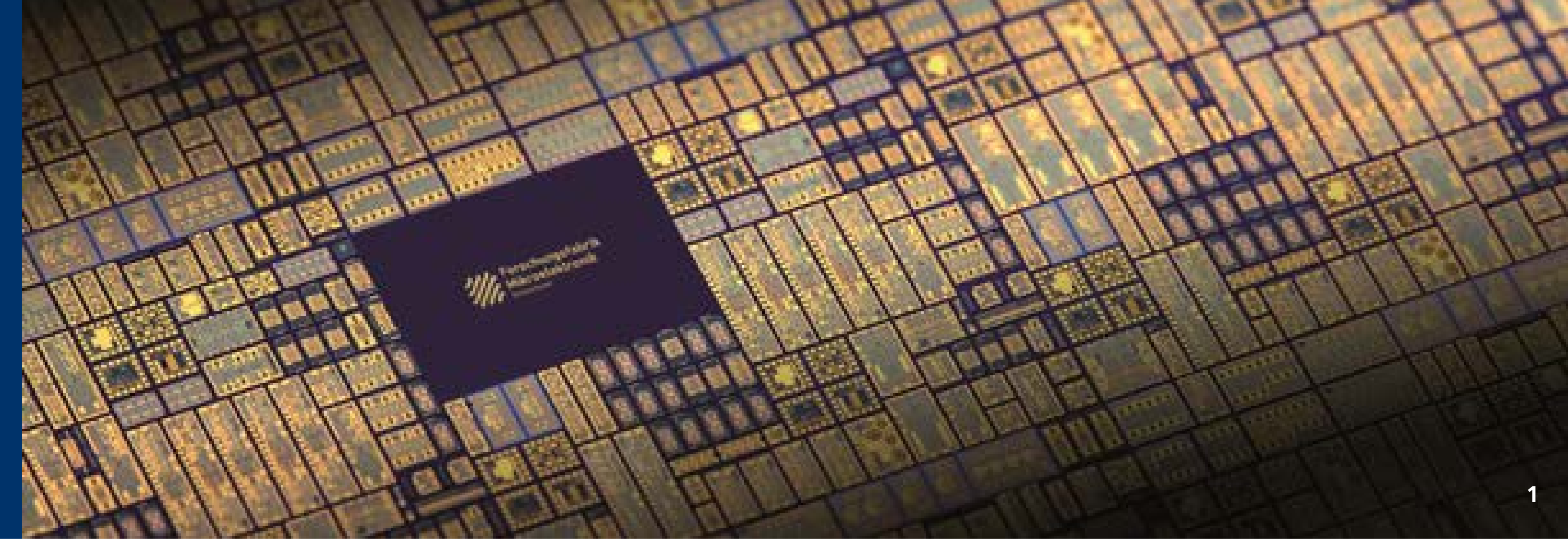
Prof. Dr. Martin März
- Power Electronics
- Power Electronics Colloquium
- Power Electronics in Vehicles and Powertrain
- Electrical Power Enigeering
- Advanced Power Electronics Topics
- Power Electronics for Decentralized Energy Supply - DC grids
- Thermal Management in Power Electronics
- Energy Electronics
- Electrical Engineering

Prof. Dr. Roland Nagy
- Quantum Technologies

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

THE RESEARCH FAB MICROELECTRONICS GERMANY

The Central Partner for Business and Science, Politics and Society



1 *Within the framework of the FMD, eleven institutes of the Fraunhofer Group for Microelectronics and the two Leibniz Institutes FBH and IHP have been pooling their expertise in order to achieve and expand a new quality in the research, development and (pilot) production of semi-conductor-based micro- and nanosystems.*
© Fraunhofer Group for Microelektronics

THE CENTRAL PARTNER FOR BUSINESS AND SCIENCE, POLITICS AND SOCIETY

Since 2017, Fraunhofer IISB, together with another ten institutes of the Fraunhofer Group for Microelectronics and the two institutes FBH and IHP of the Leibniz Association, has formed the cross-site Research Fab Microelectronics Germany, or FMD for short.

For the first time, 13 institutes from the two research organizations, Fraunhofer and Leibniz, are combining their expertise under one virtual umbrella, thus creating a new quality to the research and development of micro- and nanosystems. With more than 2,000 scientists, the FMD is one the world's largest R&D network of its kind. With its unique diversity of expertise and infrastructure at the institutes, it is helping Germany and Europe to further expand their leading position in research and development.

Transition to Regular Operation

Until the end of 2020, the FMD was in its start-up phase. The extensive investments of the Federal Ministry of Education and Research (BMBF) in the modernization of the institute´s infrastructure could be completed by the end of 2020 resp. beginning of 2021.

At the beginning of 2021, the FMD started steady operations with the merger of the two offices of the Fraunhofer Group for Microelectronics and Forschungsfabrik Mikroelektronik Deutschland and the new head of the joint office, Dr. Stephan Guttowski. This transition was marked by the digital conference "Impulsgeber FMD: Angebot & Potenzial - Köpfe & Know-how" on April 22, 2021. This model of interdisciplinary and interorganizational cooperation in the German research landscape is already bearing its first fruits and it may serve as a role model at the European level in the future.

Networking and Cooperation for Technological Sovereignty

In the meantime, the FMD is considered a role model when it comes to setting up the competencies of different R&D institutions with a joint strategy and a bundled offer to industry. With its cross-location, cross-technology and cross-competence collaboration, the FMD ensures that technological sovereignty is maintained and expanded along the entire value chain.

The Berlin office represents the FMD institutes and acts as a central point of contact for all issues related to micro- and nanoelectronic research and development in Germany and Europe.

Versatile Cooperation Opportunities

In addition to the range of services for its customers from industry, the FMD also offers a wide variety of cooperation opportunities for its partners in science and education. These are aimed directly at cooperative processing of research questions, such as collaborative work in joint projects and the operation of joint laboratories. A major opportunity for cooperation lies in the testing of special concepts and solutions from basic research on the facilities of the FMD institutes to gain a better understanding of their suitability in more application-oriented environments.

Trustworthy and Sustainable Microelectronics Systems for Innovative Strength

A future-oriented society depends on electronic components in all relevant technical application domains - whether in critical infrastructures, in Industry 4.0, in the automotive sector or even in medical devices. People must be able to rely on these in order to build trustworthy products, systems and infrastructure with them.

The cross-technology competencies needed to meet these challenges are being developed by the institutes of Forschungsfabrik Mikroelektronik Deutschland in large-scale projects such as "TRAICT" or "Velektronik". In the TRAICT (TrustedResourceAware ICT) project, for example, eight FMD institutes worked together with another ten Fraunhofer institutes until the end of 2021 to develop framework conditions to ensure that information and communication technology is trustworthy and compliant with data protection requirements, and can be used in a self-determined and secure manner.

In order to shed light on the entire value chain and create end-to-end concepts for trustworthy electronics in Germany and Europe, a platform for trustworthy electronics - "Velektronik" for short - was launched in March 2021. A total of 12 partners are involved - 11 institutes of the FMD as well as the edacentrum. Within the project, corresponding standards, norms and processes based on a national and European chip security architecture are to be developed and brought into application.

THE RESEARCH FAB MICROELECTRONICS GERMANY

Fraunhofer IISB – The SiC Specialists within the FMD

Forschungsfabrik Mikroelektronik Deutschland

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Fraunhofer IISB – The SiC Specialists within the FMD

Within the FMD, the IISB has a unique selling point with its integrated, certified production line for the processing of individual SiC-based prototype devices in an industry-compliant environment.

In the front-end area for wafer sizes of mainly 150 mm, all necessary process steps can be performed at Fraunhofer IISB, such as epitaxy, ICP dry etching, growth of silicon dioxide, aluminum implantation at elevated temperatures, activation anneal, and metallization. Usually, vertical devices are manufactured in SiC for power electronics. Therefore, the processing of the backside of the SiC wafers is of critical importance. The FMD investments now also enable the bonding and debonding of already finally processed wafers at the front side, the thin grinding of wafers at the backside and the reduction of contact resistance at the backside by means of advanced metallization and laser silicidation.

New integration technologies and innovative assembly and system concepts for prototyping and the production of future power modules are available in the backend area. This makes it possible, for example, to realize particularly complex and compact structures, heavily stressed (special) applications with sometimes small quantities or durable high-temperature power electronic modules.

Extensive, complementary methods are available along the process chain for quality control. The most important of these are a fast, high-resolution X-ray topography system for the analysis of the structural properties of crystals, wafers and partially processed wafers, and a combined surface inspection photoluminescence device for the analysis of the near-surface material properties of SiC along the process chain. The SiC metrology is supplemented by special measuring stations, which are adapted to the specific, sometimes extreme conditions of power electronics, such as an extra-high voltage measuring station as well as special lifetime and reliability test laboratories.

For the research on new semiconductor materials with large band gaps, crystals of these materials are needed, which then have to be further processed into wafers in order to evaluate the potential in the FMD for power electronics or for other applications such as in quantum technology. Since the new crystal materials, such as GaN, AlN or diamond, are usually crystals with small diameters (50 mm or smaller), Fraunhofer IISB operates a special substrate and wafer laboratory to produce wafers from such crystals. The quality of the wafers used to manufacture the devices is tested using various analytical methods, including the determination of their epitaxial suitability and the production of special test structures.

Find more information about the Research Fab Microelectronics Germany at https://www.forschungsfabrik-mikroelektronik.de/

2 *Part of the framework of Research Fab Microelectronics Germany (FMD): Cleanroom laboratory for power electronics packaging technologies for extreme operating conditions and with highest reliability.* *© Anja Grabinger / Fraunhofer IISB*

THE FRAUNHOFER-GESELLSCHAFT

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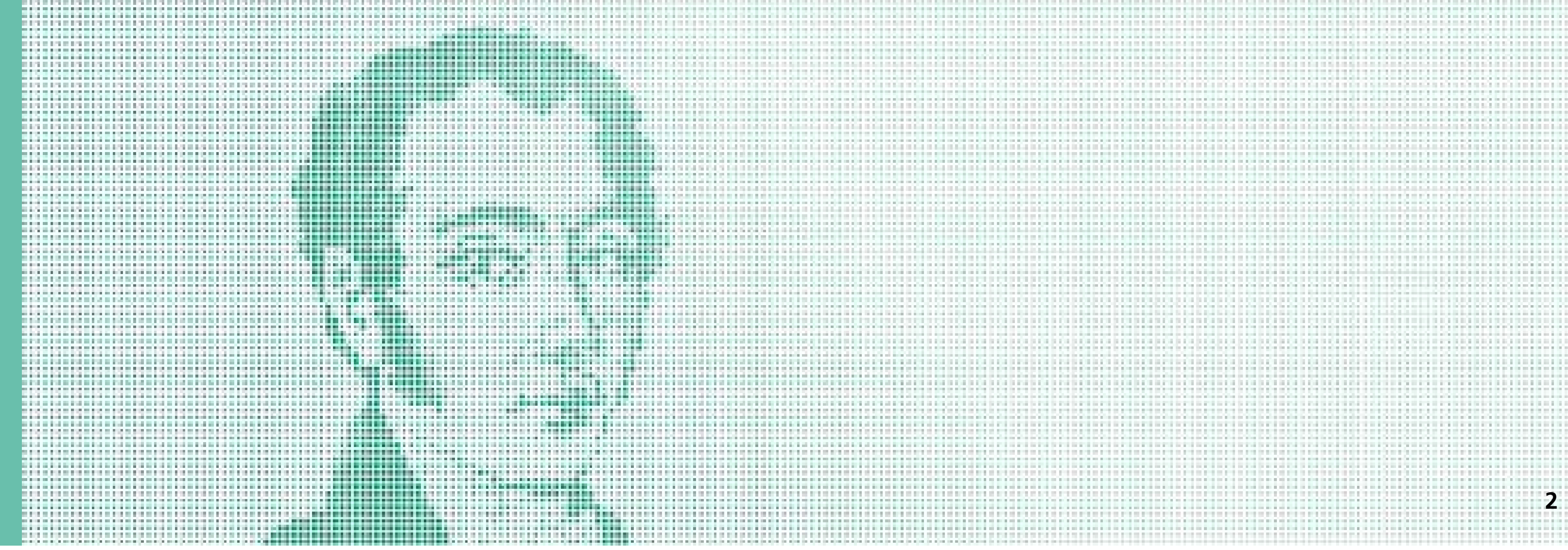

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The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of €2.9 billion, €2.5 billion of which is contract research. Industry contracts and publicly funded research projects account for around two thirds of that. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

