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IISB

Fraunhofer Institute for
Integrated Systems and Device Technology IISB

Annual Report 2024

Annual Report 2024

Achievements and Results

Prof. Jörg Schulze, Director of Fraunhofer IISB and chairholder and Head of Chair of Electron Devices

Editorial

The IISB was once again one of the most economically successful and stable institutes in the Fraunhofer-Gesellschaft. Our broad activities traditionally and uniquely serve the entire value chain, from basic materials to semiconductor devices to power electronic systems.

This approach is reflected both in the structure and strategic thinking of the IISB. We are working intensively to anchor and expand it in all our focus areas, whether silicon carbide, ultra-wide bandgap semiconductors, packaging, aviation, or battery systems. In this way, we are making a targeted contribution to ensuring the technological sovereignty and resilience of Germany and Europe and supporting our companies in the necessary diversification and transformation. In times of extreme economic, social, and geopolitical challenges – and yes, also climate protection must continue to occupy us despite all the political crises – this task can ultimately only be mastered jointly, in strategic cooperation with strong European partners.

This is playing an increasingly important role in the work of the IISB and is evident in many ways:

The power electronics institutes of the Research Fab Microelectronics Germany (FMD) presented their combined expertise for the first time in 2024 at a joint booth at our most important power electronics trade fair, PCIM Europe in Nuremberg. A repeat of this successful appearance is firmly planned for the coming years. Together with partners from research and industry, the IISB has established a continuous German aluminum nitride value chain from material to device – our new 2-inch crystal is an absolute highlight here. We are advancing our promising aluminum-ion battery technology in joint projects. Our regional High Performance Center for Electronic Systems (LZE) took first place in the 2024/25 evaluation ranking of all twenty Fraunhofer High Performance Centers.

Together with one of the LZE partners, the University of Erlangen-Nuremberg (FAU) and its production engineering chair FAPS, we initiated the E|Road-Center, which began operations in early 2025 as a new branch of the IISB in Hallstadt. The successful model of the IISB Joint Labs has been expanded to include two further collaborations with companies. The institute is also well represented at European level and has an international network, whether through our comprehensive activities within the framework of Clean Aviation or as the sole German representative in the Wide-Bandgap Pilot Line of the European Chips Act, which will also be launched in 2025. All this is complemented by joint activities to recruit and train skilled experts within the FMD, Bavaria or the Nuremberg Metropolitan Region.

Partnership-based networking is also rewarded. My colleague Dr. Jochen Friedrich, head of our Materials Department, received the 2024 DGKK Award from the German crystal growth association for his long-term merits. I myself have had the honor of serving as spokesperson for the Bavarian Chips Alliance since the beginning of 2024.

With this in mind, I would like to thank our European, German, and Bavarian funding authorities for their support. I look forward to the upcoming celebrations marking the 40th anniversary of the IISB (and its partner chair LEB at FAU) and now warmly invite you to enjoy our annual report.

Sincerely yours,

Prof. Jörg Schulze
(Erlangen, April 2025)

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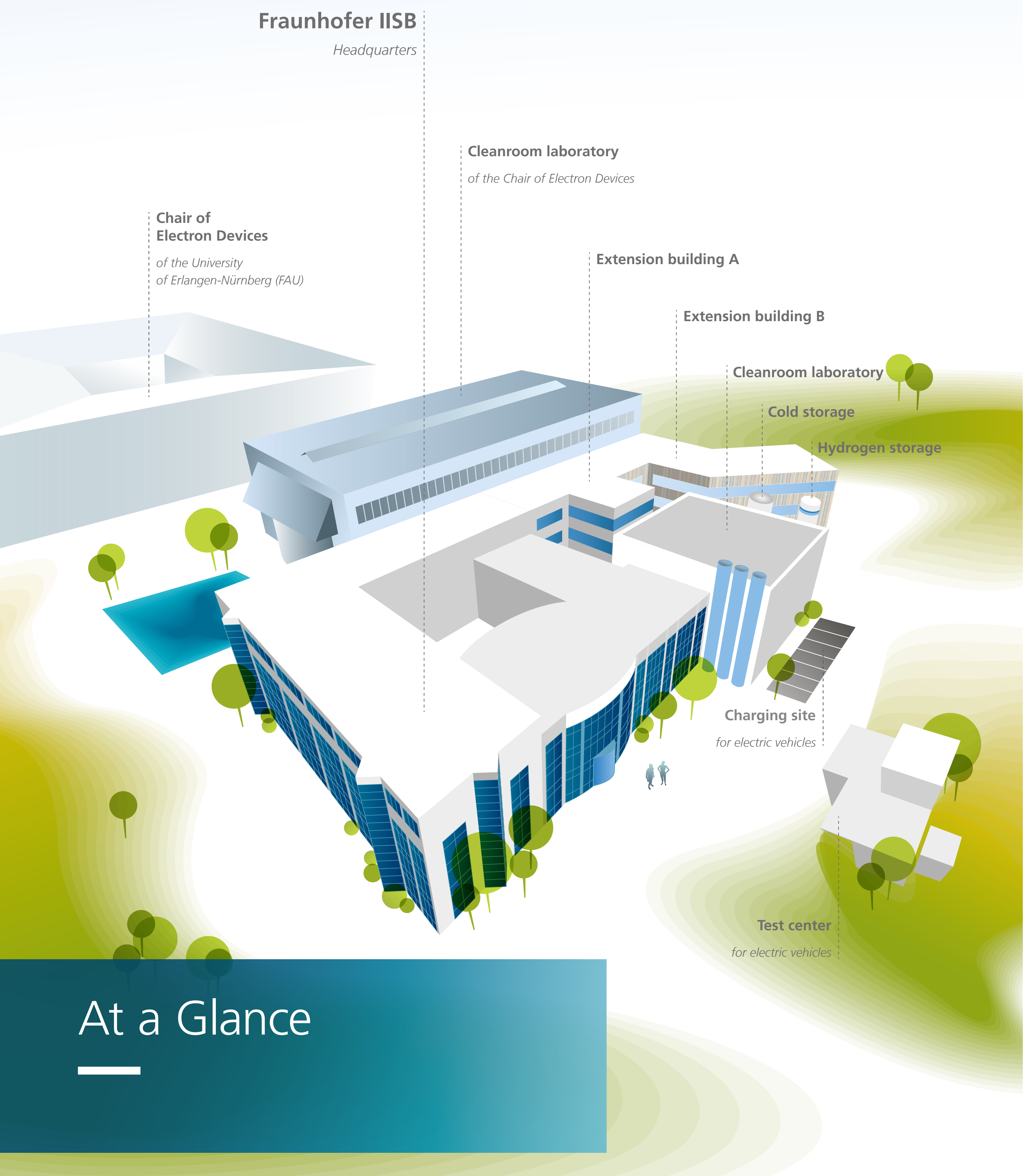
Headquarters of Fraunhofer IISB in Erlangen. © Anja Grabinger / Fraunhofer IISB



At a Glance

Profile

Intelligent Power Electronic Systems and Technologies - following this motto, the Fraunhofer Institute for Integrated Systems and Device Technology IISB, founded in 1985, conducts applied research and development for the direct 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 Semiconductors and Power Electronic Systems. 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) and (ultra)-wide-bandgap semiconductors, 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 employs about 400 people. Its headquarters are in Erlangen, with another branch at the Fraunhofer Technology Center High Performance Materials (THM) in Freiberg.

The institute cooperates closely with the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), the TU Berkakademie Freiberg and the University of Bayreuth. The IISB is a founding member of the Energie Campus Nürnberg (EnCN) as well as the Leistungszentrum Elektroniksysteme (LZE). In joint projects and associations, Fraunhofer IISB cooperates with numerous national and international partners.

iisb.fraunhofer.de/network-cooperations

History

The Fraunhofer Institute for Integrated Systems and Device Technology IISB in Erlangen is an established center of applied R&D for intelligent electronic systems, power electronics, semiconductor technology, and materials development in the Nuremberg metropolitan region, Germany, and Europe.

It was founded in 1985 as the Electron Devices department AIS-B of the Fraunhofer Working Group for Integrated Circuits. In 1993, it became a Fraunhofer institute (IIS-B), but was still formally linked to its affiliate institute IIS-A, today's Fraunhofer Institute for Integrated Circuits IIS.

In 2003, IIS and IISB became completely independent from each other as two individual Fraunhofer institutes. From 1985 until 2008, Prof. Heiner Ryssel was the head of the IISB. From 2008 to 2018, Prof. Lothar Frey was director, followed by Prof. Martin März until September 2021. Since then, the institute is led by Prof. Jörg Schulze.

From the beginning, the IISB has been closely cooperating with the University of Erlangen-Nürnberg (FAU). In 2015, the IISB together with the IIS and the FAU Erlangen-Nürnberg founded the »Leistungszentrum Elektroniksysteme« (LZE).

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Advisory Board

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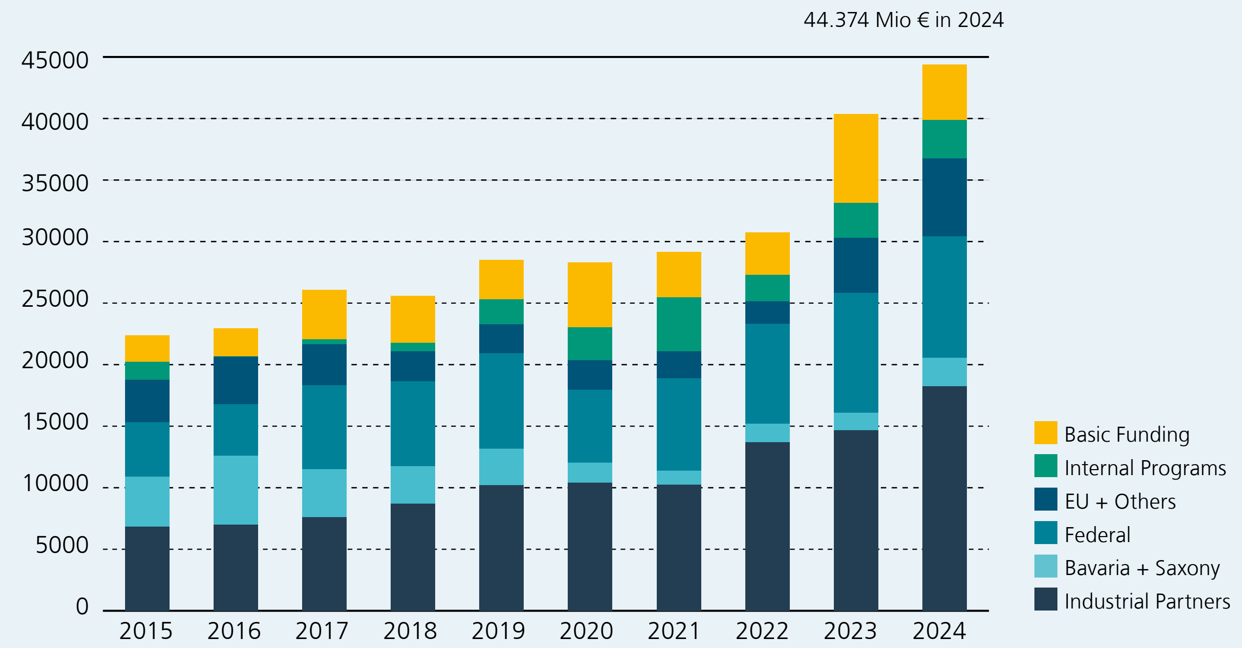
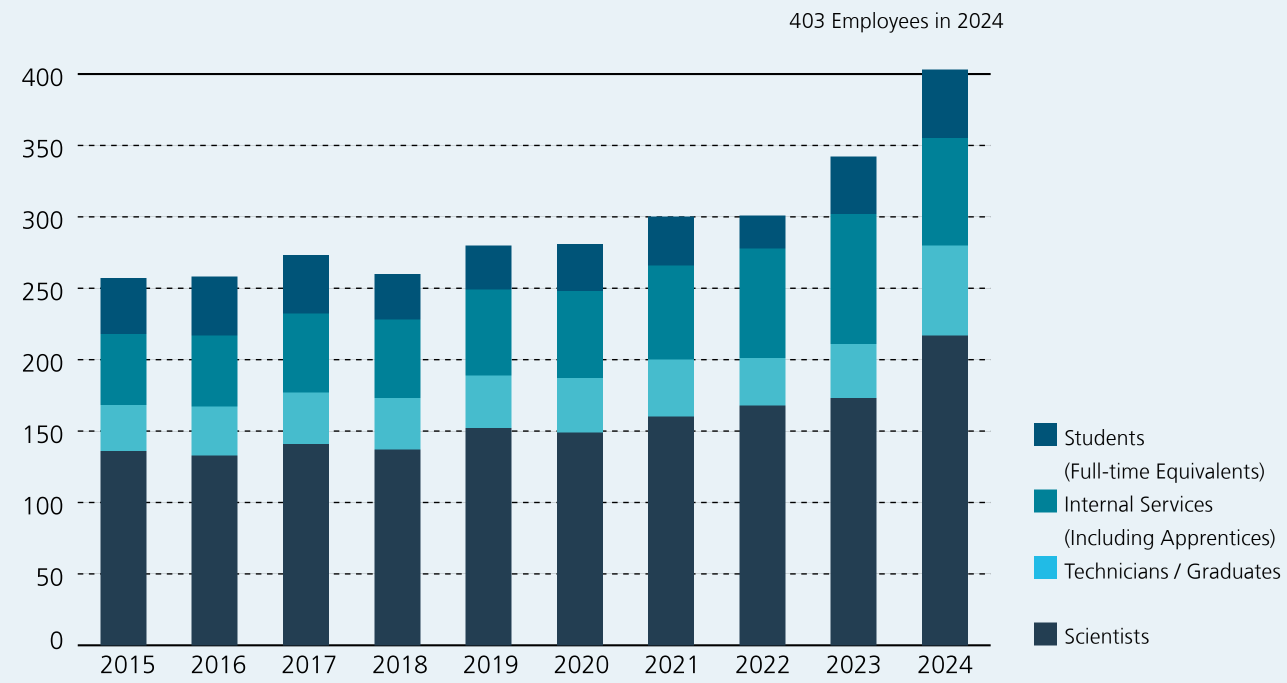
The IISB Advisory Board consists of members from science, industry and politics who advise the IISB Directorate on strategic and structural development issues