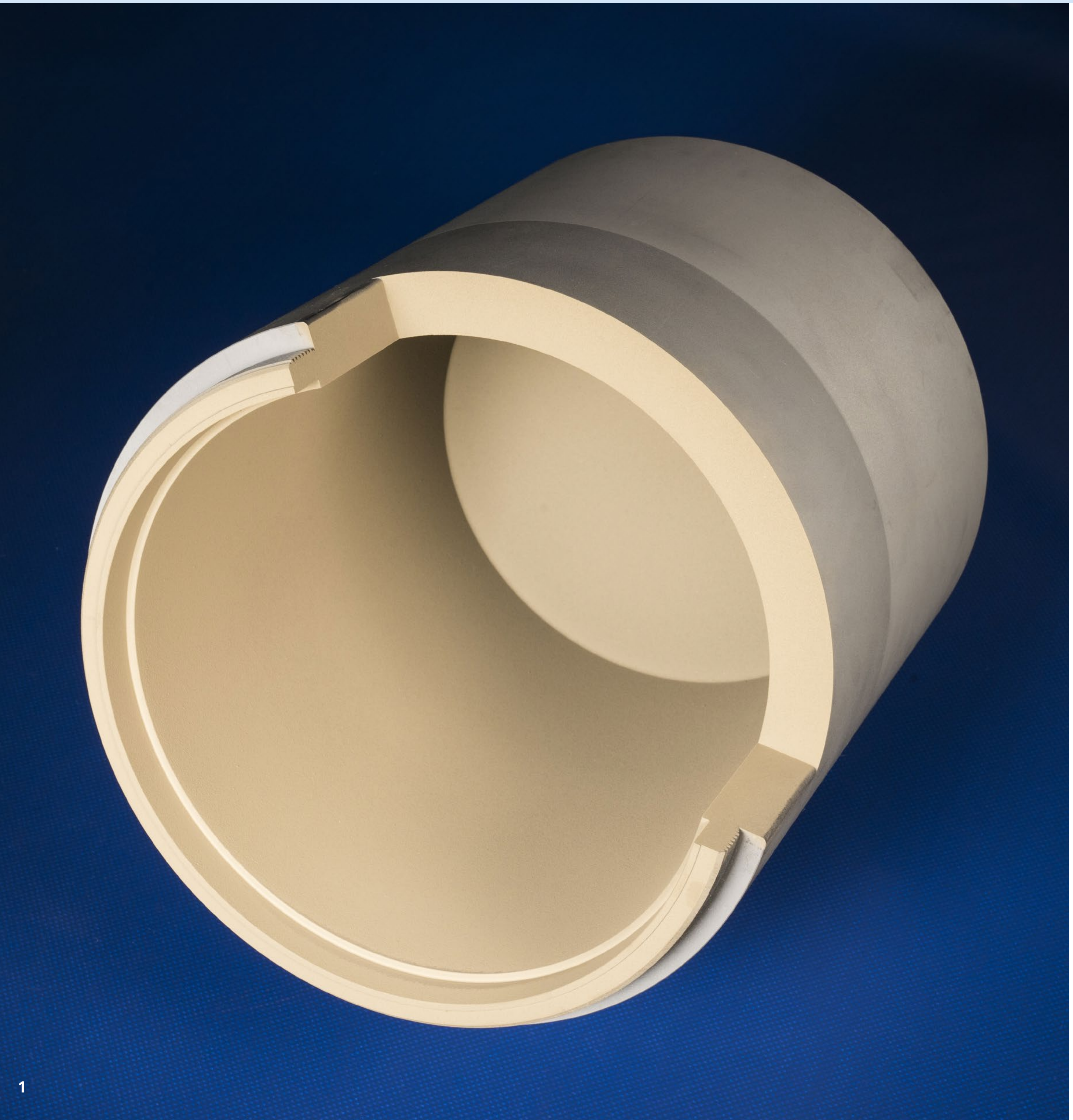
https://www.fraunhofer.de/

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

2 *Joseph von Fraunhofer: 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. © Fraunhofer IISB*

JOINT LABS @ IISB

From IP to Product – Tantalum Carbide Coating Technology



JOINT LABS @ IISB

Joint Labs offer industry the opportunity to cooperate with Fraunhofer IISB in the form of a cross-organizational development team which works together on key topics for industry. This promotes a deeper understanding of the technology, which in turn facilitates technology transfer and accelerates integration into the product. To enable the team to work together successfully, Fraunhofer IISB has been creating facilities and the correspondingly necessary technical infrastructure since 2002. Here, team members can work together on challenges in the long term and develop new technologies and products. Our partners, customers and ultimately, we as an institute for applied research benefit from our comprehensive technical laboratory environment. Within the Joint Labs, our equipment is constantly growing and combines proven production lines and new technologies. This provides our customers with a demo and application center for newly developed tools and devices. The strategic development of the Joint Labs at the IISB in 2021 was driven by the development of the 200mm capability of SiC power electronics. Here, we are working with our partners Nippon Kornmeyer Carbon Group GmbH, AIXTRON SE and Rigaku Europe SE on the three key process steps of material production, epitaxy and characterization.

From IP to Product – Tantalum Carbide Coating Technology

A coating technology invented and patented by Fraunhofer IISB is being further developed into a product in the framework of a joint lab with the Nippon Kornmeyer Carbon Group GmbH, a subsidiary of one of the world's largest graphite manufacturers, Nippon Carbon Co. Ltd.

The obtained high temperature and corrosion resistant coating can be used in semiconductor material production and processing, for instance SiC and nitride PVT crystal growth and epitaxy, ion implantation, plasma processing, and further typical high temperature and reactive gas processes to secure graphite parts from decomposition and corrosion to increase lifetime and improve coast of ownership.

Both parties joined forces in 2021 to transfer the know-how and patented coating technology into application demonstrators and already started to manufacture pilot series of coated graphite parts which are tested under industrial application conditions at end customer side.

1 *In its Joint Lab with Nippon Kornmeyer Carbon Group, Fraunhofer IISB is further developing its patented TaC coating technology to improve the performance of graphite components. © Thomas Richter / Fraunhofer IISB*

JOINT LABS @ IISB

From Strategic Investment to the Center of Expertise for X-ray Topography

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From Strategic Investment to the Center of Expertise for X-ray Topography

Rigaku Corporation and Fraunhofer IISB started their corporation in 2018 to install the first XRTmicron system in Europe. In 2021, the Center of Expertise for X-ray Topography has been built in Erlangen to support the semiconductor industry worldwide in improving and better understanding their wafer quality and yield by employing the Rigaku XRTmicron advanced X-ray topography tools. One aim is to develop industrial applicable measurement routines and defect counting algorithms which can be used in production and for R&D purposes.

Since its inception in Japan in 1951, Rigaku Corporation has been at the forefront of analytical and industrial instrumentation technology. Rigaku and its subsidiaries form a global group focused on general-purpose analytical instrumentation and the life sciences. Today, Rigaku employs over 1,500 people in the manufacturing and support of its analytical equipment, which is used in more than 90 countries around the world supporting research, development, and quality assurance activities.

In the Center of Expertise for X-ray Topography at Fraunhofer IISB, crystallographic defects on wafer scale, non-destructively, with high measurement speed and highest spatial resolution are investigated using different types of XRTmicron systems. The X-ray topography measurement method is ideally suited for the analysis of epilayer structures, wafers, wafers with epilayer structures and partially processed wafers.

Customers benefit from our full-surface and non-destructive method as well as feedback loops within a few days. Our experts analyze industry samples to support quality assurance during semiconductor production processes or R&D tasks. This may involve very local defect analysis, for example. We also provide the generation of statistical measurement data based on a large number of wafers to control the material quality on the entire wafer area during ongoing production.

The success of the joint development is particularly evident in the fact that Rigaku was able to open up a new business area in less than two years and is now the world's leading supplier of XRT tools in the field of SiC substrate and device manufacturing. This innovative technology is currently changing the way SiC wafers are characterized. As a result, it saves millions of potential substrates from being etched for characterization and then discarded. It helps wafer suppliers and customers speak the same language and find the right product for each application by specifying the relevant defect densities. The measurement routine developed became the basis for a worldwide SEMI standard, reflecting industry acceptance. It is on its way to become an indispensable quality assurance method in industrial production and will play an important role in the widespread introduction of affordable, reliable, highly energy-efficient SiC power devices in the energy market worldwide.

2 *Look into the newly established "Centre of Expertise for X-ray topography" at Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*

3 *Dr. Michael Hippler (right), President of Rigaku Europe SE and Prof. Dr. Martin März, Head of Fraunhofer IISB during unveiling the new X-ray topography tool. © Kurt Fuchs / Fraunhofer IISB*

JOINT LABS @ IISB

SiC Epitaxy on 150 mm and 200 mm Substrates

4 *Worldwide unique for a research institution: The new AIXTRON Planetary Reactor system in Fraunhofer IISB's clean room for the deposition of epitaxial layers on 150 & 200 mm substrates, in particular silicon carbide. © Kurt Fuchs / Fraunhofer IISB*

SiC Epitaxy on 150 mm and 200 mm Substrates

Since 2014, Fraunhofer IISB and AIXTRON foster a strategic cooperation in the development of SiC equipment and processes and operate a Joint Lab in a clean room at the IISB.

AIXTRON is a leading global supplier of equipment for silicon carbide epitaxy using the CVD process. Since 1999, AIXTRON has been producing SiC equipment for research and development and for the production of SiC epitaxial layers and SiC power devices. Leading industrial companies rely on AIXTRON SiC planetary technology.

While equipment development and manufacturing are located at the corporate headquarters in Herzogenrath, AIXTRON's satellite office at the IISB serves several objectives. The continuous improvement of tools and processes requires intensive development activities, for example in the areas of wafer throughput, tool maintenance, and to improve material quality. Such tasks benefit from an integration into the IISB's SiC CMOS device technology line. By using the IISB's material and device characterization, a comprehensive evaluation of the processes is quickly possible. In addition, the Joint Lab also serves AIXTRON for their customer training and equipment demonstrations. Here, too, the integration into the research factory at the IISB is an advantage.

For the IISB, the Joint Lab with AIXTRON is exactly in line with its institute philosophy: technologies can best be researched and transferred to application for the benefit of partners and society if one is also an expert in all other areas of the value chain. The cooperation with AIXTRON represents an ideal opportunity to enhance its activities in the field of industrial SiC epitaxy development like only a few other research institutes worldwide. Today's high quality material requirements presuppose large financial outlays for wafers and personnel, which would not be feasible for a research institute alone. So Fraunhofer IISB can offer top quality for epitaxy for semiconductor products that commercial suppliers cannot keep up with. The Joint Lab indirectly supports e.g. medium-sized German manufacturers of SiC-based sensors or new SiC applications in the field of quantum technology.

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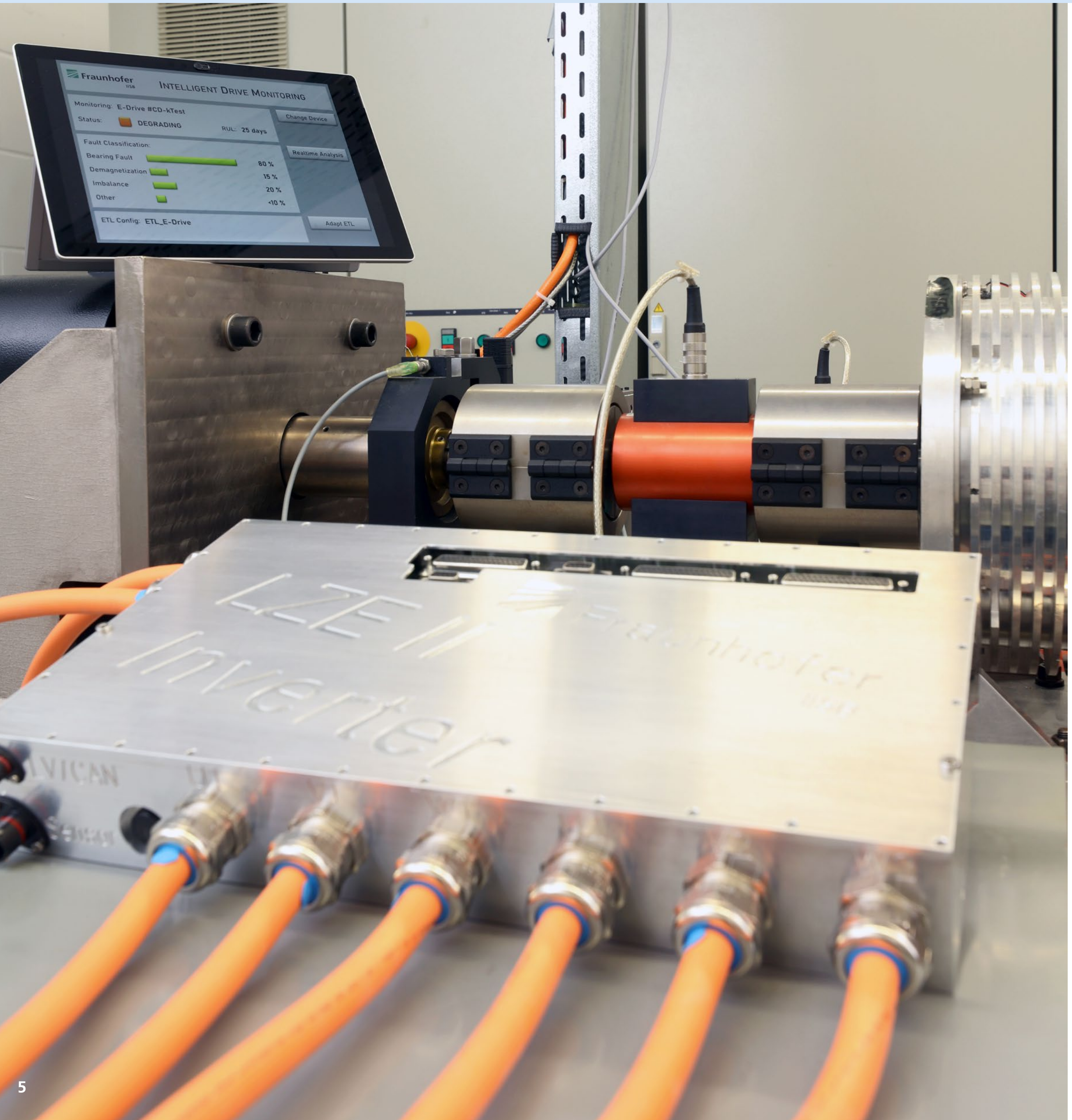

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COGNITIVE POWER ELECTRONICS @ IISB

Under the umbrella of Cognitive Power Electronics (CPE), Fraunhofer IISB combines its core competencies in the field of power electronic systems with data analytics and artificial intelligence. Our system knowledge about the conversion, provision and storage of electrical energy flows into the intelligent functionalities. This integration enables innovative applications of smart power electronics. Cognitive Power Electronics – on the one hand, this means equipping power electronics with algorithms to make them intelligent. The result is the strategic autonomy of processes and decisions through the further utilization of available data. Intelligent power electronics are able to take on data-based tasks such as integrated condition monitoring and anomaly detection. If necessary, CPE also makes adjustments to the system, for example using predictive maintenance methods. On the other hand, we are pursuing the development target of utilizing AI during the design process of power electronics, especially for circuit optimization. At the center of this second dimension of CPE are AI-based simulations of circuit layout variants, which will play an important role in the field of CPE in the future.

CPE for Intelligent Drive Systems

In the area of electric drives, our research focus is on highly integrated solutions of motors and inverters for mobile applications, like electric vehicles and aviation. The application of artificial intelligence according to the CPE principles described before allows for integrated condition monitoring, anomaly detection and optimized operation of both the motor and the power electronics. Based on a broad market research and user interviews we found that one of the first interesting use cases is the detection of bearing related damage - preferably without the use of additional sensors, only using already recorded current waveforms, as envisaged by the CPE concept.

For laboratory investigations, we developed a new, highly modular permanent magnet synchronous motor, where we can introduce different types of failures. We also developed a high-performance SiC-based drive inverter and acquired the stator currents as basis for our machine learning pipeline. For the actual failure detection, we implemented and trained a manifold-learning pipeline. We achieved an overall accuracy of up to 95 % in the detection of the actual condition of the motor bearing.

5 *Drive Inverter featuring Condition monitoring of an electric drive by CPE4.0, with estimation of the most probable cause of failure.*

6

We then applied the learnings and algorithms from the laboratory investigations to motors of an Unmanned Aerial Vehicle (UAV), where the propulsion system is exposed to varying loads and harsh ambient conditions. A regular estimation of bearing condition in the field enables a more predictable and cost-efficient maintenance planning for the customer.

To assess our CPE-driven condition monitoring for the UAV application, we prepared a test-setup as depicted in figure 2 and recorded the phase currents from several motors with new (healthy) bearings and damaged bearings returned from the field application. We then carried out our machine learning pipeline and found that after applying a kernel PCA (Principal Component Analysis), the data clusters from healthy and damaged motors can be well separated. Furthermore, an important strength of the chosen modelling approach has proven itself: We not only rely on mere data analysis, but also on physical interpretability. By analyzing prominent peaks in the frequency domain of the phase currents, a rotor eccentricity in one of the motors could be identified as the relevant bearing related fault.

Our future research on intelligent drive systems focuses on the detection of more failure types, the generalization for a large variety of operation conditions and the transfer of the developed methods to other drive systems and applications.

CPE for Stability Measurements in DC Microgrids

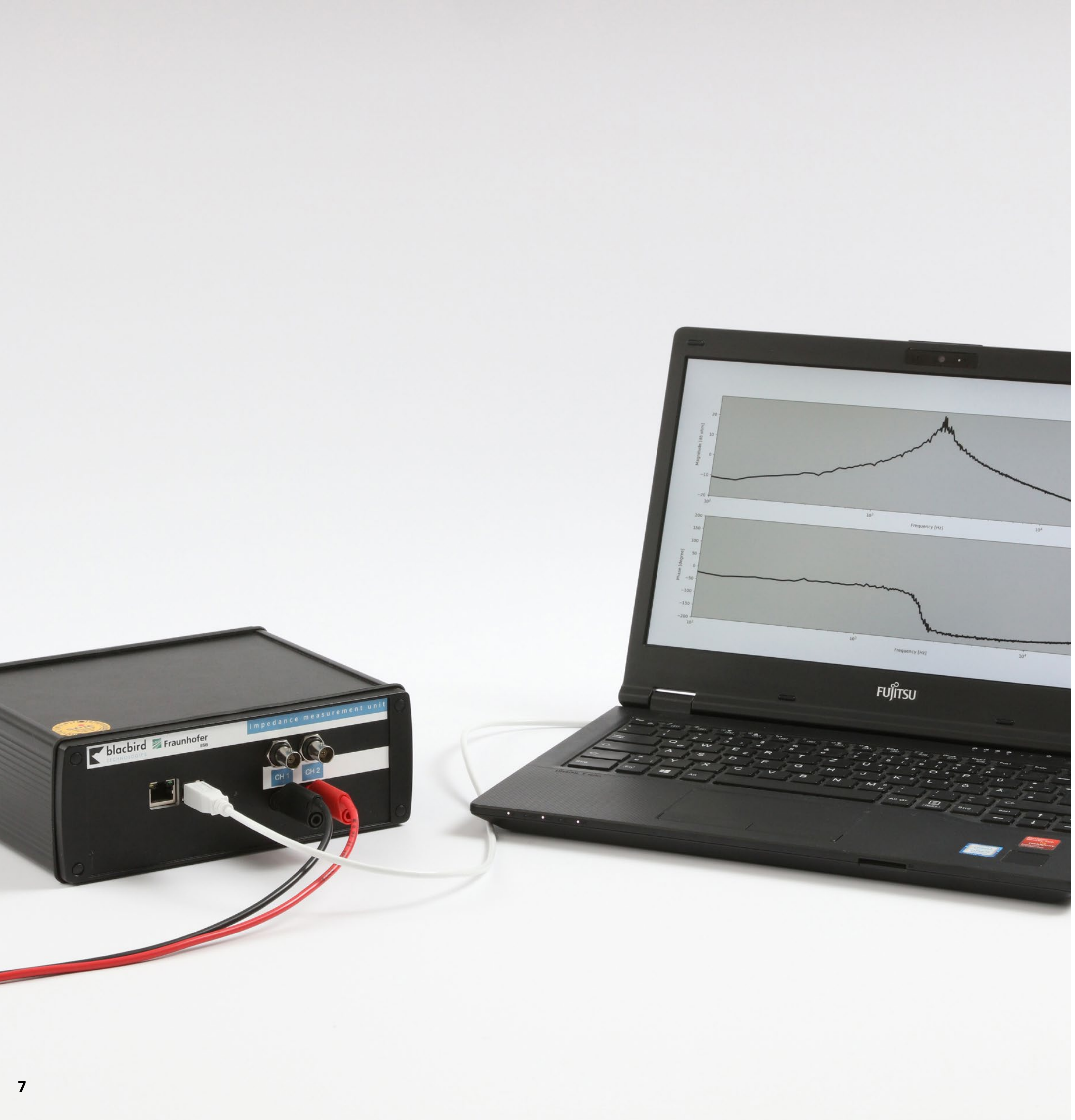
As modern decentralized DC microgrids have more and more become the focus of research and application for industrial plants, their network grid structures and the corresponding interactions have become increasingly complex. On one hand, this is due to the size of the grids and the number of devices in that grid. This includes multiple energy sources besides the AC grid, like photovoltaic, batteries, and fuel cells, as well as a multitude of different loads. Depending on the state of the energy sources, the DC microgrid will also see a multitude of possible states. On the other hand, the number of available power electronics for DC grid application increases.

Still, all the devices must form a stable DC microgrid, because the stable operation of DC networks is of great importance, especially for complex DC networks. Instabilities in DC networks can be caused, for example, by switching operations that generate high-frequency AC currents and cause the DC network to oscillate, leading to undesired load shifts and damage. Cognitive Power Electronics assists in the building and operation of stable DC microgrids, from the selection of components in the design phase, to adjusting control parameters online.

While instabilities can be mitigated by counteractive measures, the instability has to be detected in the first place. We have therefore developed and patented a measurement system that actively monitors system stability, while the DC microgrid is online.

6 *Test setup for CPE-driven condition monitoring of an electrical drive for Unmanned Aerial Vehicles. The setup comprises a drone motor with propeller and an oscilloscope with three current clamps for motor current recording. © Thomas Richter / Fraunhofer IISB*

COGNITIVE POWER ELECTRONICS @ IISB



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To determine if the DC microgrid is stable, we are able to measure and analyze the impedance of the whole grid. To measure the output impedance, a wide bandwidth test current is injected into the system. We create this wide bandwidth signal by using pseudo-random binary sequences (PRBS) of current pulses. A PRBS is a sequence, whose autocorrelation has a sharp peak at zero. Within the limitations of the bit duration and the length of the sequence, the PRBS acts like white noise. By measuring the grid voltage, we can therefore determine the impedance over a wide frequency range with a single measurement. Since the PRBS is known, we can also increase the signal-to-noise ratio, by cross-correlating the grid voltage with the test current.

The benefit compared to regular impedance measurement systems is that the coupling circuit can be relatively simple. For our prototype, we use a semiconductor, which is switching a large resistance in and out of the DC microgrid. The PRBS test current is generated by control signal for the semiconductor, which is a pseudo-random binary sequence, therefore the resistance draws a PRBS shaped test current. This eliminates the need for bulky coupling transformers and amplifiers and leads to a compact and robust system, which can be integrated into any DC grid. The measured impedance is then used to determine the DC micro grid stability. This is done by applying stability criteria, like the minor loop gain criterion or the passivity criterion, which can be evaluated automatically for subsequent use in machine learning. With the help of cognitive algorithms, we can then optimize the individual source converters control to ensure stability.

7 *Eliminating the need for coupling transformers, the stability measurement system becomes more compact and easy to integrate into a DC microgrid.*
© Kurt Fuchs / Fraunhofer IISB

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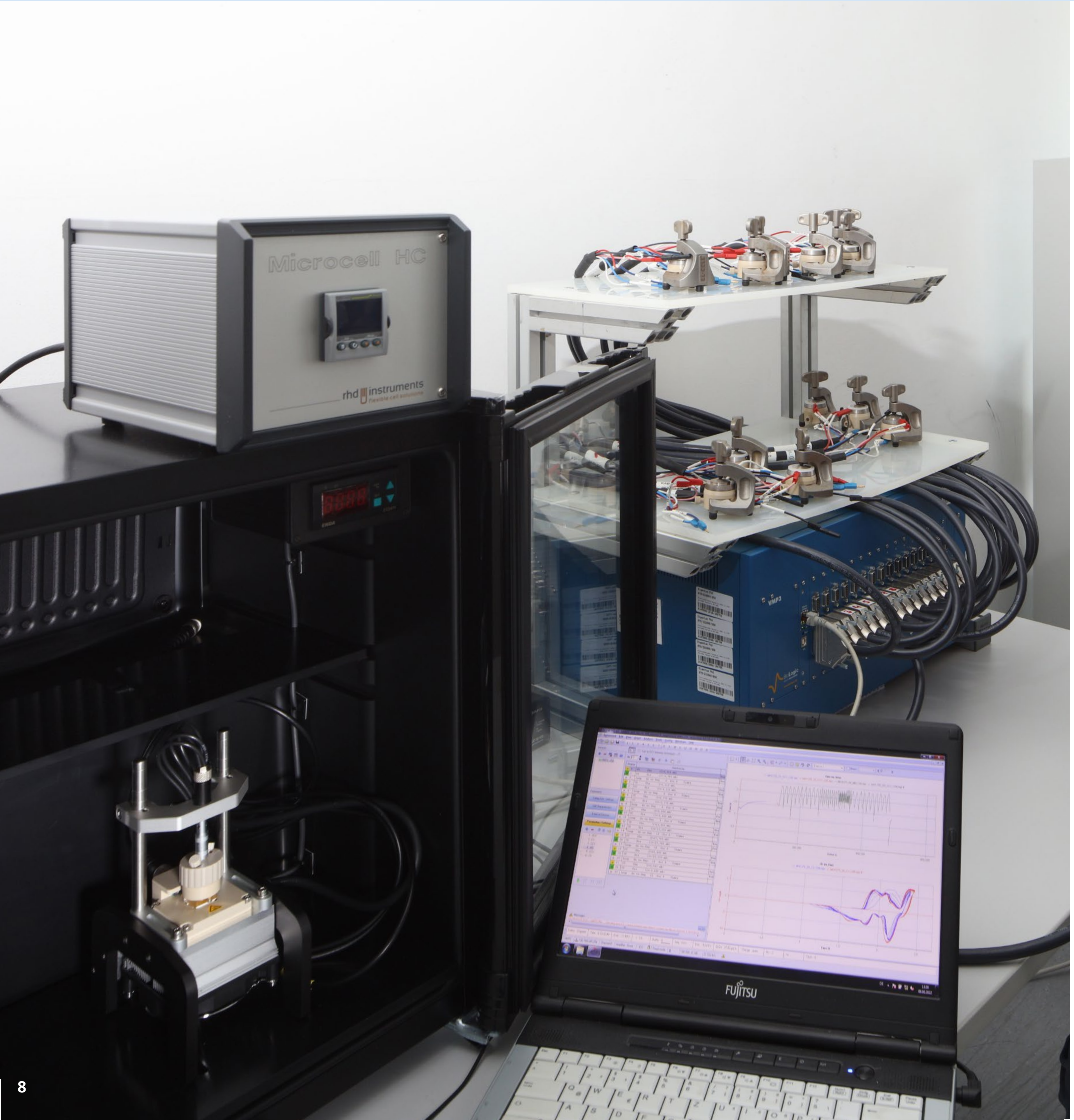
BATTERIES @ IISB