Operating Budget



Staff Development



Fraunhofer IISB: one Institute, many opportunities © Elisabeth Iglhaut I Fraunhofer IISB

Organizational Chart 2024

Institute Management

Institute Director
J. Schulze

Staff Group of the Institute Director
B. Fischer

Central Services
Ferdinand Weidmann

Divisions

Energy Materials and UWBG Semiconductor Technology
J. Heitmann

Semiconductor Production Technology
J. Schulze

Power Electronic Systems
M. März

Intelligent Energy Systems
V. Lorentz

Departments

Energy Materials and Test Devices
U. Wunderwald

Materials
J. Friedrich

Advanced R&D
M. Jank

Front End
S. Oertel

Modeling and AI
A. Rosskopf

π-Fab Mgmt.
M. Pfeffer

Power Electronics
B. Eckardt, M. Hofmann

Drives
Section

Central Technologies
Section

Voltage Converters
Section

Intelligent Energy Systems
V. Lorentz

The IISB covers the entire value chain for next-generation power electronics: from material to chip and from module to system
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The Fraunhofer IISB specializes in wide-bandgap semiconductors and efficient power electronics.

Here, materials and device know-how merges with complex system development, especially for e-mobility and sustainable energy supply.

Unique Value Chain for Next-Generation Power Electronics

In operando and real-time observation of battery test cells © Daniel Karmann / Fraunhofer IISB

Division
Energy Materials and
UWBG Semiconductor Technology

»High-performance materials such as new semiconductor and energy materials are fundamental to solve the major challenges of our time: the transformation of our energy system towards sustainability, intelligent mobility and digitalization. Our main interest is a profound understanding of the material properties in order to develop new processes and integration schemes for the need of battery and semiconductor technology.«

Prof. Johannes Heitmann,
Head of Energy Materials and UWBG Semiconductor Technology Division,
Head of Technology Center High Performance Materials THM and
Director of the Institute of Applied Physics
of the TU Bergakademie Freiberg
© Daniel Karmann / Fraunhofer IISB

At our site in Freiberg, Fraunhofer IISB and the Institute of Applied Physics (IAP) at TU Bergakademie Freiberg jointly investigate new, high-performance semiconductor materials and the associated efficient manufacturing technologies for the processing and characterization of novel electron devices.

Similarly, we develop Li-free Al-ion batteries, which are based on cost-effective electrode materials and non-flammable electrolytes, achieving high charging currents and high cycle stability. Researching a totally new battery approach allows us to address a recycling friendly design and to establish a model system for the realization of a circular economy already in an early stage of technology development.

In the field of semiconductor materials and devices, one major point of our work is to evaluate the role of defects for the reliability and functionality of upcoming power electronic or quantum devices based on ultra-wide-bandgap materials. The development of processes and materials and their integration into prototypes and test vehicles are among the most important tools we use here. We are developing in-operando characterization techniques using spectroscopy and X-ray metrology for the characterization of our devices in working conditions or for the identification and recognition in sorting and recycling processes.

thm.fraunhofer.de

Energy Materials and Test Devices

»Within the value chain for power electronics at the IISB, we see ourselves as the link between material development and the final electron device or electrical energy storage system.«

Dr. Ulrike Wunderwald,
Head of Energy Materials and Test Devices Department
© Daniel Karmann / Fraunhofer IISB

The Energy Materials and Test Devices department is located at the Fraunhofer IISB branch in Freiberg, Saxony. Here, we operate the Fraunhofer Technology Center for High-Performance Materials THM in collaboration with Fraunhofer IKTS. Both institutes complement each other thematically at this location and can work together closely in joint projects. In cooperation with the Institute of Applied Physics (IAP) at the TU Bergakademie Freiberg, we are researching new, high-performance electronic materials and related efficient process technologies for the processing and characterization of electron devices.

Our focus is on gaining a deep understanding of fundamental material properties and physical mecha-nisms. Based on this, we develop new manufacturing processes and integration methods for the re-quirements of our customers in industry and research.

Within the value chain for power electronics at Fraunhofer IISB – from semiconductor materials to power electronic systems – we see ourselves as the link between material development and the final electron device or electrical energy storage.

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.

With many years of experience in analytics, characterization, and metrology, particularly using operando and inline methods, and with state-of-the-art laboratory equipment, we act as a front-end foundry for two major research areas:

1. Development and evaluation of innovative semiconductor devices and associated processing steps, especially on the basis of WBG and UWBG semiconductor materials such as SiC, AlN, GaN or Ga_2O_3.

We carry out device and process development in the jointly used, CMOS-compatible clean room at the TU Bergakademie Freiberg. Here, we are able to independently and flexibly integrate novel materials into test devices and to develop and evaluate individual processing steps, all the way to piloting. A special feature is our expertise in atomic layer processing and atomic scale precision. For functional characteriza-tion, we use comprehensive in-operando analytics at Fraunhofer THM, which allows us to observe the test devices live during switching. We work hand in hand with the Materials department at Fraunhofer IISB, which provides us with innovative substrates, for example based on gallium nitride (GaN) or alumi-num nitride (AlN). After the evaluation phase, the processes and process chains will be transferred to the joint cleanroom of the IISB and FAU Erlangen-Nürnberg for further development and to achieve higher levels of technological maturity and reliability. To this end, we are in close contact with our semiconduc-tor technology departments.

2. Development of new battery technologies and their evaluation using appropriate cell prototypes, in particular based on aluminum-ion cell chemistry.

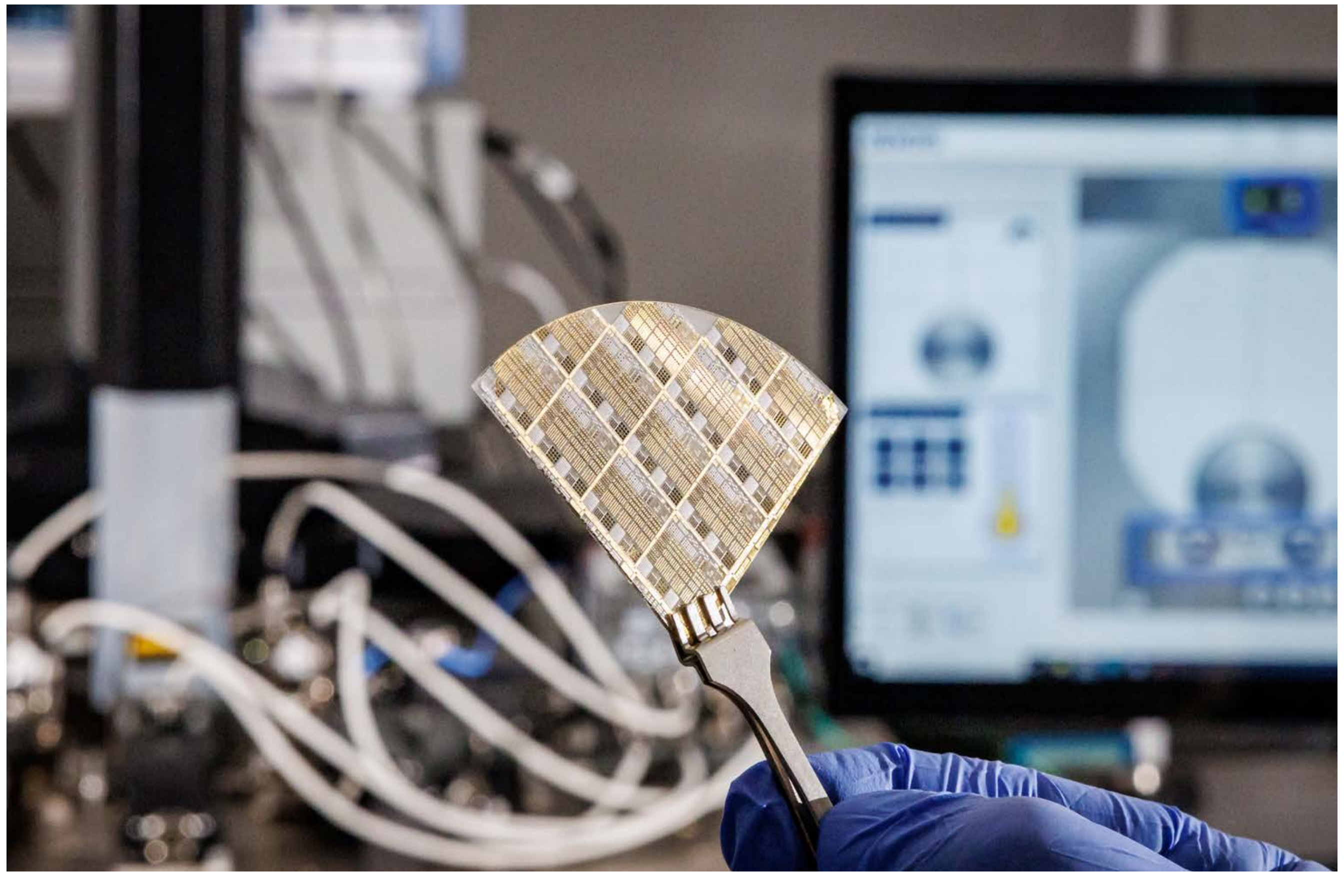
We develop new cell concepts and manufacturing processes for sustainable batteries, such as the alumi-num-ion cell chemistry, which does not require critical materials likesuch as lithium or cobalt and is safe, cost-effective and recyclable. We then assemble suitable test cells for evaluation using our analysis and characterization tools. Here, our in operando measurement methods enable us to observe the battery cells in real time and analyze structural changes. In order to ensure that our cell chemistries meet the requirements of the applications and to continuously develop them further, we work together closely with the Intelligent Energy Systems department at the IISB.