Aluminum Ion Battery



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8 *Electrochemical measurements such as cyclovoltammetry and charge / discharge cycling are part of the comprehensive battery characterization at Fraunhofer IISB.*
© Kurt Fuchs / Fraunhofer IISB

BATTERIES @ IISB

The increasing electrification in many areas of our everyday life, but especially in industry and technology, would hardly be possible without the use of innovative batteries. The Energiewende and the growing electromobility are driving demand for efficient electrical energy storage systems. Enormous efforts are required in all areas of technology development, from future-proof battery materials to high-performance battery systems.

Fraunhofer IISB's broad competence profile enables us to significantly improve energy storage systems at specific points in the battery value chain. At our institute, we look at the optimization of modern batteries from a materials and a systems perspective. The link between the two topics is the knowledge of the cell characteristics and the cell chemistry. This is not only of immediate importance for research into novel battery materials, as currently in our research into the aluminum ion battery (AIB). Knowledge of the cell chemistry also gives us an advantage when it comes to addressing the problem of swelling in certain types of batteries. Battery swelling in turn has a direct impact on the whole battery system and housing. Another field of our research activities is battery management. So, our self-developed and very successful battery management system foxBMS® is now available in the second generation. foxBMS® 2 is characterized by its outstanding flexibility for the use in mobile and stationary applications. Among many other benefits, this means that foxBMS® 2 can handle new materials as well as new battery types such as redox flow batteries.

Aluminum Ion Battery

We profitably use our expertise in material development in the field of alternative battery materials, to use cost-effective active materials for the rechargeable aluminum ion battery (AIB) technology without critical raw materials such as Lithium, Cobalt and Nickel. The AIB cell chemistry is a promising energy storage technology as it is based on highly abundant materials, combines high charge/discharge rates and long cycle lives with non-toxic and non-flammable materials.

AIBs employ an Al anode and typically a graphite cathode. The electrolyte is a deep eutectic solvent (DES) type I, commonly called an ionic liquid (IL), or a deep eutectic solvent type IV, also known as an ionic liquid analogue (ILA). Because of the cell chemistry, the technology is referred to as Aluminum Graphite Dual Ion Battery (AGDIB). AGDIBs are the most mature secondary

BATTERIES @ IISB

Redox Flow Batteries

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Al-battery technology that has a high potential for stationary energy storage applications because of their low cost and relatively high energy densities. For example, highly dynamic applications such as grid stabilization can be realized with this storage technology. It can be also suitable buffer storage for fuel cells in mobile applications.

The results achieved so far for the AGDIB are extremely promising. In this way, specific capacities of up to 170 Wh/kg in relation to the active material could be achieved in laboratory cells. The cells show a very high cycle stability of more than 20,000 cycles at charging rates up to 150C and a charging efficiency >90%. The successful use of low-cost urea-based electrolytes could also be shown.

The task now is to develop an application-relevant cell concept in order to qualify the AIB in demonstrators for specific storage requirements. The challenge lies in the strong corrosiveness of the electrolytes. In order to find a corrosion-resistant, long-term stable cell housing, extensive material evaluations are carried out. First tests in a cell already show a stability of 1000 cycles. However, numerous other effects such as self-discharge or temperature and volume effects during charging and discharging must be further investigated.

With the application-relevant development of a new type of cell chemistry, there are direct points of contact with the questions of battery control for this new material system. This means that a new storage technology can be established as a battery system based on the expertise of the IISB.

Redox Flow Batteries

The steadily increasing share of renewable energies reducing the carbon footprint requires a growing demand for stationary storage systems. Redox flow batteries provide a promising electrochemical technology for storing electrical energy in large-scale energy applications. They provide a relatively simple technology to store, e.g., energy from wind farms and other large renewable energy producers. By decoupling power and capacity, they offer the advantage that the capacity can be easily increased also in a running system by enlarging the amount of electrolyte. A disadvantage of redox flow batteries is the relatively low energy density, e.g., compared with lithium-ion batteries. Nearly 90 % of the systems are vanadium redox flow batteries (VRFB). Intensive research is also done on organic redox flow batteries to replace the metal ions.

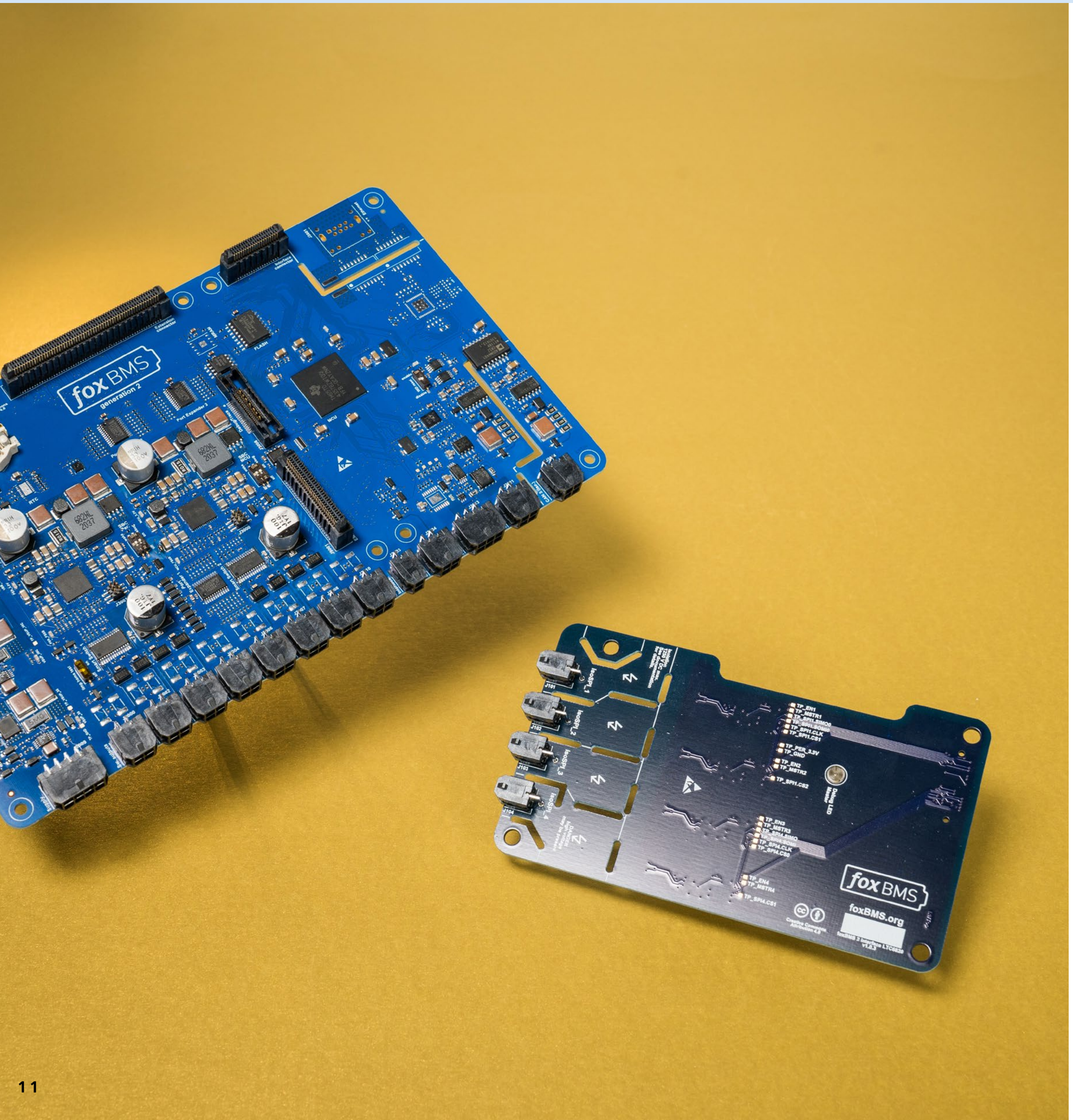
Fraunhofer IISB developed in the framework of its intelligent energy system a vanadium redox flow battery which is integrate into its real-world laboratory. The entire system is integrated into a 20-foot container constructed around redox flow stacks from an external supplier. The system, the system integration as well as the control of the system was developed by Fraunhofer IISB. The VRFB system serves to demonstrate the IISB's competence in system integration on component

9 *Fraunhofer IISB has integrated a vanadium redox flow battery into its intelligent energy system. A 20 foot container houses all the components of the battery system. © Kurt Fuchs / Fraunhofer IISB*

10 *The main components of an aluminum-ion battery: graphite powder, aluminum foil and a special electrolyte consisting of a molten salt that is liquid at room temperature. © Maximilian Wassner / Fraunhofer THM*

BATTERIES @ IISB

Swelling - Components as System Setup
foxBMS® 2 – Next Generation Battery Management System



and energy system level. Specific focus is power electronics, battery management systems and the improvement of efficiency, e.g., by operation strategies.

Swelling – Components as System Setup

Volume effects over charging and discharging (i.e., swelling) mentioned before also pose a challenge in the context of new cell designs based on silicon-rich anodes. Cells with these anodes can reach very high energy densities (450Wh/kg and more) that are very desirable e.g., in weight sensitive applications such as endurance UAV (unmanned aerial vehicles). The cell thickness changes by 10% over the SOC range, at the same time a constant pressure needs to be applied to the pouch cell to guarantee maximum lifetime and performance. At the IISB we design and prototype battery systems with minimum weight overhead to get the most out of new cell chemistries for all kinds of highly demanding applications.

foxBMS® 2 – Next Generation Battery Management System

In recent years, it has become apparent that the market shows a strong demand for battery systems with higher energy densities, longer lifetimes, and lower costs, but without compromising safety. To help developers, engineers, and researchers worldwide, Fraunhofer IISB has established the free and open Battery Management System platform foxBMS® back in 2015. This BMS platform consists of a modular hard- and software architecture and a complete toolchain for software development. Based on more than a decade of experience in providing BMS solutions to customers and communities, foxBMS® 2 is now strongly focused on functional safety. By providing certification-ready hardware and software function blocks, the time to market including the certification process according to specific norms (e.g., ISO 26262, IEC 61508, DO-254, DO-178, ED-80) can be reduced.

11 *foxBMS® is IISB's free, open and flexible research and development environment for the design of Battery Management Systems (BMS). Since April 2021, the second generation of foxBMS® (foxBMS® 2) with strong focus on functional safety is available.*
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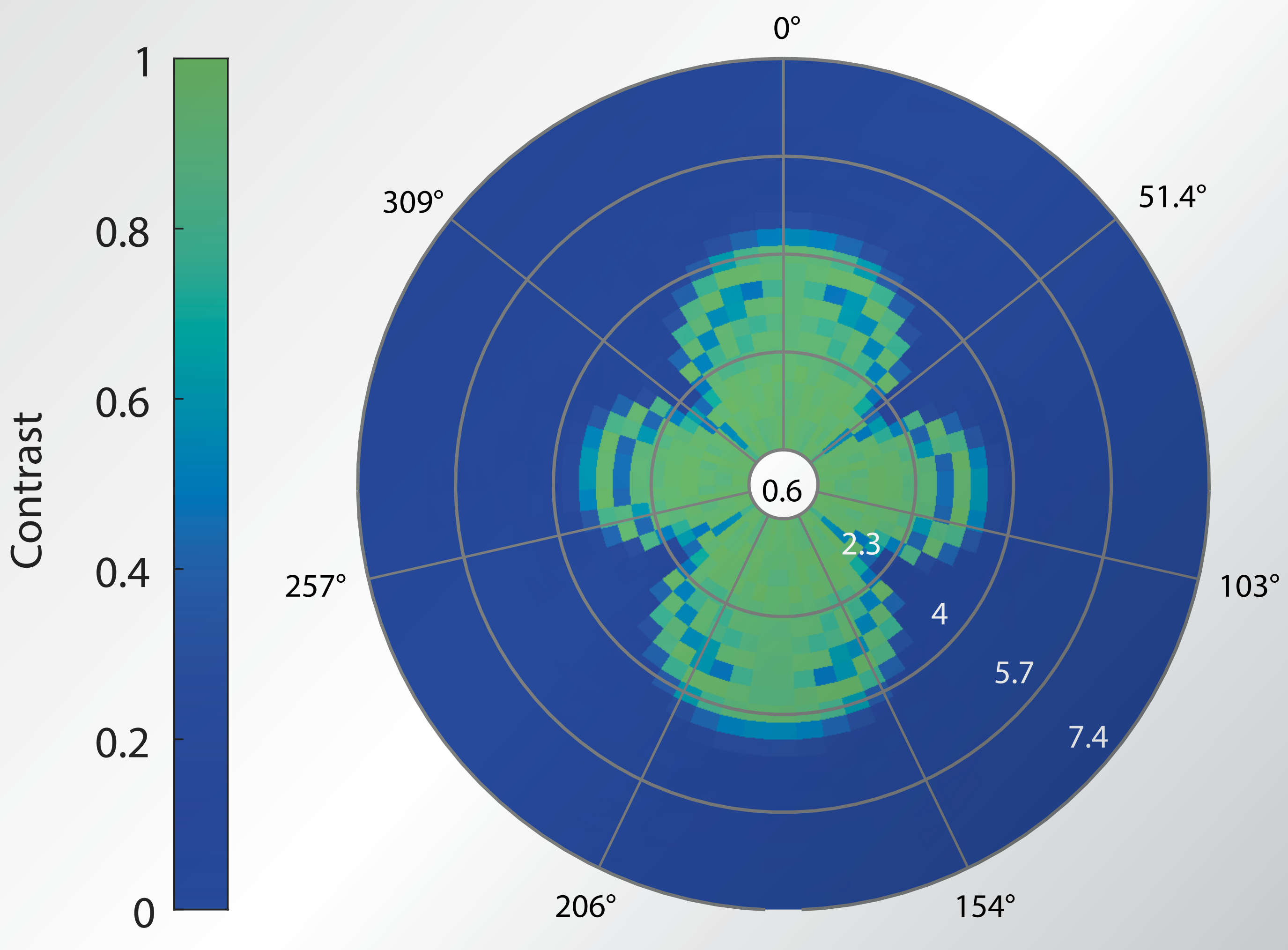

12 *Simulation of the contrast, i.e., signal quality, of a nuclear spin depending on its position in relation to the central color center. The green clover leaf shaped area depicts the area of high-quality qubits.*
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SILICON CARBIDE @ IISB

In addition to the established silicon technology, the IISB has a strong focus on wide-bandgap semiconductors, especially silicon carbide (SiC). 4H-SiC is the ideal semiconductor for the realization of high-voltage and high-power electronic devices due to its outstanding material properties. This semiconductor is also of interest for other applications, for example as an universal material platform for quantum electronics. In accordance with our approach “From Material to System”, silicon carbide has been established as a cross-cutting topic at Fraunhofer IISB and our services in this area cover the whole value chain. In close cooperation with our in-house brand π-Fab we offer a complete technology backbone, from material development to device prototypes, power modules with highest reliability and for extreme requirements, and their integration in highly efficient power electronic systems. We are currently expanding our continuous 150 mm SiC process line to 200 mm capability. Drawing on 20 years of cooperation with partners from SiC industry and research, Fraunhofer IISB has been established as a European hotspot for silicon carbide power device manufacturing. In this way, our customers find with us a unique ecosystem of scientific excellence, applied research and industry-compatible laboratory and process environments.

SiC for Quantum Applications

While SiC is widely known for its power electronic applications, the IISB is also researching on SiC for another highly relevant field of applications: quantum technologies. The IISB is one of the very few institutions capable of producing SiC material with suitable properties for quantum applications. One focus of the IISB is therefore the optimized material quality tailored to the respective quantum application.

In SiC, quantum information can be stored in so-called solid-state defect spins, i.e., electrons trapped in the vacancy of single missing atoms of the crystal lattice. Such defects are also known in other quantum materials like diamond, but SiC combines its highly attractive quantum properties with SiC’s mature material platform, including wafer-scale commercial availability, complementary metal-oxide semiconductor (CMOS) compatibility, and the ability to fabricate hybrid photonic, electrical, and mechanical devices.

The useful defects in SiC can be manipulated by microwave radiation, and since they absorb and emit light, they are also called color centers. Color centers in SiC are proven to be useful

SILICON CARBIDE @ IISB

SiC Process Development
Integrated SiC-Power-Module on Ceramic Heat Sink

for quantum information processing, sensing, and communication. For such applications, long lifetimes of quantum states are necessary, e.g. for robust quantum memory. In SiC this can be realized by transferring quantum information from a color center to surrounding Si or C nuclei.

Not every Si or C atom in SiC is useful as a quantum memory, only certain isotopes are. Most scientists up to now either used the isotope concentrations naturally found in SiC, or SiC free of memory isotopes. However, Fraunhofer IISB's epitaxial SiC manufacturing processes are capable of tuning isotope concentrations, which motivated us to investigate the optimum placement of isotope positions relative to the central nuclear spin, and to determine which isotope content would be best for the application in quantum communication or quantum computing.

The image on the page before shows one of our simulations, performed with a self-developed numerical algorithm. The clover shaped area of best isotope positions must be populated by the optimum number of nuclear spins. Too low a concentration would result in less qubits than possible. Too high a concentration would result in overlapping signals of the qubits which would then be difficult to distinguish.

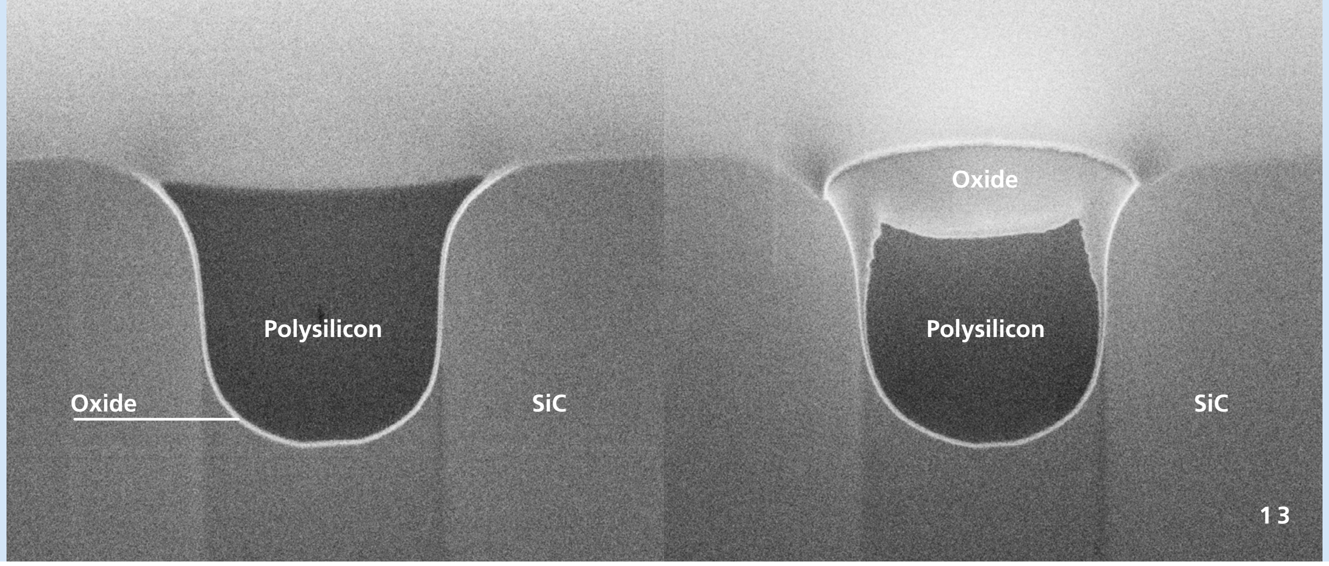
Building on this optimized material we are currently developing color center and device fabrication, as well as SiC quantum applications, in order to establish SiC as a platform for quantum communication, computing and sensing.

SiC Process Development

Novel semiconductor device concepts are key technologies to solve today's challenges of digitalization and the ongoing transition to renewable energy sources. With that, requirements regarding efficiency, power density, robustness and cost of the power components are steadily increasing. With superior properties like wide bandgap and high critical electrical field strength, silicon carbide (SiC) is a very attractive choice for power semiconductor devices. Nevertheless, SiC devices are comparatively new, so challenges regarding fabrication and yield still exist and thus have a high potential in terms of improving process technology, not only to counteract the high material costs.

In the field of power semiconductors, SiC MOSFETs (metal-oxide-semiconductor field-effect transistor) are widely established. Due to their low switching losses in applications with high switching frequencies and low conduction losses at high voltages, SiC MOSFETs are commonly used in electrical drive and solar energy systems as well as power supplies for example.

One approach to further improve the properties of a MOSFET device is to introduce a vertical instead of a horizontal channel. The device patterning is realized via trench plasma etching. The reduced cell-pitch of the so-called TrenchMOS due to the absence of a JFET region enables a higher cell integration density, allowing to save chip area and ultimately chip costs, respectively. In addition, the increased channel mobility on the trench sidewall leads to an overall on-resistance reduction compared to the planar MOSFET.



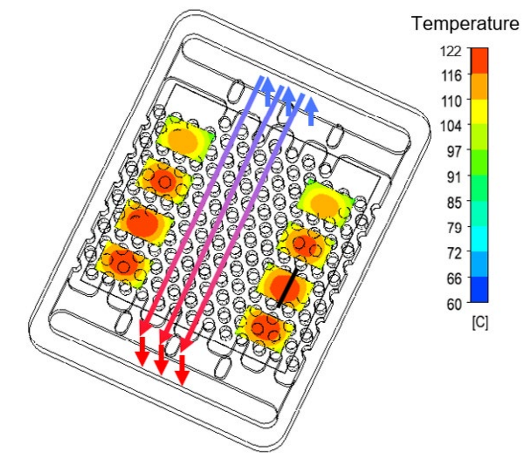
13 *SEM cross-section image of trench profile prepared via FIB after polysilicon deposition and planarization (left) and after oxidizing the planarized polysilicon (right).*
© Oleg Rusch / Fraunhofer IISB

However, as device architecture becomes more complex, additional manufacturing risks arise. In general, a conventional manufacturing process uses a lithography mask in which the device can be patterned by defining appropriate resist structures with areas covered and not covered by photoresist, respectively. Therefore, it is crucial to achieve a high resolution and precise alignment for a mask-compliant structure, which comes with significant lithography system related limitations that impose further high costs. To overcome these challenges, a self-aligned manufacturing process for the formation of the n^+ source and p-well areas, whose alignment is essential for device functionality, was developed and patented at the IISB. By oxidizing the previously deposited and planarized polysilicon in the trenches, see the image above, a self-aligned implantation mask for n^+ source and p-well region is formed. This eliminates the risk of device failure due to misalignment of the corresponding lithography layers. With that, the major advantage here is that implantation for n^+ source and p-well regions within the active area is independent of restrictions regarding the resolution limit and alignment accuracy of the photolithography system. Therefore, using a self-aligned process compensates for the increased technological effort for TrenchMOS production simplifies the manufacturing process. Consequently, the production yield increases by minimizing the risk with of misalignment of the n^+ source and p-well regions within the active area.

Integrated SiC-Power-Module on Ceramic Heat Sink

Innovative power module concepts in combination with appropriate packaging technologies are key points to exploit the advantages of SiC power devices. Main requirements hereby are a low thermal impedance, low inductance, high reliability as well as a high power density and low weight. For this, power module concepts and technologies for SiC are investigated and steadily improved at the IISB to fulfil the demands of future power electronic applications.

Together with the ceramics specialist CeramTec GmbH an innovative 1200 V SiC power module based on an integrated ceramic cooler was developed at the IISB and introduced at PCIM Europe and PCIM Asia in 2021. Compared to a state of the art approach with a ceramics substrate on a metallic cooler, the ceramic cooler becomes integral part of the whole power module. The power module uses front as well as backside of the ceramics cooler, where the 1200 V SiC devices are sintered on the front side and a module-integrated capacitor is located on the backside of the cooler, with a low inductive cooler edge encompassing metallization.