Our activities regarding the characterization of semiconductor base materials and semiconductor test devices as well as the development of innovative battery technologies are supported by extensive analyt-ics, which we perform with a very high degree of technical expertise. The level of expertise and scientific know-how that we have achieved with our in operando and in line methods are a unique selling point for the Energy Materials and Test Devices department at Fraunhofer IISB.

Due to their outstanding importance, these research activities and services have been organized in a separate working group called “Operando and In-line Analytics.” This methodology also allows material flows and process sequences to be tracked. This generates a large amount of data, which we evaluate using AI routines.

The triad of scientific theory, research methodology, and practical application makes us a reliable re-search and service partner for the semiconductor and battery sectors.

iisb.fraunhofer.de/materials



GaN-HEMT and test devices on sapphire substrate
© Daniel Karmann / Fraunhofer IISB

Hardware and process development for SiC epitaxy in the Joint Lab with Aixtron SE © Daniel Karmann / Fraunhofer IISB

Division Semiconductor Production Technology

»Novel wide-bandgap semiconductor materials and devices constitute the beginning of the value chain for globally competitive electronic systems and applications. Forming an essential basis for highly performant chips and sustainable power electronics, their availability ensures the technological sovereignty of Europe and serves the specific needs of our industry in the fields of automotive and transport, aerospace, energy supply, security, or production.«

Prof. Jörg Schulze,
Director of Fraunhofer IISB,
Head of Semiconductor Production Technology Division and
Chair of Electron Devices (LEB) of the
Friedrich-Alexander-Universität Erlangen-Nürnberg
© Kurt Fuchs / Fraunhofer IISB

Following our well-established R&D value chain, the portfolio of Fraunhofer IISB in semiconductor technology covers the development of crystalline and other functional materials as well as of power, sensor, passive, and thin-film devices and processing technologies in a comprehensive laboratory and cleanroom environment. Focusing on (ultra-)wide-bandgap semiconductors, this is a prerequisite for the assembly of innovative and highly efficient power modules and systems, supplemented by research on novel sensors and quantum technologies.

Supported by characterization, test, and metrology, modeling and artificial intelligence, our prototyping fab ensures high flexibility with regard to our customers' needs and provides a continuous silicon CMOS as well as a unique silicon carbide (SiC) process line in an industry-compatible environment. This includes a proprietary high-temperature SiC CMOS technology.

In aluminum nitride (AlN) for future power electronics or UV-C LEDs, we are heading for perfect crystals with diameters of two inches and beyond. In this context, IISB is the competence center and contact point for SiC, UWBG, and power devices within the Fraunhofer-Gesellschaft and the Research Fab Microelectronics Germany (FMD).

Modeling and Artificial Intelligence

»The MKI department continuously expands know-how in physics, mathematics, artificial intelligence, and cutting-edge computing to tackle real, industry-relevant challenges.«

Dr. Andreas Roßkopf,
Head of Modeling & Artificial Intelligence Department
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Technology Computer-aided Design (TCAD) continues to be an essential pillar for the advancement of microelectronics, nanoelectronics, and power electronics.

At the IISB, we unlock the full benefits of TCAD by combining simulation with ongoing verification and iterative improvement of our models through high-quality measurements. This close interplay between measurement and simulation is not only a technical imperative, but also a distinctive strength of our institute: In today's dynamic and highly specialized research landscape, the integration of experimental and simulation expertise under one roof provides a unique advantage – enabling us to tackle real, industry-relevant challenges and engage in projects that address authentic, production-oriented problems.

Our department operates at the crossroads of mathematics, physics, advanced coding across diverse hardware platforms, artificial intelligence, and profound application know-how. This interdisciplinary approach empowers us to push the boundaries of solution quality, achieving optimal trade-offs between accuracy and computational efficiency.

In particular, our expertise in parameter and geometry optimization positions us to actively support the product development of leading semiconductor and lithography companies in Europe. By bringing together these capabilities, we ensure that our simulation tools and methodologies remain at the forefront of innovation and are directly applicable to the evolving needs of industry and research.

The semiconductor sector – and the field of simulation in particular – is characterized by a continuous change and a relentless drive for innovation. At the IISB, and especially in the MKI department, we are committed to this spirit of progress: Based on the experience of our senior experts (supporting us even beyond their official retirement), we are building a growing team of highly skilled scientists to further push the boundaries of simulation and deliver solutions to real-world problems of today and tomorrow.

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Materials

»We have profound experience in the areas of semiconductor crystal growth, epitaxy, and device processing including characterization and modeling.«

Dr. Jochen Friedrich,
Head of Materials Department
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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.

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 find 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.

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Fraunhofer IISB has established a Joint Lab with
Semilab Zrt, a leading supplier for semiconductor metrology
© Daniel Karmann / Fraunhofer IISB

Front End

»The Front End department is your partner for advanced process steps and reliable electron devices. As part of the π-Fab, we operate a continuous silicon CMOS and silicon carbide process line in an industry-compatible environment.«

Dr. Susanne Oertel,
Head of Front End Department
© Elisabeth Iglhaut / Fraunhofer IISB

The Front End department consists of a Process Enhancement group, as well as a team of scientists, engineers, technicians, and microtechnologists with extensive expertise in electronic device processing and manufacturing in cleanroom facilities. It is responsible for all technology areas: wet etching, lithography, metallization, dry etching, ion implantation, hot processing, and back end.

Process Control and Analytics

In 2024, the Process Control and Analytics group was established, led by Dr. Helene Gehles, with support from the Fraunhofer Talenta initiative Speed Up. The group consist of six experienced employees and focuses on contamination analysis and quality assurance across various industries. Contamination analysis currently consists of inorganic and organic ultra / trace analysis and defect surface inspection. With its experience in contamination analysis, the Process Control and Analytics group supports quality assurance and contamination management at our institute as well as in industry and at other Fraunhofer institutes. By identifying material defects and manufacturing faults, the group supports both our internal process control from the start to the finished component and customers from industry. The patented method for Focused Ion beam (FIB) analysis allows for contamination-free process characterization. In addition to the wafer materials Si and SiC, the group plans to fully incorporate GaN as a substrate for the metrology methods. Among other projects, the research results from the work in the EU CLOSER project, in which the group has been involved since 2024, will be used for this purpose. Furthermore, the group permanently works on optimization of non-destructive process control capabilities.

Si(C) Process Enhancement

The Front End department carries out the manufacturing processes with higher Technology Readiness Levels (TRL 6 to TRL 8). The Si(C) Process Enhancement group focuses on improving these processes and implementing customer-specific modifications. The Front End department works closely with the Advanced Development department to assist our customers in implementing new processing concepts. This collaboration facilitates access to semiconductor technology for small and medium-sized enterprises (SEMs), potentially leading to small-volume prototype runs. Standard wafer size is 150 mm, while 200 mm and other diameters can be accommodated upon request..

Continuity in Semiconductor Processing

Fraunhofer IISB´s CMOS technology is provided via the Europractice platform, commencing with early-access prototypes. Front End closes the gap between single-unit production and high-volume manufacturing in commercially operated foundries.

The π-Fab, the Advanced Development department, and the Front End department serve various markets, including custom devices, power electronics, sensors, and CMOS technologies. Notably, we achieved a significant year-to-year increase of 18% in wafer movements, with 64% of these moves originating from SiC processes.

To further strengthen opportunities, the Front End department, the π-Fab Management Team, and the Spectroscopy and Test Devices group at THM Freiberg are collaborating to establish links to other cleanrooms within the Fraunhofer-Gesellschaft as part of the Fraunhofer internal cleanroom strategy 2.0 III/V UWBG project. These connections and the lessons-learned from it are crucial aspects for the APECS and UWBG pilot line projects set to launch in 2025.

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The µe-bauhaus erlangen-nürnberg

New organizational structure makes it possible to coordinate the usage of the cleanroom laboratory across the board and optimally utilize capacities. For each requirement, individual responsibilities are assigned in the departments. The core team at the front end is supported by employees from the research sector. For this purpose, the concept of the Doctoral Student Line was developed, which, in addition to increasing capacity for processing, above all enables an in-depth networking. This guarantees that the device developers are more closely linked to the implementation of “their” processes and can gain a deeper understanding of the key process steps.

This close integration of technical and scientific disciplines results from the implementation of the Bauhaus concept, which is established at the IISB together with the Chair of LEB at FAU, from industrial and student training to the integration of doctoral students.

The common goal of all the teams involved is the coordinated provision of an efficient, quality-assured process and development environment for Si and (U)WBG device prototypes as well as associated training and education concepts. In this way, excellent research and services can also be made available and realized for our industrial and public clients in the future.

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µe-bauhaus erlangen-nürnberg:
triad of study, laboratory, research & development
© Rida el Ali / Fraunhofer IISB

Division Semiconductor Production Technology

R&D Semiconductor Devices and Processing

»The R&D Semiconductor Devices and Processing department conducts research on new device concepts and their realization, and offers development services for customers and project partners.«

Dr. Michael Jank,
Head of R&D Semiconductor Devices and Processing Department
© Elisabeth Iglhaut / Fraunhofer IISB

In the silicon carbide value chain, the development of devices and the process integration as standardized sub-process sequences, known as modules, are essential steps.

Process Modules are Key

Process modules define the electrical parameters of components through the harmonized interaction of sequentially executed semiconductor manufacturing steps. One example is contact formation, which, starting with surface doping, cleaning, metallization, thermal silicide formation, purification, and finally coating with the connection metal, leads to an overall result through several steps, each with its own specific characteristics. In this case, the result is the optimized specific contact resistance. Numerical models and analysis tools are available at all stages of the development process.

Since the process modules can be used across applications for power devices, CMOS circuits, or radiation detectors, they form a universal basis for deriving new device concepts or for quality assurance in the IISB's p-FAB. At the same time, development services based on semiconductor technologies from third-party suppliers, known as foundries, can be carried out.

Ways to Work Together

For the deployment of research and development capacities, various cooperation models have been established. These range from the demonstration of single functionalities at process or module level to the development of complete prototypes based on customer-specific parameters through to joint labs. The technology transfer is executed in close collaboration with the client, even down to the individual process level. Together with the Front End department and the p-FAB management group, it is possible to manufacture established prototypes in medium quantities.

In addition to its activities in the field of silicon carbide, the R&D Semiconductor Devices and Processing department also focuses on silicon technologies for special devices and conducts research into process and device technologies for new semiconductor materials with wide bandgap.

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Europe's only high-temperature 4H-SiC CMOS technology: IISB's SiC CMOS early access technology enables fabrication of integrated analog & digital circuits on 150 mm wafers which can operate at temperatures up to approx. 600 °C
© Daniel Karmann / Fraunhofer IISB

Megawatt medium-voltage test lab at Fraunhofer IISB in Erlangen © Daniel Karmann / Fraunhofer IISB

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,
Head of Power Electronic Systems Division and
Chair of Power Electronics (LEE)
of the Friedrich-Alexander-Universität Erlangen-Nürnberg
© Amelie Schardt / Fraunhofer IISB

One focus of our research work is on sustainable mobility systems whether in the automotive sector, commercial vehicles, ships, or aircrafts. Electric flying in particular poses enormous challenges for power electronics, especially with regard to safety, robustness, availability, power density, and weight. In addition, there are demanding technical boundary conditions such as cryogenic cooling media, the use of superconductors or cosmic radiation.

We are also constantly expanding our research activities in the area of local DC networks, particularly with regard to new protection components and converter concepts for applications up to the medium-voltage and megawatt power range.