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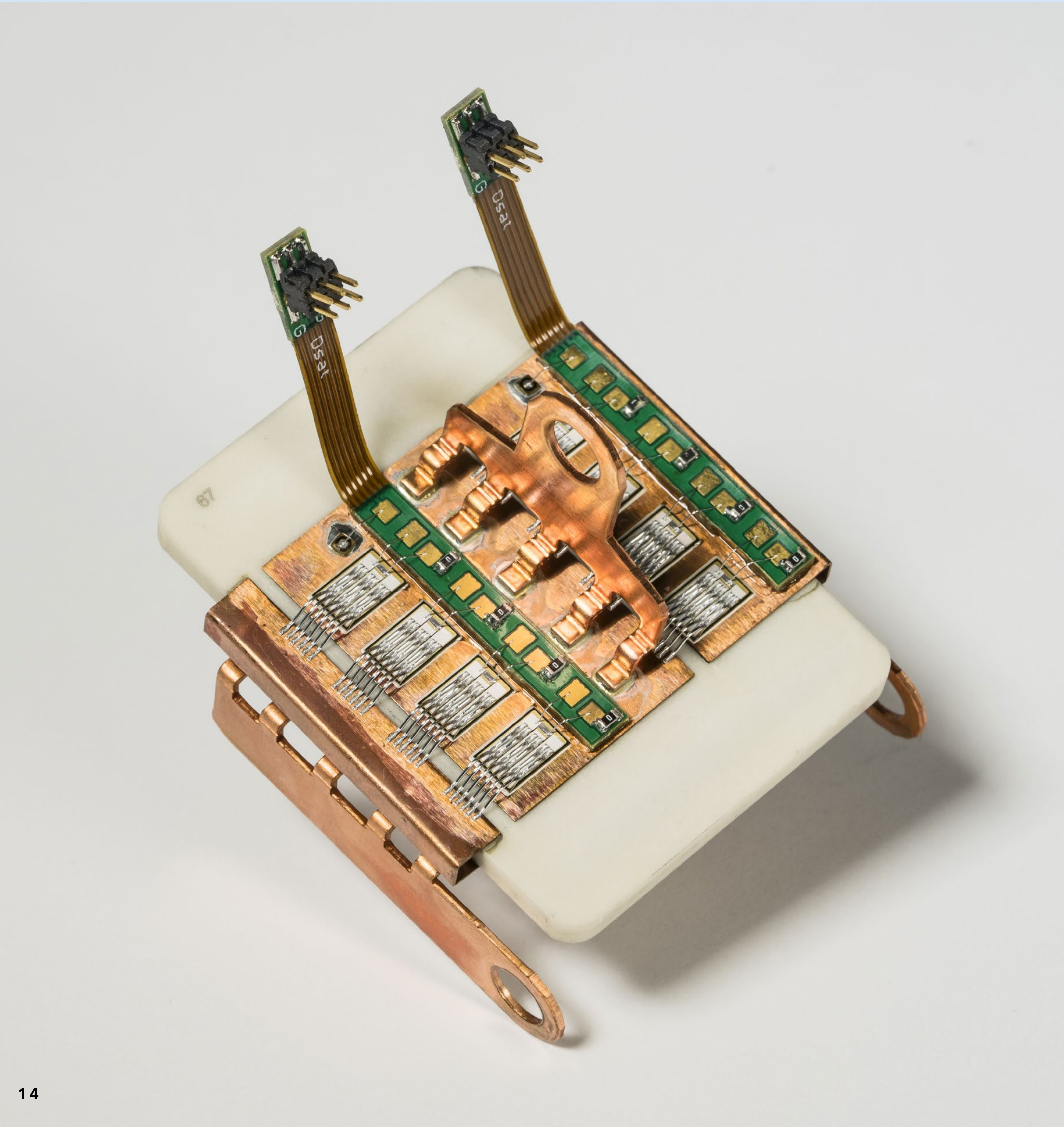

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The development of this integrated power module approach includes investigations on thermal, electrical as well as manufacturing issues combined with the possibilities of the ceramics cooler.

Performed measurements have confirmed calculations and simulations on the SiC power module. For the thermal performance a low thermal resistance of 0.16 K*cm²/W is confirmed, this enables a high current capability related to the semiconductor area. Key factors are a short thermal path from the chip to coolant as well as the high thermal conductivity of the AlN cooler material. Within the ceramics cooler, an optimized PinFin-structure enables uniform distribution of the coolant flow under all SiC devices to achieve uniform thermal conditions for all chips.

Pressure-assisted silver sintering on the back side and wire bonding as top side connection of the SiC devices ensure a reliable attachment on the ceramics cooler. In consequence thermal as well as manufacturing issues are in scope of the design, next to thermal performance the cooler has to resist mechanical stress while silver sintering. A high shear strength of the sinter layer above 40 MPa without any damages of the ceramic cooler is confirmed by means of the realized power modules.

This power module approach shows the potential of power electronics packaging regarding high packaging density, high thermal and electrical performance especially for future applications with SiC integration.

By steadily providing the newest concepts and technologies for SiC and further wide bandgap semiconductors, the complete value chain from concept to prototyping as well as analysis and test are available at the Fraunhofer IISB.

SiC-based Converter Design

On a system level, Fraunhofer IISB works on evaluating and benchmarking novel SiC devices in highly efficient power electronic applications for automotive and industrial solutions.

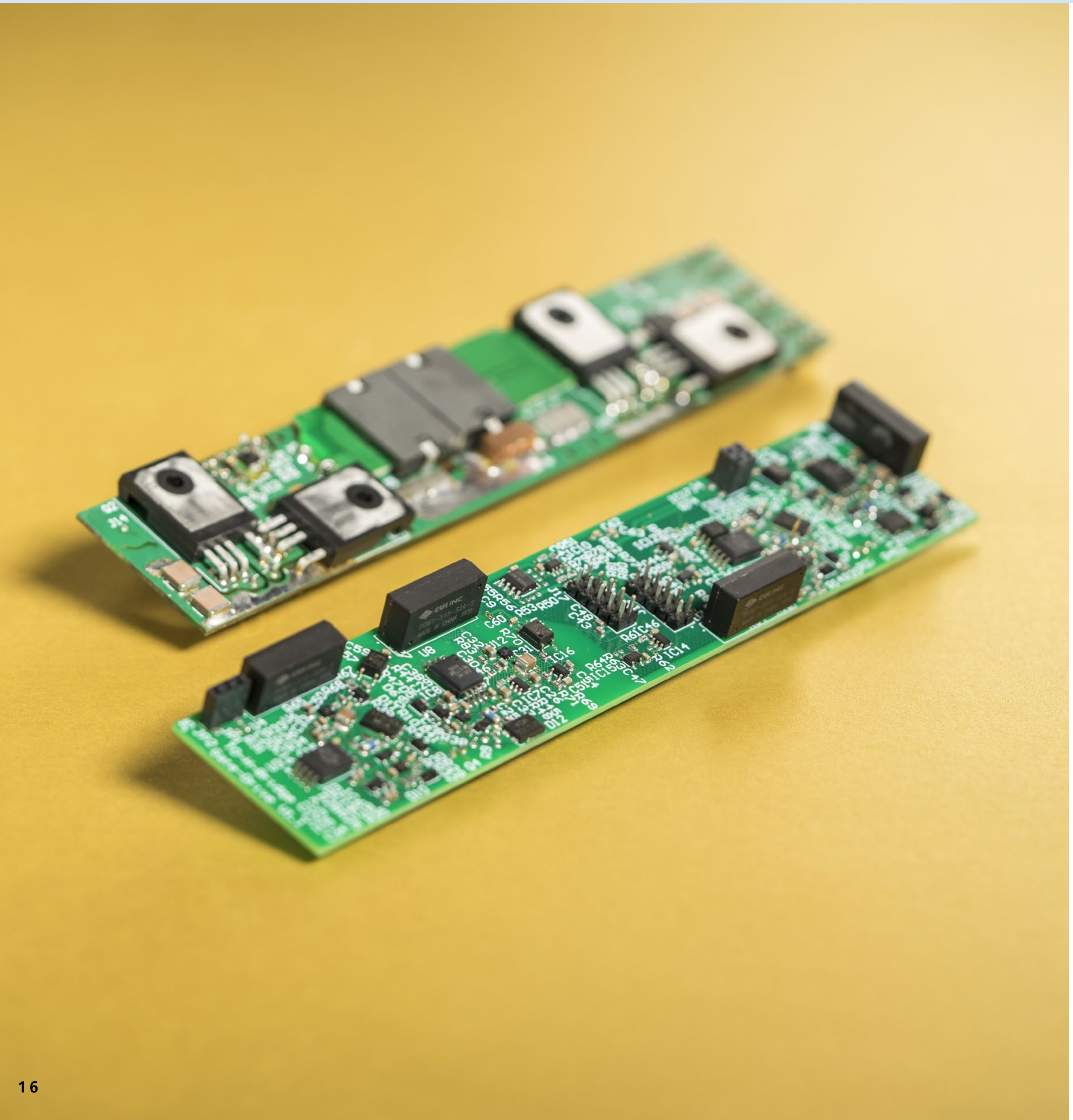
In automotive applications, especially electric mobility, SiC based power electronics allows to follow the trend of miniaturization and integration and offer huge advantages like higher power density and system efficiency. Fraunhofer IISB has developed numerous applications from drive inverters to modular charging systems and has set multiple new benchmarks.

More and more industrial plants install a factory-wide DC grid to avoid unnecessary conversion losses and reduce the overall energy consumption of the plant. The grid also includes local energy generation and storage by linking photovoltaic and battery systems via converters as well as connecting the DC circuits of frequency converters of speed-variable electric drives. All

14 *1200 V full SiC half bridge with sintered semiconductor devices on CeramTec AlN ceramic cooler.*
© Thomas Richter / Fraunhofer IISB

15 *Thermal design with PinFin structures for coolant flow under all SiC devices.*
© Hubert Rauh / Fraunhofer IISB

SILICON CARBIDE @ IISB



those converters benefit immensely from the material properties of SiC: Higher power densities and overall system efficiency are achieved through, for example, higher voltage classes, lower transmission losses, and higher switching frequencies.

Fraunhofer IISB has developed various converters for those industrial applications and has merged the two application areas automotive and industrial. The institute is working on a multi-phase H-bridge SiC-Converter that is to be used in an off-board high power charging system for electric vehicles and is supplied by an industrial 650 V DC grid.

By distributing the total load of 50 kW over multiple power phases passive components can be designed very small in volume. State of the art SiC MOSFETs in half bridge configuration enable a low conduction loss and switching loss power module design as the semi-conductors are switched at fast commutation transients. The planar power inductor and 3D gate drive board-to-board interconnection help to improve the power density. By linking the power modules in parallel a simple and effective assembly process to a common heatsink is achieved.

Computational power is provided by the FPGA of the control board, which can analyze voltage and current measurements of all nine phases in real time and can run a digitally implemented regulator. In order to achieve high grid voltage quality the bidirectional power transfer is precisely regulated by a droop controller.

16 *H-bridge DC/DC converter phase with SiC power circuit module and gate driver PCB.*
© Thomas Richter / Fraunhofer IISB

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ZEPOWEL: CONVERTING ELECTRIC POWER WITH ALMOST UNOBSERVABLE LOSSES

Outstanding Efficieny of 99,8 Percent

17

ZEPOWEL: CONVERTING ELECTRIC POWER WITH ALMOST UNOBSERVABLE LOSSES

17 *Within the ZEPOWEL project, a 60 kW DC-DC converter with an efficiency of 99.8% was developed. The converter was equipped with a universally usable IoT module.*
© Thomas Richter / Fraunhofer IISB

Power electronic converters are needed to couple photovoltaic systems, storage batteries and other components to the power grid. However, they usually lead to power losses. As part of the Fraunhofer lighthouse project ZEPOWEL, Fraunhofer IISB has therefore developed a particularly power-saving and efficient power electronic DC/DC converter with an efficiency of 99,8 percent. Thanks to an intelligent control module, the converter adapts itself to different grid states; and it even can put itself into power-saving deep sleep.