Another important field of research is cognitive power electronics, i.e., power electronics that is able to generate maximum information about its environment – whether it is monitoring the stability of grids or the condition of customer systems and machines.

Power Electronics

»*Vehicle Electronics* becomes *Power Electronics*, covering the value chain from power modules to complete power electronic systems and gets a well-coordinated dual leadership focusing on upcoming developments.«

Dr. Bernd Eckardt,
Head of Power Electronics Department
© Daniel Karmann / Fraunhofer IISB

»Innovations like electric aircraft and cryogenic power electronics, utilizing supra conducting technologies to enhance efficiency and reduce emissions, pave the way for a cleaner, more sustainable future in aviation and energy systems.«

Dr. Maximilian Hofmann,
Head of Power Electronics Department
© Kurt Fuchs / Fraunhofer IISB

In order to address the growing demand of our customers and project partners for laboratory infrastructure for the megawatt and kilovolt range, Fraunhofer IISB has et up a unique medium-voltage test field
© Daniel Karmann / Fraunhofer IISB

The ongoing electrification in trucks, ships, and aircrafts are driving the demand for more powerful and tailored power electronic solutions. Consequently, the Power Electronics Department is focused on designing the next generation of power electronics, incorporating wide (e.g., SiC and GaN) and ultra-wide (e.g., AlN and GaO) bandgap semiconductors, as well as advanced power electronic concepts and control strategies for innovative applications, including aircraft.

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Collaborating with industry and research partners, we are already showcasing power electronic solutions that will enter production by 2035. Our efforts include the development of the latest SiC and GaN devices, alongside new power modules designed for low parasitic impedance and enhanced thermal conductivity. These modules are integrated into advanced mechatronic solutions that prioritize compactness, lightweight construction, and mechanical robustness, ensuring that cutting-edge technology is ready for reliability testing and vehicle integration.

A key focus area is drive trains for next-generation electric vehicles, along with the development of SiC and multi-level GaN inverters for high-speed drives necessary for electric air compressors in fuel cell systems, capable of spinning up to 160,000 RPM. These inverters must operate at switching frequencies around 100 kHz to minimize magnetic losses in the motors, and the low switching losses associated with wide-bandgap semiconductors significantly enhance efficiency.

Additionally, DC/DC converters with up to 1MW play a vital role in adapting the output voltage of fuel cells to the vehicle's DC link voltage. With over 25 years of experience, Fraunhofer IISB excels in custom converter designs for diverse requirements, with several prototypes already operational in test vehicles and trucks, demonstrating the advantages of this new technology.

To provide comprehensive powertrain solutions, the Power Electronics Department expands its expertise to include electric motor drives, magnetic and mechanical design, testing, and co-simulation of electric motors and power electronic inverters. This integration enhances drive system performance and delivers reliable data on efficiency and performance.

For dependable solutions, we maintain a test lab specializing in active and passive power cycling and electromagnetic compatibility (EMC), while also developing innovative active and passive EMC filters. These advancements will further reduce the size and weight of next-generation power converters.

New challenges arise with supra conducting powertrains operating at temperatures as low as -200 °C, which alter the behavior of semiconductor devices and passive components, creating significant thermomechanical stress on interconnections. To address these challenges, we have established new test benches and simulation capabilities, successfully providing our research partners with fully functional prototype systems for testing applications.

Over the past 25 years, the demand for power has grown substantially. In response, we have set up our medium voltage and high-power lab, capable of handling voltages up to 30 kV and electric power up to 10 MW.

All this positions Fraunhofer IISB as an outstanding partner for developing innovative power electronic solutions.

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Fast-charging capable, weight-optimized, modular 800 V high-performance traction battery developed at Fraunhofer IISB for the European 1000kmPLUS project
© Thomas Richter / Fraunhofer IISB

Division Intelligent Energy Systems

»Effective energy storage systems and good power conversion systems require three essential components: a modular hardware, a robust yet evolutive software, and a comprehensive data set!«

Prof. Vincent Lorentz,
Head of Intelligent Energy Systems Division and
Chair of Electronics for Electrical Energy Storage (LEEE)
of the University of Bayreuth
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The Intelligent Energy Systems Division at Fraunhofer IISB develops electronic solutions and advanced technologies for the digitalization of energy storage and power conversion systems, serving both mobile and stationary applications. These intelligent devices and methods are part of our Cognitive Power Electronics (CPE) ecosystem, aimed at the transportation and energy sectors, and cover a wide power range, from milliwatts to megawatts.

We integrate innovative data analytics into our systems, enabling smart monitoring with enhanced diagnostics, anomaly detection, and self-healing capabilities. These technologies are implemented in our cutting-edge electronic power converters and high-performance battery systems, including our disruptive open-source battery and fuel-cell management system, foxBMS®, developed in close collaboration with the University of Bayreuth and its Bavarian Center for Battery Technology (BayBatt).

Our research and development focus on power and control electronics, software, and data processing technologies, leveraging the latest advancements in artificial intelligence to provide innovative state estimation and anomaly detection functions for energy storage systems, power conversion systems, and energy management systems.

Intelligent Energy Systems

»Our department develops innovative electronic hardware, embedded software, backed with AI solutions for digitalizing energy storage and power conversion systems in mobile and stationary applications.«

Prof. Vincent Lorentz,
Head of Intelligent Energy Systems Department
© Anja Grabinger / Fraunhofer IISB

The Department Intelligent Energy Systems combines four research groups developing hardware and software solutions for electrical energy storage and electrical power conversion applications in the submarine, waterborne, road, railway, airborne, and space domains.

The group "Battery Systems" develops innovative solutions for lithium-ion and solid-state energy storage systems for mobile and stationary applications. The activities range from the development of battery management systems based on our open-source foxBMS® platform, algorithms for battery state estimations and predictions, up to the design of full-custom ultra-high-performance battery systems for applications like racing cars, submarines, UAV and airships.

The group "DC Grids" focuses on innovative solutions for DC grid systems. Its work ranges from applied research on efficiency, safety, and stability of DC networks, up to the development of innovative grid components, such as DC/DC converters and solid-state DC protection devices (e.g., solid-state circuit breakers). The group is also deeply involved in standardizations such as in VDE/DKE, IEC, and IEEE Smart Grid.

The group "Industrial Power Electronics" supports its customers in solving complex power electronic challenges in the field of multi-level converters. The list of strengths in the field of troubleshooting of this group is large: longstanding industrial application experience, fast response time, optimized designs, seamless integration into demanding environments, and familiarity with industrial processes and challenges.

The group "Data Analytics" helps its customers to get the most out of their data in the context of IoT and Industry 4.0. It takes an application-oriented approach that includes system analysis, data collection, filtering, clustering, and finally the development and implementation of algorithms in industrial processes or in embedded systems. The group also provides solutions and methods for the development of algorithms for anomaly detection and early fault recognition in complex systems.

The sum of these competences enables the development of cognitive power electronics (CPE), that consists in power electronics able to consider its environment (e.g., sources and loads, energy costs, system and network faults, grid stability, weather forecast) and adapt itself to it (e.g., in terms of energy efficiency, priorities, maintenance).

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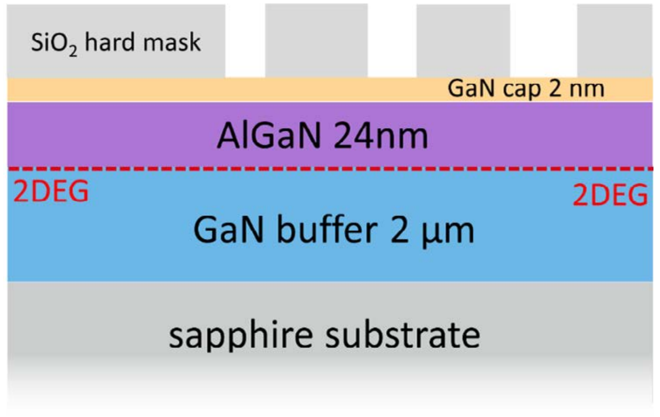
Division Intelligent Energy Systems

Cleanroom operator inserting a wafer into the transfer chamber of the deposition / etching cluster for structuring by means of atomic layer etching © Daniel Karmann / Fraunhofer IISB

Spotlights

Atomic Layer Etching (ALE) as an Effective Process for Recess of Nitride-Based Devices

In recent years, the Spectroscopy and Test Devices group has developed and optimized an efficient atomic layer etching process for low-damage etching of AlGaN/GaN heterostructures.

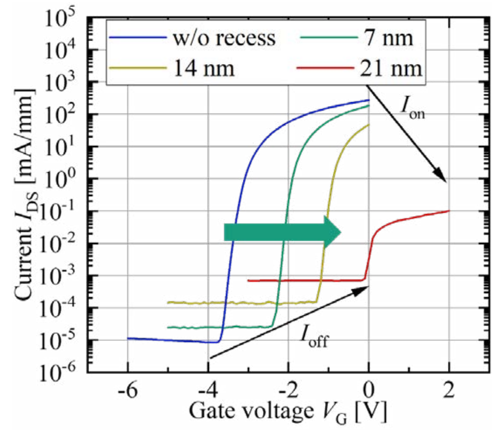


Schematic illustration of AlGaN/GaN HEMT

The cyclical process consists of two steps. While the substrate surface is chemically modified in a Cl_2/BCl_3 plasma in the first step, the modified layer is physically removed by argon ions of defined energy in the second step. Rinsing and evacuation sequences between the steps are generally implemented to remove any remaining reaction products and to prevent cross-contamination and side reactions.

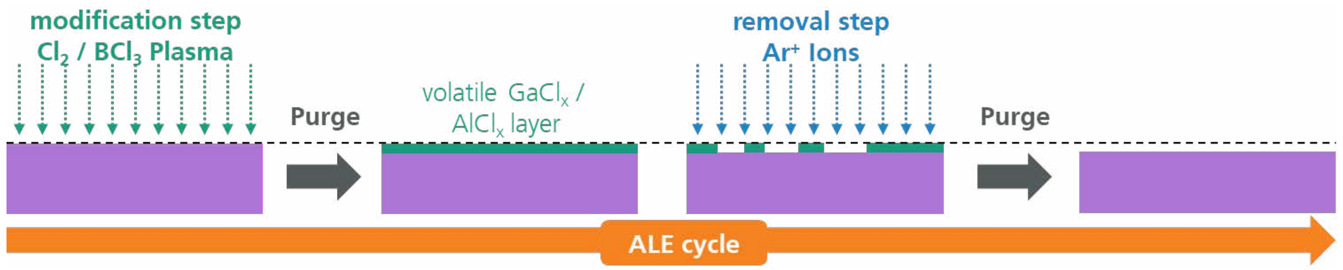
Using test structures, the etch per cycle (EPC) and surface roughness were determined using an atomic force microscope. The success of the development is characterized by a low, precise, and controlled etch rate as well as low surface roughness. Furthermore, high electron mobility transistors (HEMTs) with a thinned barrier under the gate contact (gate recess) were manufactured as part of the process evaluation.

In a sample series with three different gate recess depths, the feasibility of transforming an intrinsically switched-on HEMT (d-mode) into an intrinsically switched-off (e-mode) type was investigated. Electrical measurements showed a linear correlation between the threshold voltage and the etching depth. An e-mode HEMT was successfully realized starting at an etch depth of approx. 20 nm, where the threshold voltage is positive. However, a gate recess depth of more than 20 nm led to reduced saturation current and increased gate leakage current, see Figure 1. Recent adjustments to the process and layout design significantly improved the performance of the transistors. This demonstrates the great potential of ALE recess etching with precisely controlled EPC for contact and channel optimization of AlGaN/GaN HEMTs.[1]



Transfer characteristics of unetched and ALE-retreated HEMT devices before process optimization

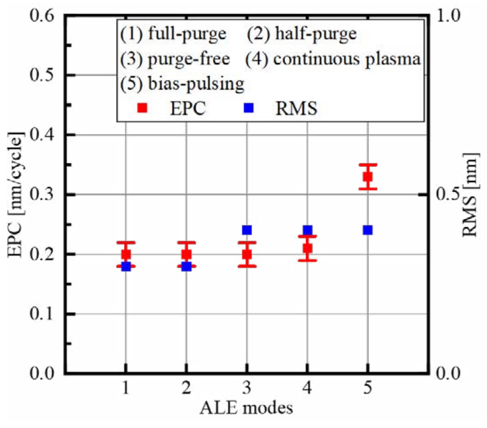
In the further development of the complex ALE process for AlGaN/GaN heterostructures, the focus was set specifically on optimizing the process time. Compared to a conventional, continuous reactive ion etching process, atomic layer etching requires significantly more time.