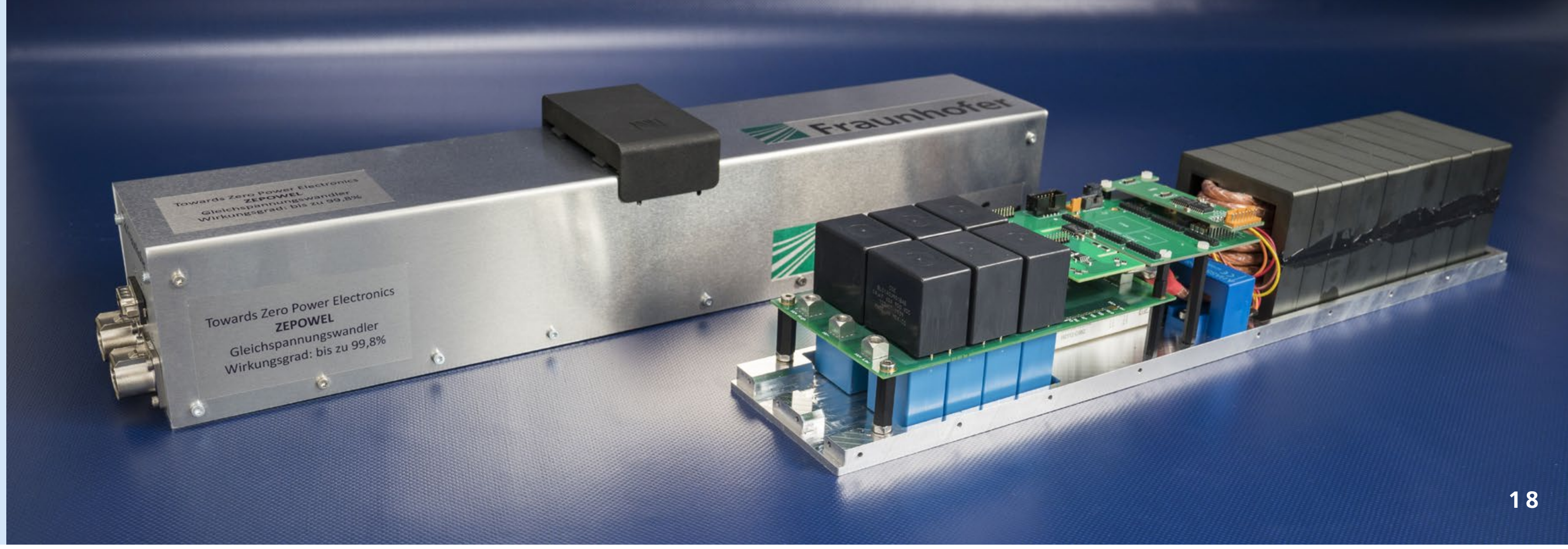
Electric power from the sun and wind has been fed into the power grid for the most part in recent decades. But with the development of increasingly powerful batteries, there is actual a trend to store and consume self-generated electricity directly on site. Supermarkets now use electricity from rooftop solar systems to power their freezers and lighting, while industrial companies use it to drive production lines and robots. The drawback is that the electricity has to be converted several times. Solar cells supply electricity at different voltages depending on solar radiation and temperature. Their output voltage must be stabilized before it can be fed into the grid on site. On sunny days, photovoltaic systems often supply more electricity than is needed. It then makes sense to store it temporarily. However, the electricity must be converted once again before it can be fed into the battery. If the battery is discharged later, it has to be converted one more time in order to feed the electricity back into the grid. The problem is that with each conversion, a considerable amount of the energy is lost, which is dissipated as heat.

Outstanding Efficieny of 99,8 Percent

In the lighthouse project ZEPOWEL (Towards Zero Power Electronics), the Power Electronics Systems division of Fraunhofer IISB, in cooperation with other Fraunhofer institutes, has developed a bidirectional DC/DC converter that is extremely energy-efficient thanks to a whole series of innovations. It is suitable for use both in buildings and in vehicles. The device achieves a converter efficiency of a remarkable 99.8 percent. Values between 95 and 99 percent have been the norm up to now. The step to 99.8 percent seems tiny. But losses are significantly reduced. The converter developed in ZEPOWEL can handle up to 20 kilowatts of electrical power. Such a converter with an efficiency of 95 percent would have a loss of 1000 watts. These thermal losses have to be dissipated by a correspondingly strong water or air cooling solution. This requires fans or pumps, which in turn consume electrical power. This makes conventional current converters even more inefficient. The new DC/DC converter with an efficiency of 99.8 has only 40 watts of waste heat and dissipates the small amount via a simple aluminum housing.

ZEPOWEL: CONVERTING ELECTRIC POWER WITH ALMOST UNOBSERVABLE LOSSES

Enormously Low Resistance
The Smart IoT Core
Boost for DC Technology



"For electrical components in this power range, every tenth of a watt really does matter!" says Bernd Eckardt, who heads the Vehicle Electronics department at Fraunhofer IISB. "With our DC/DC converter, we have now demonstrated a solution to avoid unnecessary losses during the conversion of electrical power."

Enormously Low Resistance

This success was made possible by the use of silicon carbide (SiC) power semiconductors, from which the heart of the converter is constructed. Silicon carbide is generally known as a robust ceramic but can be used as a semiconductor with a very low on-resistance and switching losses. Since it causes less losses than conventional silicon semiconductors, it is subjected to less thermal stress. This extends the service life. In addition, the converter has been optimized in terms of control technology. The converter operates in a boundary conduction mode, activating the semiconductor switch just in the moment of the zero voltage. Thanks to the control system, this switching prevents the turn on losses in the power module.

The Smart IoT Core

A main part of the ZEPOWEL project was the development of an energy-saving computing module, the IoT core. The module can be used universally to control various electronic components, not only Fraunhofer IISB's voltage converters, but also sensors for monitoring machines, for example. The IoT core consists of a microcontroller, batteries and energy-saving control electronics. If required, it can be expanded with a radio module to control or monitor machines remotely. The smart IoT core is characterized by the fact that it can process measured values directly on its CPU and control devices accordingly. Until now, it has been more common for sensors to send measured values to a control center, which then takes over control. The IoT core does this itself. Dr. Bernd Eckardt and his team have equipped their DC/DC converter with an interface to which the IoT core can be plugged. Its task is to measure the current flow, voltage, etc. and to optimally control the current converter. To save electricity even further, the IoT core can switch off the current converter independently - for example, at night when the solar system on the roof is no longer supplying power, or when the machines are shut down at the end of the day. Once the device is turned off, the IoT core itself goes into deep sleep mode, consuming only a few nanowatts. Only when it is activated via radio it starts up again. Even after days of dormancy, it can be revived in seconds.

The IISB is working on so called "Cognitive Power Electronics" for some time now. These are components that control themselves or detect faults independently. The new smart IoT core is an important building block for the development of such Cognitive Power Electronics. Because the IoT core is modular, it can be easily adapted to different applications. For example, ZEPOWEL has

also developed a sensor that supplies itself with energy through energy harvesting. In the future, it will be used on buses to send air quality information and alike to a data center, for example.

18 *Towards zero losses: DC/DC converter with up to 99,8 % efficiency of the Fraunhofer flagship project ZEPOWEL.*
© Thomas Richter / Fraunhofer IISB

Boost for DC Technology

The Fraunhofer IISB's DC/DC converter is less about self-sufficiency. After all, it is linked to power sources such as the photovoltaic system. Instead, the IoT core contributes to energy efficiency overall. As a result, it has what it takes to give the entire DC technology a new boost. Dr. Bernd Eckardt states, "because this is on the rise anyway!" Most buildings traditionally use alternating current. But the alternating current must first be converted into direct current with the help of power adapters in order to operate electrical devices such as computers or televisions. "That's why many companies are now switching to direct current when building new factories or production lines," Eckardt continues. Among other things, this also makes it easier to integrate photovoltaic and battery systems. And it is also easier to feed electricity back into the grid with direct current, as is the case with electric cars. In the future, machines and industrial robots will be able to easily feed electricity back by recuperation. Eckardt: "In this respect, the demand for power electronics for direct current networks is growing. So with our voltage converter, we are right on trend." In recent years, Fraunhofer IISB has transformed itself into a real world laboratory. A DC grid was also implemented here. It has a photovoltaic system with 150 kilowatts, a 60-kilowatt power storage unit, and it allows various components to be tested virtually in everyday operation - not just the new DC converter.

The ZEPOWEL Partners

The Fraunhofer lighthouse project ZEPOWEL (Towards Zero Power Electronics) ran for three years and ended in the second half of 2021. A total of nine Fraunhofer institutes were involved, in addition to Fraunhofer IISB: Fraunhofer Institute for Reliability and Microintegration IZM, Fraunhofer Research Institution for Microsystems and Solid State Technologies EMFT, the former Fraunhofer ESK – now Fraunhofer Institute for Cognitive Systems IKS, Fraunhofer Institute for Applied Solid State Physics IAF, Fraunhofer Institute for Integrated Circuits IIS, the Division Engineering of Adaptive Systems EAS of Fraunhofer IIS, Fraunhofer Institute for Photonic Microsystems IPMS, and Fraunhofer Institute for Silicon Technology ISIT.

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SCIENCE STARS

New Institute Director at Fraunhofer IISB
Happy Birthday, Prof. Ryssel!

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1 *Since September 1, 2021, Prof. Dr.-Ing. Jörg Schulze is the new director of Fraunhofer IISB in Erlangen. © Kurt Fuchs / Fraunhofer IISB*

NEW INSTITUTE DIRECTOR AT FRAUNHOFER IISB

AS OF SEPTEMBER 1, 2021, PROF. DR.-ING. JÖRG SCHULZE IS THE NEW DIRECTOR OF FRAUNHOFER IISB. HE TAKES OVER THE POSITION FROM PROF. DR.-ING. MARTIN MÄRZ, WHO HAS LED THE IISB ON AN ACTING BASIS SINCE 2018.

Simultaneously, Jörg Schulze assumes the Chair of Electron Devices at the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), with which the IISB closely cooperates in research and academic teaching. The semiconductor expert is excited about being able to cover the entire range from basic research to industrial application: "With our broad spectrum of technological understanding, system knowledge and application proximity, we want to further expand the IISB's position as a unique center of excellence in Europe for highly efficient power electronic systems and the semiconductor technologies required for them, and thus make important contributions to sustainable mobility and energy supply."

Since 2008, Jörg Schulze was director of the Institute for Semiconductor Engineering at the University of Stuttgart. There, he worked intensively on the material system silicon germanium tin and its use in transistors, photonics and quantum electronics, but also on the semiconductor material silicon carbide applied in power electronics. Previously, the native of Leipzig studied physics and genetics at the Technical University of Braunschweig, earned his PhD and habilitation at the Universität der Bundeswehr München with a research stay at the University of California in Los Angeles. He then worked for several years in the area of technical risk management and mathematical engineering in the Corporate Technology department of Siemens AG in Munich.

Jörg Schulze takes over his position from Prof. Martin März, who has led Fraunhofer IISB on an acting basis since 2018. "I am really looking forward to working with Martin März and my colleagues at the institute and at FAU," says Schulze.

HAPPY BIRTHDAY, PROF. RYSSEL!

PROF. HEINER RYSSEL, FORMER AND FIRST DIRECTOR OF FRAUNHOFER IISB AND THE CHAIR OF ELECTRON DEVICES (LEB) AT THE FRIEDRICH-ALEXANDER-UNIVERSITÄT ERLANGEN-NÜRNBERG (FAU), CELEBRATED HIS 80TH BIRTHDAY.

Heiner Ryssel is one of the pioneers and leading experts in the field of semiconductor technology in Germany. In particular, he was instrumental in transferring the ion implantation process to industrial use.

SCIENCE STARS

Space Research in Franconia

After studying electrical engineering and earning his doctorate at the Technical University of Munich, Heiner Ryssel worked at the Fraunhofer Institute for Solid State Technology in Munich. In 1985, he was appointed to the Chair of Electron Devices (LEB) at the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), one of the two founding chairs on the road to Bavaria's "Silicon Valley". In the same year, he became director of the Fraunhofer Working Group for Integrated Circuits, Department of Device Technology, which gave rise to today's Fraunhofer IISB, which he directed until his retirement in 2008.

Educating the next generation and promoting enthusiasm for semiconductor technology have always been of particular concern to Heiner Ryssel. His dedication to teaching included lectures at the Virtual University of Bavaria in addition to a wide range of courses at the FAU. He played a significant role in the modernization of the "Electrical Engineering - Electronics - Information Technology" course and in the implementation of the Mechatronics course at the FAU.

Heiner Ryssel has received numerous awards for his work, including the Fraunhofer Medal, the Wilhelm Exner Medal and the appointment as Life Fellow of the Institute of Electrical and Electronic Engineers (IEEE).

SPACE RESEARCH IN FRANCONIA

INSIGHTS INTO SEMICONDUCTOR AND SPACE RESEARCH WERE PROVIDED BY A PROJECT SEMINAR FOR STUDY AND CAREER ORIENTATION AT ECKENTAL HIGH SCHOOL, WHICH FOCUSES ON SUCCESSFUL RESEARCH IN FRANCONIA. IN COOPERATION WITH THE IISB AND THE HERMANN OBERTH SPACE MUSEUM IN FEUCHT, THE SEMINAR DEVELOPED AN EXHIBITION THAT COULD BE VISITED FROM OCTOBER 21 TO NOVEMBER 9, 2021.

About 130 visitors gathered in the auditorium of the Eckental High School for the ceremonial opening on October 21, 2021. Interesting and astonishing connections were highlighted by Dr. Jochen Friedrich, head of the Materials Department at the IISB, in his keynote speech "Crystals - Space - Franconia". Scientific experiments under zero gravity have a long tradition at the IISB, especially in the field of semiconductor materials. Franconian research has been involved in several space shuttle flights: Among others, astronaut Ulf Merbold grew crystals from and for Erlangen on the Spacelab.

The exhibition showed numerous examples of the areas of space research in which Franconian scientists have been very successful and will continue to be involved in the future. In addition to an extensive collection of posters, this also included exhibits from the IISB and the Hermann Oberth Space Museum.