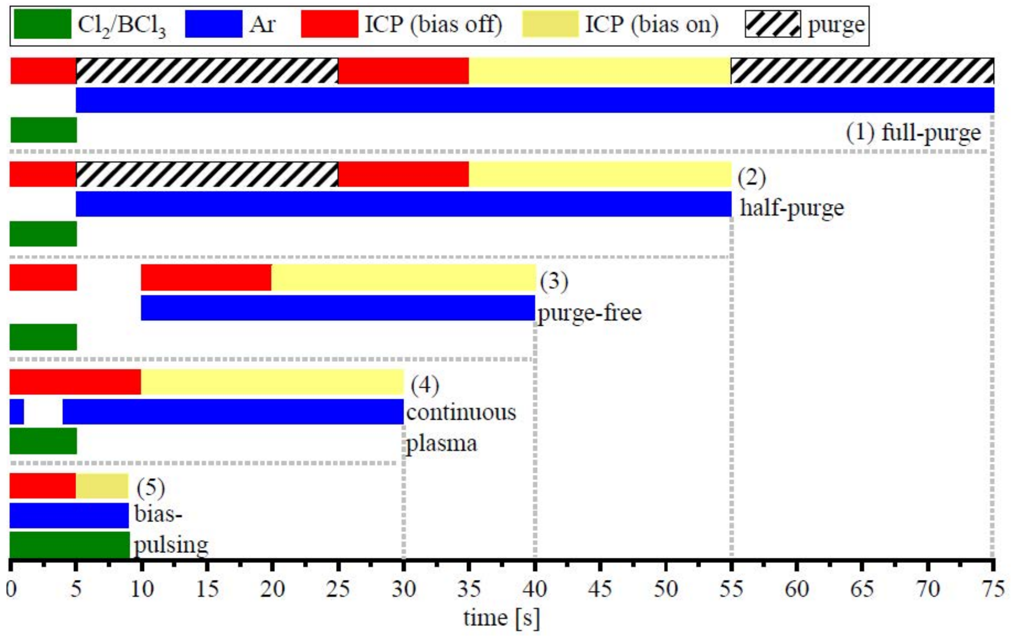
Schematic illustration of an ALE cycle consisting of modification, rinsing, and removal Steps

Reducing the cycle time and thereby the overall process time has a positive impact on process costs and sustainability.

Time optimization was achieved by gradually reducing the purging sequences between the modification step and the removal step. Together with a process adjustment, five different ALE modes were developed: Full Purge (1), Half Purge (2), Purge-Free (3), Continuous Plasma (4), and Bias Pulsing (5). Compared to the Full Purge mode, the purge times are initially reduced step by step (Half Purge or Purge-Free). Compared to the Full Purge mode, the purge times are initially reduced step by step (Half Purge or Purge-Free). In Continuous Plasma Mode, only Cl2/BCl3 and Ar gas are alternated in a continuous plasma, and in Bias Pulsing Mode, all gases used are present in the etching chamber at the same time, with only the RF power being cyclically switched on and off.



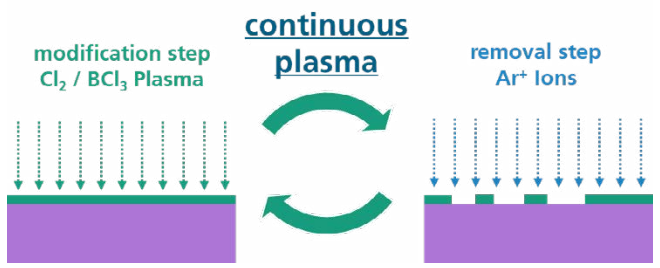
Removal per cycle (EPC), as well as surface roughness for the various ALE modes



Cycle times for the various ALE modes

The first four modes showed a consistently low EPC with a comparable surface roughness. In contrast, the EPC for mode 5 increased to 0.33 ± 0.02 nm/cycle, which is due to a lack of self-limitation of the individual subcycles. A chlorine contamination on the surface was also detected only for this mode.

The Continuous Plasma mode enables a maximum time reduction of 60% without compromising the etching quality. This reduces gas and energy consumption, which improves both production costs and sustainability, and therefore reduces the ecological footprint.[2]



[1] **Ch. Miersch et al. "Morphological and electrical characterization of gate recessed AlGaN/GaN high electron mobility transistor device by purge-free atomic layer etching", J. Vac. Sci. Technol. A 42, 022604 (2024)**

[2] **Ch. Miersch et al. "On the way to more sustainability: development of Al0.25Ga0.75N ALE processes with reduced cycle time", submitted J. Vac. Sci. Technol. A (2025)**

Process diagram of the continuous plasma ALE mode

Simulation for Quantum Devices in the Munich Quantum Valley

The development of quantum computers has gained significant interest, especially due to the prospect of up to exponential increases in simulation speed, promised by quantum algorithms. The Munich Quantum Valley is a Bavarian research and development project with the goal to build a quantum computer. Here, we present simulation approaches to support the development of quantum computers based on superconducting qubits and on SiC color centers.

Currently, however, the operating temperatures of SiC devices are not limited by the semiconductor itself, but rather by the utilization of conventional metallization and packaging technologies. The materials and components that make up the interconnects are not suitable for operating temperatures above 200 °C.

Overview

The field of quantum computing has been discussed since Richard Feynman first proposed such a machine in 1982. His idea was to use a quantum system to effectively simulate quantum mechanical problems. Talk about quantum computers intensified when algorithms were proposed for these – at the time non-existent – machines that should severely outperform our classical computers. Probably the best-known example here is Shor's algorithm from 1994, that would be able to break the heavily used RSA encryption. This would possible be thanks to quantum computers using qubits as the smallest piece of quantum information, similar to a bit in classical computing. These qubits exhibit two main effects, superposition and quantum entangling, which can be used to facilitate these speed-ups in quantum algorithms.

Driven by these promises, engineers started to try and build a quantum computer. That this would be feasible was first shown in 1998, when a first two-qubit quantum computer was built. Since then, the complexity of these machines grew significantly and today's biggest quantum computer by IBM features 1000 qubits. However, for quantum algorithms to effectively show their superiority in real-world problems, quantum computers with millions of qubits will probably be necessary.

So, there is still quite some work to do, which lead to several big research and engineering projects. One of those is the Bavarian project "Munich Quantum Valley" (MQV), which started in 2021 with the goal to build a quantum computer in Bavaria, to further our knowledge about these systems, and to provide software and new algorithms for quantum computers.

The project itself was initiated by the physics department of TU München, but many additional partners joined the project, including several Fraunhofer institutes, like IIS, EMFT, IKS, and IISB.

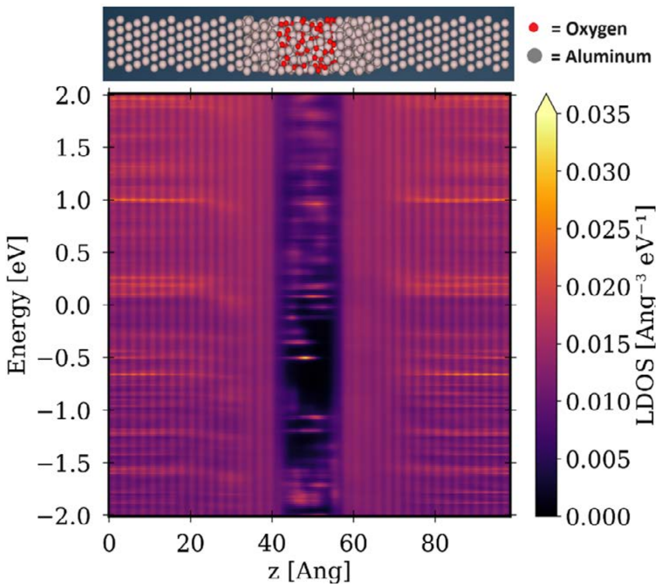
In the MQV project and its vicinity the colleagues at IISB work on a range of different topics: The department R&D Semiconductor Devices and Processing is supporting other Fraunhofer institutes with innovative metallization techniques for cryogenic temperatures. They also develop a SiC-based low-noise amplifier that is supposed to work at temperatures down to 4 Kelvin. The group AI-augmented simulation is conducting research to find new quantum algorithms to get a better understanding of possible future application areas of quantum computers. In the lighthouse project TeQSiC, that is directly connected to MQV, the group Quantum Materials is channeling their efforts towards a SiC-based qubit platform. Finally, the group TCAD is providing simulation support for the development of several devices necessary to build quantum computers, which is what we want to discuss a bit more in-detail here.

The Classics: Superconducting Qubits

Many different architectures have been proposed to create qubits, which are essentially quantum mechanical two-state systems. The most well-known approach is based on superconducting oscillating circuits, where an anharmonicity is introduced by a so-called Josephson junction. These systems are basically two superconductors with an insulating layer between them. Electron-pairs can tunnel through the barrier causing via the Josephson effect. The main problems of this qubit architecture are that it needs to be cooled heavily to enable superconductivity, and that the qubit state is short-lived. Finally, due to variability in the production of the Josephson junctions, entangling two or more qubits – to bring them in a joint state, such that their measurement outcomes depend on each other – can be challenging.

A better understanding of the creation process of an aluminum-based Josephson junction and its electronic properties, could help to improve the latter two problems. We started conducting atomistic simulations, hoping to get deeper insights. These simulations are a mixture of quick Molecular Dynamics simulations to create the general structure and lengthy tight-binding simulations to analyze its electronic properties. We focus on the role of the insulating layer made from amorphous aluminum oxide and study the impact of its density, stoichiometry, and thickness.

An exemplary result can be seen in the figure, where on the top a sketch of the atomistic structure of the junction is visible and at the bottom the corresponding local density of states (LDOS) is depicted. From the suppressed LDOS in the aluminum oxide layer, we can read out its insulating properties. In addition, clear defect-levels with high LDOS within the insulating gap are visible, which have a significant impact on transport properties. However, their energy and position vary based on the specific atomistic configuration of the insulating layer and, as a result, we are searching for ways to get rid of this source of variability, e.g., by introducing an additional annealing step.

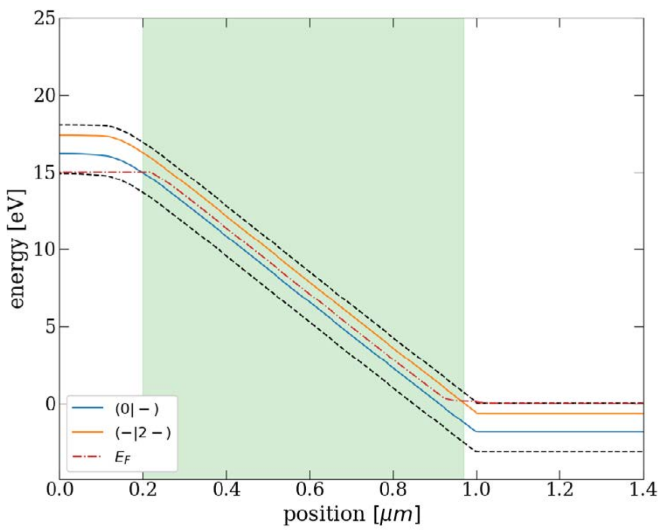


The simulated atomistic structure of a Josephson junction (top) and its local density of states (bottom). The insulating properties of the aluminum oxide layer are clearly visible from a suppressed density of states (dark blue and black)

Qubits à la IISB: SiC Color Centers

An entirely different qubit platform is based on defects in crystal lattices, so-called color centers. Similar to atoms, crystal defects possess an electronic structure that allows for the excitation of different energy transitions, in particular, transitions between different spin-states. By selectively exciting specific spin-transitions using a combination of optical lasers and microwave pulses, we can thereby realize a physical qubit system. While many host materials for such crystal defects exist, among the most promising candidates is SiC, since it offers an ideal compromise between excellent qubit properties and a mature technology platform.