2 *Prof. Dr.-Ing. Heiner Ryssel, former and first director of Fraunhofer IISB, celebrated his 80th birthday. © Kurt Fuchs / Fraunhofer IISB*

3 *Opening of the exhibition "Space Research in Franconia" at Eckental High School. The exhibition was developed by pupils in a project seminar in collaboration with the Hermann Oberth Space Museum and Fraunhofer IISB. © Uwe Rahner / NOVUM Verlag & Werbung*

SCIENCE STARS

IISB Awards for Research and Inventions 2021

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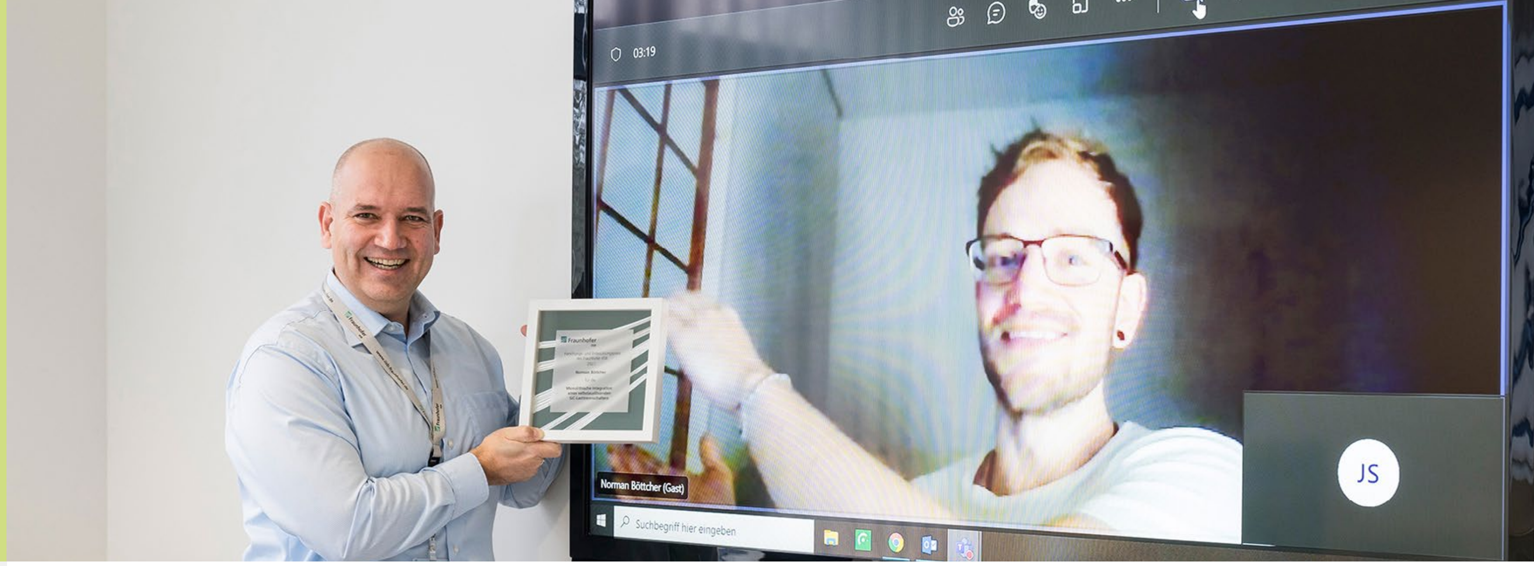

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IISB AWARDS FOR RESEARCH AND INVENTIONS 2021

Team Award | Individual Prize | Additional Prize

THE IISB AWARDS FOR RESEARCH AND INVENTIONS PRESENTED ANNUALLY BY THE FRAUNHOFER IISB DIRECTORATE ACKNOWLEDGE OUTSTANDING ACHIEVEMENTS BY IISB SCIENTISTS.

This year's Team Award was presented by IISB director Prof. Jörg Schulze to Dr. Tobias Erlbacher and Dr. Jürgen Leib for their outstanding cross-departmental collaboration in the project "Cross-departmental development of fast-switching specialized electron devices".

The award-winning project is based on Fraunhofer IISB's unique vertical integration along the power elecronics value chain. In order to fulfill the project requirements holistically, 4 out of 6 of our research departments collaborated closely and successfully. Every step on the way to a functioning SiC-based electron device was covered in our institute: Wafer material development, simulation-based device design and optimization, process development, device fabrication in our own wafer fab for silicon and silicon carbide as well as packaging.

As one of the three award winners, Norman Böttcher was honored by IISB director Jörg Schulze for his development of a novel monolithically integrated 4H-SiC circuit breaker device suitable for 800 V DC-applications. Its 800 V capability makes the 4H-SiC circuit breaker a fitting component in the field of e-mobility or in smart grid environments, for example. The innovative devices provide self-sensed operation and, therefore, unite the benefits of mechanical and solid-state circuit breakers in a single semiconductor chip.

At Tokyo Metropolitan University, Norman Böttcher was able to demonstrate the promising electrical performance in international collaboration with renowned power electronics expert Prof. Keiji Wada.

And last but not least, Dr. Andreas Erdmann received the award for his strategic development of lithography simulation, especially for extreme ultraviolet lithography (EUV).

Of particular importance are the novel models and simulation techniques that provide a better understanding of lithographic mask imaging for the next generation of EUV. Such understanding of so-called 3D mask effects and the identification of appropriate new types of absorber materials are essential for the application of high NA EUV lithography. High NA EUV lithography is a key component for the fabrication of future generations of computer chips.

4 *Prof. Jörg Schulze (left), Dr. Jürgen Leib (center), and Dr. Tobias Erlbacher (right) during the presentation of the Fraunhofer IISB Research and Inventions Award.*
© Amelie Schardt / Fraunhofer IISB

5 *While on his research stay at Tokyo Metropolitan University, Normann Böttcher was awarded the IISB prize "virtually" by Prof. Schulze.*
© Amelie Schardt / Fraunhofer IISB

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STAEDTLER FOUNDATION DISSERTATION AWARD

DR. JULIETTA FÖRTHNER, A MEMBER OF THE „SILICON CARBIDE AND RELATED MATERIALS“ GROUP IN THE MATERIALS DEPARTMENT AT FRAUNHOFER IISB, WAS AWARDED A DOCTORAL PRIZE BY THE STAEDTLER FOUNDATION.

Since 1999, the STAEDTLER Dissertation Awards have regularly honored outstanding achievements by young scientists at Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU).

Prior to her work at the IISB, Dr. Julietta Förthner completed her doctorate as part of a DFG project at FAU's Chair of Electron Devices (LEB) on the topic of "Lateral and Vertical Charge Compensation Structures in 4H Silicon Carbide". The head of the LEB chair is Prof. Jörg Schulze, director of the Fraunhofer IISB institute, and the PhD was supervised by Priv.-Doz. Dr. Tobias Erlbacher, also head of the Department of Semiconductor Devices at Fraunhofer IISB.

In her dissertation, Dr. Julietta Förthner investigated advanced manufacturing processes for silicon carbide (SiC) semiconductor devices. Based on experiments, she first developed a model for the preparation of so-called charge compensation structures in the semiconductor. The new model is based on the physical effects in the semiconductor and takes into account the material defects occurring in the semiconductor material and during the device processing.

With her model, Dr. Julietta Förthner successfully described a technology for the manufacturing of electronic charge compensation structures on SiC substrates and precisely defined the required process parameters. On this basis, she succeeded in manufacturing and electrically characterizing her own silicon carbide power electronic devices using the extensive process technology of the clean room laboratory at the LEB.

The investigations carried out by Dr. Julietta Förthner enable especially low-loss SiC devices with high dielectric strength using charge compensation. Such devices are urgently needed, for example, in electrical power transmission and especially for medium-voltage technology. With the comprehensive technological preparation and formulation, the work of Dr. Julietta Förthner makes an important contribution to more efficient supply of electrical energy and to CO_2 reduction as well as acceleration of the energy transition.

6 *Dr. Julietta Förthner was honored with the STAEDTLER Foundation Dissertation Award for her doctoral thesis entitled "Lateral and vertical charge compensation structures in 4H silicon carbide". © Julietta Förthner / Fraunhofer IISB*

7 *Dr. Andreas Erdmann (right) was awarded by Prof. Schulze (left) with another IISB prize for his strategic development of lithography simulation, especially for extreme ultraviolet lithography (EUV). © Amelie Schardt / Fraunhofer IISB*

SCIENCE STARS

Energy Prize of the Energy Campus Nuremberg

ENERGY PRIZE OF THE ENERGY CAMPUS NUREMBERG

JOHANNES GEHRING, MASTER'S STUDENT IN MECHATRONICS AT FAU, WAS AWARDED THE ENERGY PRIZE 2021 OF THE ENERGY CAMPUS NUREMBERG (ENCN) FOR HIS MASTER'S THESIS.

The thesis is entitled "Development and Characterization of a Dual-Active Bridge with GaN Transistors" and was submitted to the Chair of Power Electronics (LEE) at the FAU. The chair holder of the LEE is Prof. Martin März, also head of the main department Power Electronic Systems at Fraunhofer IISB.

The Energy Prize 2021 was presented by Christian Zens, Chairman of the Board of EnCN e.V. and Chancellor of FAU, as well as Dr. Michael Fraas, professional City Councilor and Economics and Science Officer of the City of Nuremberg.

Johannes Gehring has developed and comprehensively characterized a galvanically isolating DC/DC converter with GaN transistors based on the "dual-active bridge" principle. His DC/DC converter enables bidirectional energy transfer - i.e. in both directions - and can step up or step down voltages with very high energy efficiency.

Such a converter topology is suitable, for example, for DC charging of electric vehicles, because energy from the vehicle battery can also be fed back into the power grid. This functionality will be important in the future for stabilizing the power grid, especially in regard to the rapidly growing amount of renewable energy sources in the context of the energy transition.

The special feature of the converter is its modular design in the form of several stackable boards. This makes it possible to create almost any topology - including multiphase topologies - by simply plugging in additional boards. Johannes Gehring's goal was to create a construction kit with standard boards for further investigations of a wide variety of converter topologies.

Johannes Gehring is one of a total of six young scientists honored with the 2021 Energy Prize for their outstanding contributions in the area of research and development in renewable energies.

8 *Johannes Gehring, master's student in mechatronics at FAU, was awarded the EnCN Energy Prize 2021 for his master's thesis. His master's thesis was supervised at the Chair of Power Electronics (LEE, Prof. Martin März).* *© Amelie Schardt / Fraunhofer IISB*

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SCIENCE STARS

Outstanding Training Qualification at the IISB

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OUTSTANDING TRAINING QUALIFICATION AT THE IISB

KEVIN EHRENSBERGER, WHO COMPLETED HIS APPRENTICESHIP AS A MICROTECHNOLOGIST AT IISB IN JULY 2021 WITH A GRADE OF „VERY GOOD," WAS HONORED AT THE FRAUNHOFER-GESELLSCHAFT'S „HONORING THE BEST" CEREMONY ON NOVEMBER 3 AND 4.

The excellent graduation is especially highly valued in Corona times due to the difficult boundary conditions. After completing his education, Kevin Ehrensberger was hired by the IISB as an employee and is now working in the Department of Semiconductor Devices. The IISB has been educating microtechnologists very successfully and in close cooperation with the FAU since 1999.

What Does a Microtechnologist Do at Fraunhofer IISB?

In the semiconductor industry, microtechnologists represent the link between pure "operators" and process engineers. The technically demanding job requires solid technical knowledge and a high level of flexibility. As a microtechnologist, one learns how semiconductor components, micromechanical sensors and microchips are processed on silicon wafers or other semiconductor substrates. This involves the production of minuscule structures and ultra-thin layers in the micro- and nanometer range, many times smaller than the diameter of a human hair.

The very sensitive devices and circuits must be protected from the slightest chemical contamination and the smallest particles. Because even a single grain of dust is harmful to the proper function of a microchip, microtechnologists work in clean room laboratories. In these special laboratories, there are clearly defined and controlled environmental conditions. For example, humidity and temperature are precisely controlled and the air is constantly exchanged and filtered. The cleanroom laboratories may also only be entered through airlocks, and wearing protective clothing and complying with hygiene regulations are part of everyday working life.

At our institute, microtechnologists are directly involved in the processing and development of electron devices and integrated circuits. During the three-year apprenticeship period, the trainees are developing into specialists in high-tech equipment, process steps, materials, analysis methods and nanotechnologies. With a wide range of possible employments in industry, such as in the manufacturing of computer chips, power electronics, sensors or light-emitting diodes, the future prospects are excellent.

By the way, the average share of our female apprentices is fifty percent.

9 *Kevin Ehrensberger was honored by the Fraunhofer-Gesellschaft for his outstanding completion of his apprenticeship as a microtechnologist. He finished the three-year education at Fraunhofer IISB in Erlangen. © Amelie Schardt / Fraunhofer IISB*

10 *View into the clean room laboratory of the Chair of Electron Devices (LEB, Prof. Jörg Schulze). The cleanroom laboratory is operated by the University of Erlangen-Nürnberg in close cooperation with Fraunhofer IISB. © Kurt Fuchs / Fraunhofer IISB*