Compared to superconducting qubits, a major advantage of color centers is that they operate at higher temperatures, reducing the need for complicated and expensive cooling systems. Additionally, due to the IISB's existing expertise on SiC device processing we can embed a color center in a specially designed electronic device to control its quantum state, e.g., by precisely modulating the electric field in the vicinity of the color center. TCAD simulations play a vital role in designing such devices, since they allow us to analyze their interior properties by generating maps of the electric field, current densities, band diagrams – as seen in the figure below – and other relevant quantities. Knowing these quantities in detail is crucial to designing a working SiC-based spin qubit system.

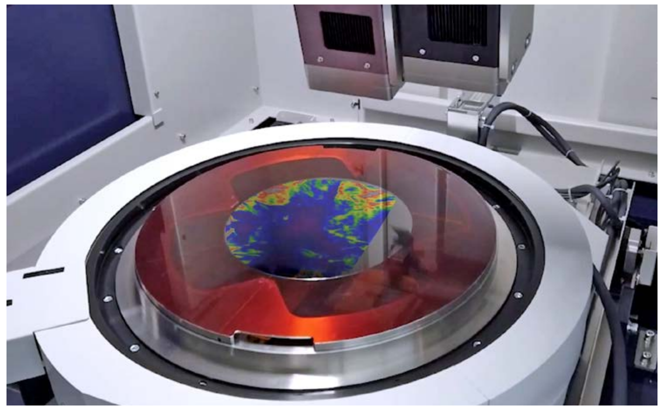


The energy bands in a SiC PiN diode simulated with TCAD. The red (dash-dotted) curve shows the Fermi energy in comparison to the valence and conduction bands (black dashed) and the charge transition energies (blue, orange) of the silicon vacancy. Only a particular charge state of the vacancy (negative charge) can be used as a qubit, which is present in the green shaded area, where the Fermi-level lies between the two transition energies

In summary, in the last few years we were able to show that simulations are a useful tool to better understand the physics behind the different qubit platforms and to improve fabrication processes and device designs. Our future goal is to make simulations just as indispensable in the field of quantum computers as they are in the area of classical semiconductor processes and devices. We firmly believe that simulations are a necessary tool to understand and optimize these complex devices and their performance.

Metrology for Wide Bandgap Semiconductor Materials

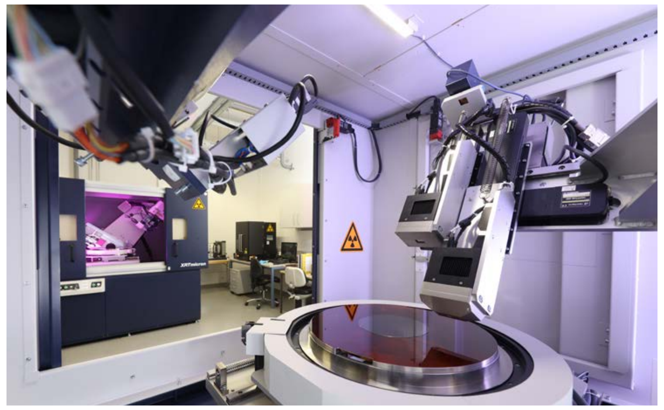
Metrology acts as an absolutely vital support of both R&D and production, e.g. for material development and process control. Developing metrology tools and analysis routines requires a deep knowledge of the different parts of the value chain and of the industrial requirements therein. Having this expertise from the in-house value chain and the cooperation with various industrial partners, IISB has become a renowned institute for the characterization of wide bandgap semiconductors and a very attractive partner for metrology tool producers.



The efforts carried out at the IISB transformed the XRT technique into a powerful, quantitative metrology applied in the semiconductor industry © Elisabeth Iglhaut / Fraunhofer IISB

X-Ray Topography for SiC Wafer Qualification

The success story of x-ray topography (XRT) started with the purchase of an XRTmicron tool from the company Rigaku in 2018. At that time, the tool was considered a research tool with brilliant image quality, but an industrial application seemed far away. Quickly after the installation of the tool, IISB developed dislocation density quantification routines based on XRT and verified the results using their scientific expertise.



Fraunhofer IISB is a pioneer in the application of XRT for the dislocation quantification in SiC and continues to explore industrial use cases of this technique with its broad range of lab-scale XRT equipment © Kurt Fuchs / Fraunhofer IISB

With a robust quantification routine established, XRT was ready to supersede KOH etching as the established method for dislocation analysis in SiC. This technique not only suffered from being destructive to the test wafers, but also from a poor reproducibility and comparability of the results from different companies. To overcome these problems of comparability, IISB also pushed the development of SEMI Standards for the defect quantification by XRT, which now have been released as SEMI M91 and SEMI M93 and which are the basement of a new, reliable language of defect density assessment of SiC wafers.

IISB also implemented the routines compliant with said SEMI Standards in the software XRT Toolbox, which is distributed by Rigaku together with their XRTmicron tool. This strongly facilitated the implementation of XRT measurements for dislocation quantification at industrial sites. At the same time, it ensures worldwide comparability of the results obtained.

The ddefect analysis software XRT Toolbox developed by Fraunhofer IISB is distributed by Rigaku and is now in the field worldwide © Elisabeth Iglhaut / Fraunhofer IISB

By the end of 2024, XRT has become the gold standard for dislocation detection in SiC, which is accepted and applied in the whole community. Major players in the business, distributed from America over Europe to Asia, use IISB's software XRT Toolbox to analyze their measurements and to qualify their material.

Epi-ready, single crystalline PVT-AlN-wafer fabricated at Fraunhofer IISB
© Elisabeth Iglhaut / Fraunhofer IISB

Metrology for in-House Development of AlN Growth
Despite the strong commercial focus on SiC, x-ray topography is a far more versatile technique, which can also be applied to other materials. For example, it is a great support for AlN crystal growth and epi-ready AlN wafer fabrication carried out at IISB and its partners.

AlN is a semiconductor material with outstanding properties on paper for power, RF- and optoelectronics. However, it is a material still in early development and many technological challenges need to be mastered within the next years and decades. One of these challenges is wafer diameter increasement with simultaneous improvement of crystalline quality or at least without deterioration of it. Diameter enlargement and associated quality of grown AlN crystals are strongly influenced by the design of the crystal growth process carried out by the so called Physical Vapor Transport (PVT) method. IISB is constantly adapting its own crystal growth processes to address above mentioned challenge. The effort for this could be greatly facilitated by the use of XRT as a method that is not only applicable to wafers, but also to bulk crystals. IISB therefore uses XRT as a standard tool to characterize all of its grown crystals with regard to material quality and thus to get a fast, detailed and non-destructive feedback on any process design changes.

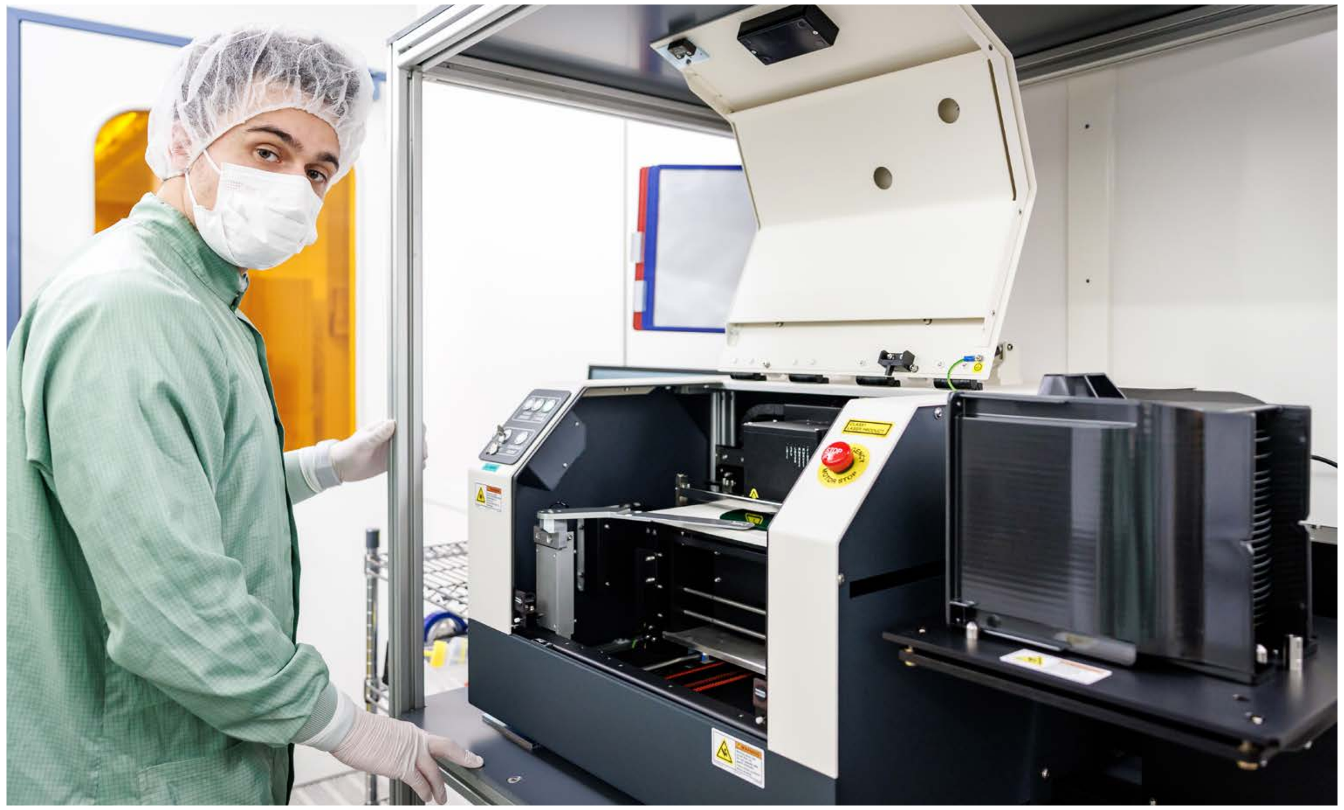
Beside supporting AlN crystal growth technology development, IISB uses XRT also routinely for the quality assessment of AlN wafers that have been fabricated from the AlN crystals. Here, two aspects are in our focus: intrinsic defects (i.e. grown-in by crystal growth process) and extrinsic defects (i.e. brought in by external sources). Intrinsic defect densities can be quantitatively analyzed and provided to customers to potentially predict the electrical behavior (e.g. in terms of reverse bias leakage) of electronic devices fabricated on the AlN wafers. Extrinsic defects such as scratches in the very near-surface region of the wafer can be visualized on full wafer scale, which greatly helps IISB to constantly optimize the chemical mechanical polishing (CMP) process together with its partners and to adapt it to successively increasing wafer diameters.

Residual Stress in Semiconductor Substrates
Residual stress in the substrate is a material property that has been underestimated for a long time. However, it has a severe impact on the mechanical behavior of the wafer during further processing stress. Fraunhofer IISB teamed up with the small company ilis gmbh from Erlangen to adapt their existing stress birefringence measurement tools for the needs of the semiconductor business. These measurements allow the quantification of the residual stress in the material with an unprecedented accuracy and detection limit. Within the cooperation, IISB is working on the understanding of the stress distribution in SiC wafers and how they affect the further device processing, thereby helping industry to make better SiC wafers and specify them according to their requirement.

Characterization of SiC Homoepitaxial Layers
Improved characterization methods, such as XRT and birefringeance, in combination with intense research and development activities in bulk PVT growth of SiC and large production volumes of SiC boules and wafers have been enormously improving the wafer quality within the last few years. These SiC substrates with 150 mm and 200 mm diameter are used for 4H homoepitaxial growth in chemical vapor deposition (CVD) processes because these homoepitaxial layers are the centerpiece of all devices – from power electronic to photonic and quantum-based device types. Hence, the quality of the epilayers is decisive for later device performance, reliability and production yield, especially regarding defects, epilayer thickness, doping concentration and their uniformities. The CVD reactors, processes, and the resulting epilayers have also improved to a level that the new generation of metrology tools needs to be more precise and more stable to resolve the actual epilayer properties.

Standard epilayer characterization comprises defect characterization by UV-excited photoluminescence imaging (UVPL), FTIR-based thickness and capacitance-voltage (CV) measurements for doping concentration profiling. Moreover, next generation SiC devices demand for suitable charge carrier lifetimes to enable bipolar device operation as well as to indicate any processing deviations that affect the doping background and point defects. With our new lifetime scanner based on the microwave-detected photoconductivity decay (μ-PCD) method and we are collecting statistical data for all our epilayers and aim to establish it for process and quality control.

For support and further development of methods and tools, IISB is running a joint lab with Semilab including latest tool generations for thickness, doping and lifetime measurements on SiC epilayers and inline process control along the device production based on atomic force microscopy (AFM) and ellipsometry.



Carrier lifetime measurements for process and quality control of SiC epiwafers based on M-PCD method
© Daniel Karmann / Fraunhofer IISB

Dedicated Metal Stacks and Diffusion Barriers for Reliable Operation of High-Temperature SiC Devices

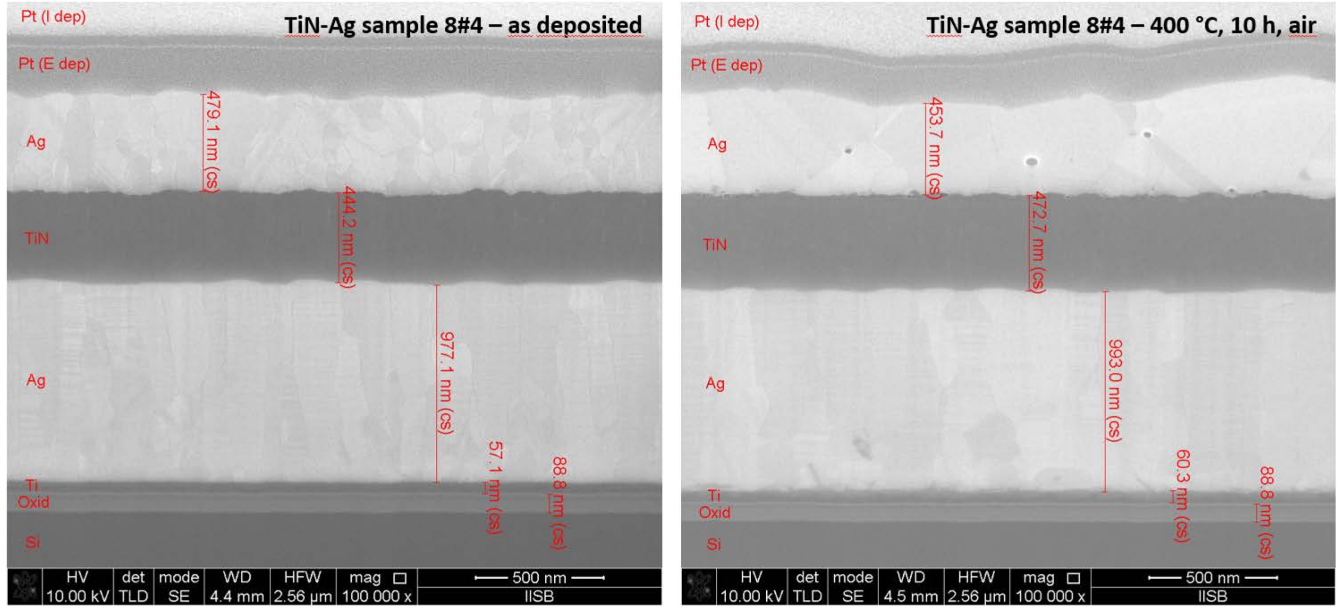
Due to its wide band gap and high thermal conductivity, SiC is a promising semiconductor for high-temperature applications. Furthermore, compared to widely used semiconductor materials such as Si, it has superior properties regarding breakdown field strength and Mohs hardness. Therefore, devices manufactured on SiC have the potential to withstand harsher conditions and to operate at higher temperatures for longer periods of time.

Currently, however, the operating temperatures of SiC devices are not limited by the semiconductor itself, but rather by the utilization of conventional metallization and packaging technologies. The materials and components that make up the interconnects are not suitable for operating temperatures above 200 °C.

An essential part of the packaged device is its source and drain metallization, which must not only carry high currents, but should also act as a diffusion barrier to protect the device against humidity or reactive species like oxygen. With the goal of increasing the reliability of 4H-SiC devices under harsh conditions as high temperatures, various contact and metallization concepts are continuously being developed at IISB. A major challenge is the protection of the ohmic contacts, which are prone to oxidation and degradation at elevated temperatures. This degradation compromises electrical performance, limiting device longevity. To address this, the development of high-temperature capable diffusion barriers is key. These diffusion barriers also need to exhibit sufficient electrical conductivity, to not degrade the efficiency of the device.

For this purpose, several metal stacks were assessed regarding their high-temperature capability and electrical conductivity. In past experiments, titanium nitride (TiN), a diffusion barrier often used in semiconductor devices, was investigated in silver-titanium nitride-silver (Ag-TiN-Ag) metallization stacks and tested for its thermal stability at 400 °C in atmospheric conditions. Besides the high melting points of these two materials, Ag is well suited as a contact metal due to its low electrical resistivity, corrosion resistance and sintering abilities. While TiN can withstand extreme conditions for short periods of time, prolonged exposure normally reveals limitations. TiN slowly reacts with oxygen and expands, harming both, its barrier functionality as well as the electrical performance.

The figure shows an optimized Ag-TiN-Ag stack. Sputter deposition was chosen for applying the metal stack on top of silicon oxide, as previous studies have shown that sputtered metal layers exhibit better adhesion compared to corresponding vapor-deposited layers. The TiN layer was optimized with respect to stoichiometry and deposition conditions to form a dense, chemically stable and impermeable layer, protecting the lower silver layer as well as the contact area. A temperature



Ag/TiN/Ag stacks before and after heat soak testing at 400 °C in ambient air. Whereas both silver layers show heat-induced grain growth and the upper silver layer forms voids, the optimized TiN barrier is stable against diffusion of oxidizing species as well as degradation

treatment in an ambient air for 10 hours at 400 °C shows a negligible alteration of the TiN barrier and the interfaces to the top and bottom silver layers. Vice versa, the silver layers exhibit grain growth due to thermal annealing effects. Furthermore, the upper silver layer which is exposed to the ambient without mechanical confinement on the top side shows surface roughening and void formation due to interference with the atmosphere.

In addition, a lift-off process was developed to pattern the metal stack on the front of the wafer to form the gate and source contacts of the MOSFETs. The lift-off technique offers several advantages over dry or wet metal etching. In general, the selectivity of etching processes must be high enough to avoid over-etching so that no other important elements of the MOSFET are harmed, whereas the lift-off process uses only an organic solvent to pattern the metal stack, making the process gentler on the surrounding contact surfaces. Furthermore, halogenide ions from etchants or gases, that may lead to corrosion of metals, are ruled out.

To further improve robustness and performance, ternary systems incorporating Si into transition metal nitrides, form titanium silicon nitride (TiSiN) or tantalum silicon nitride (TaSiN) that show good prospect for meeting the thermo-mechano-electrical requirements. As an alternative, pure silicides such as tantalum disilicide ($TaSi_2$) are known for their excellent high-temperature stability. Metallization schemes including the latter material as a diffusion barrier against oxygen are currently under evaluation.

Cryo Power Electronics for Supra Conducting Aircraft Powertrains

In recent years, the development of electric aircraft has gained significant momentum, promising to revolutionize the aviation industry with cleaner, quieter, and more efficient transportation. By leveraging advanced electric propulsion systems, these aircraft can greatly reduce greenhouse gas emissions and noise pollution, making air travel more sustainable.

Moreover, the integration of cryogenic power electronics plays a crucial role in enhancing the efficiency and performance of electric vehicles, including aircraft. Cryogenic cooling technologies allow for higher power densities and improved thermal management of power electronic components, which is essential for the demanding operational conditions of electric aviation. The combination of electric aircraft and cryogenic power electronics represents a groundbreaking advancement towards a more sustainable future in air mobility.

Electrical test of a cryogenic GaN inverter module in liquid nitrogen © Elisabeth Iglhaut / Fraunhofer IISB

High Availability Energy Storage Systems for UAV

Lithium-ion batteries (LIB) are an efficient technology in terms of storing and providing energy for aviation, unmanned aerial vehicles (UAV), and high-altitude platform systems (HAPS) due to their high energy density, performance, and reliability. To ensure a safe and economically viable operation of a battery system over the entire lifetime, a battery management system (BMS) is used to measure and monitor battery parameters and control the battery. However, battery systems and their corresponding BMSs used in aviation and space applications are operated under extreme environmental conditions (e.g., temperature and radiation) that can degrade the reliability and accuracy of sensors and other electronic components. Consequently, the measurement accuracy, the control, and operation of a battery system can be deteriorated. Therefore, aged batteries can fail to meet mission-specific energy and performance requirements. This can have a dramatic impact on the availability and the safety of systems, particlarly in avaiation and space applications, potentially resulting in fatal scenarios.

Battery System Architectures

Fraunhofer IISB has further improved its open-source BMS platform foxBMS® to meet specific requirements for monitoring, control, and operation of battery systems in space and aviation applications. Following its cross-domain approach, the foxBMS team was able to transfer its expertise in large-scale multi-string battery systems from the stationary and marine domain to the challenging high-availability domain of aviation. As part of the EU funded project FLEXSHIP (https://www.flexship-project.eu) Fraunhofer IISB is responsible for developing the BMS for the two planned electrified ship demonstrators, which will be equipped with 1 MWh and 3 MWh multi-string redundant battery energy storage systems developed within the project.

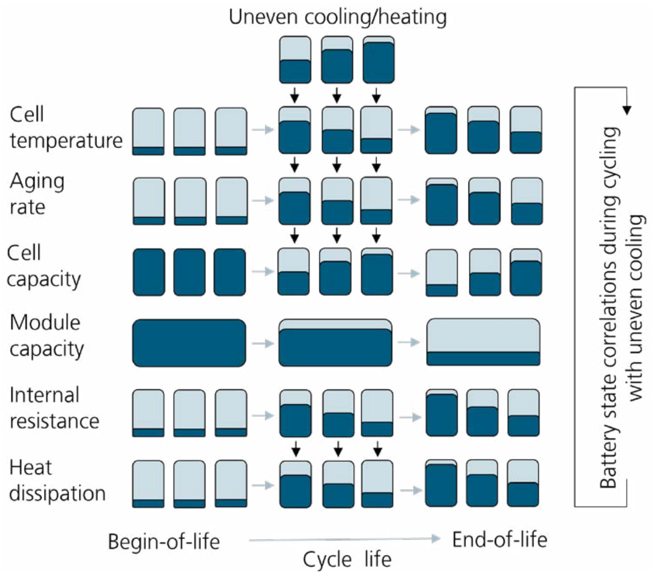
Redundant battery systems for UAVs significantly enhance reliability and operational safety by ensuring a continuous power supply, even in the event of a battery failure. A common configuration is the parallel arrangement, where multiple battery strings are connected to increase overall capacity and provide redundancy. If one battery and its corresponding string fails, the others can maintain power to continue the mission. Active monitoring through the BMS allows for real-time tracking of each battery's health, voltage, and temperature, helping to identify potential issues before they lead to failure.

From a mechanical point of view, multi-string battery packs can be designed for easy swapping in the field, reducing downtime and ensuring quick replacements. Additionally, utilizing several smaller batteries instead of one large battery helps improve weight distribution and enhances redundancy, supported by load balancing algorithms that efficiently manage power usage. Smart charging solutions, including adaptive charging profiles and wireless options, can further optimize battery life and minimize turnaround times between flights. By integrating these features, redundant battery systems greatly improve the performance, reliability, and safety of UAV operations, making them suitable for a wide range of applications.

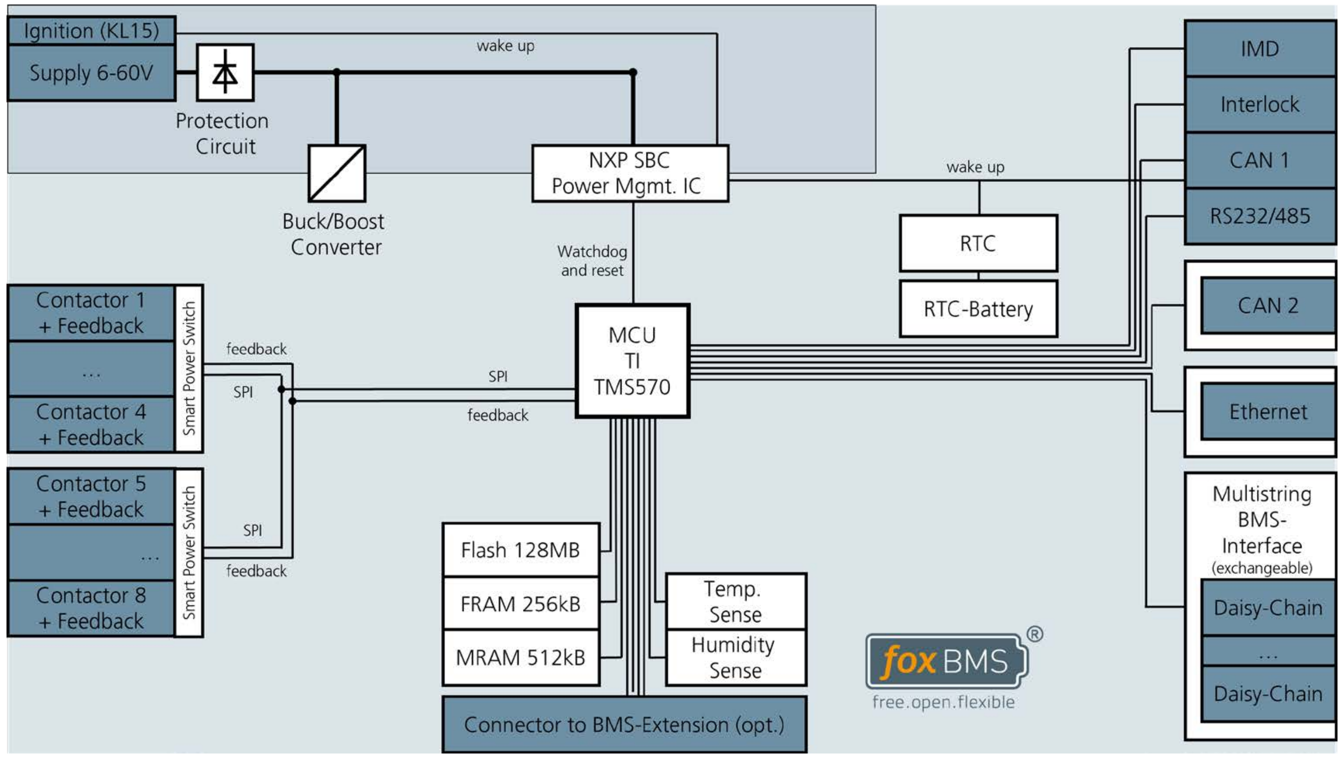
Battery System Design

As typical LIBs used for UAV must operate under harsh environmental conditions (e.g., extreme ambient temperature) the battery system needs to be optimized thermally and mechanically. Fraunhofer IISB has developed suitable measures for the implementation of compact and lightweight thermal management mechanisms and insulation materials, with a strong focus on thermal runaway safety. In addition to the extreme ambient temperature, reduced air pressure at high altitudes affects convection rates potentially making heat conduction the dominant way of heat transfer.

At the same time, the limited allowable weight overhead rules out sophisticated thermal management methods as well as over-dimensioning to compensate for capacity losses due to premature ageing. Since the weakest cell in a series connection determines the performance of the entire string, one of the most important requirements for homogeneous battery system ageing is achieving homogeneous cell temperature and current distributions.



Impact of heterogeneous cell temperature on cell aging over lifetime



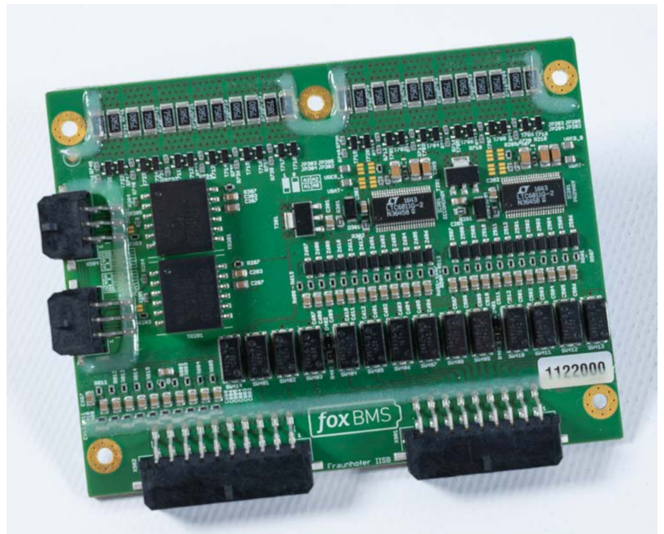
Block diagram of foxBMS BMS-master modified for redundand multi-string battery system architecture

The first figure shows the complex correlation between cell ageing, cell heat dissipation and usable cell capacity. Temperature differences between cells can arise from various factors, such as unavoidable inhomogeneities in cooling, e.g., warming cooling fluid. Over lifetime, aged cells will show higher heat dissipation due to increased internal resistances. Against this background, a detailed spatial measurement of temperature distribution become essential. However, multiple sensors increase cost and weight. To adress this challenge, a suitable battery monitoring architecture must be implemented.

BMS Electronics Design

Fraunhofer IISB's foxBMS electronics comprise a central BMS-Master unit and multiple BMS-Slave units located near the battery cells, utilizing a combination of analog, digital, and mixed-signal components. The BMS-Slave provides voltage measurements for each cell and temperature inputs through thermistors, along with a passive cell balancing circuit that discharges cells via resistors. While this balancing method is energy-inefficient, it is robust for harsh environments, while being cost- and space-effective. In applications with limited thermal convection, a proper thermal management is mandatory to reduce the effects of temperate gradients within the battery as described earlier (e.g., using the dissipated energy as battery heater to increase the overall system energy efficiency).

The foxBMS 2 BMS-Master includes features such as a wide input voltage range, control outputs for contactors, and various communication interfaces, ensuring high reliability and modularity. Another crucial component required for safe and



Fully redundant BMS-slave electronics with reed-relay reset circuitry to handle single event effects
© Elisabeth Iglhaut / Fraunhofer IISB

reliable operation of batteries are state-estimation algorithms, which rely on the quality and integrity of sensor input data, especially challenging in environments with higher probabilities for single event effects (SEE) caused by (cosmic) radiation. The probability for SEEs is dependent on latitude, longitude, and altitude of the battery and its BMS as well as the solar activity. For instance, a microcontroller located over the pole at 12 km height has its mean time between failure reduced by a factor of roughly 630 compared to an operation at sea-level in NYC.

Fraunhofer IISB has developed additional mitigation strategies, such as a 64-bit CRC checksum to safeguard raw sensor data as well as post-processed voltage, current and temperature measurement data stored on the external memory in addition to the ECC capabilities of the hardware. In addition, complex detection and reset circuits (e.g., by using mechanical reed relays) have been developed and implemented as part of the BMS electronics.

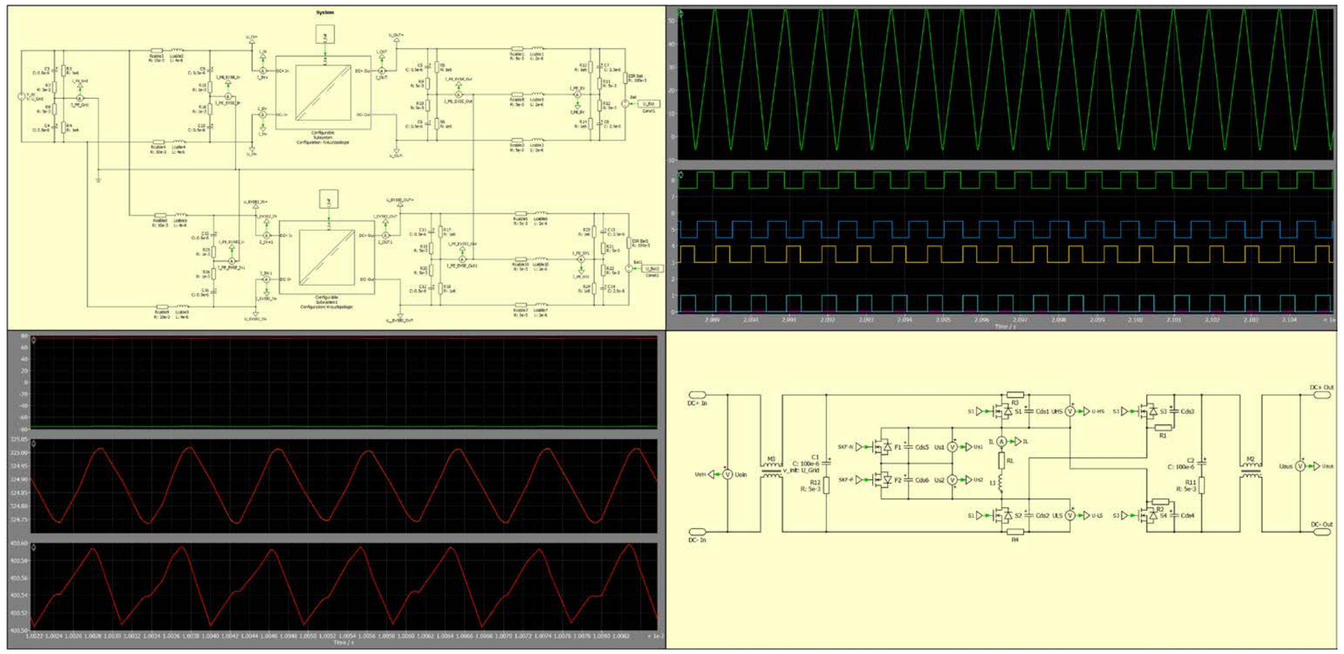
EV Charging as a Growing Application for DC Grids

The application of DC grids has significantly expanded in recent years. Initially, the concept originated in the realm of data centers, matured with industrial applications and from there the advantages of DC networks have been recognized in a variety of other sectors. A concrete example of this is the emergence of charging parks supplied by a DC grid.

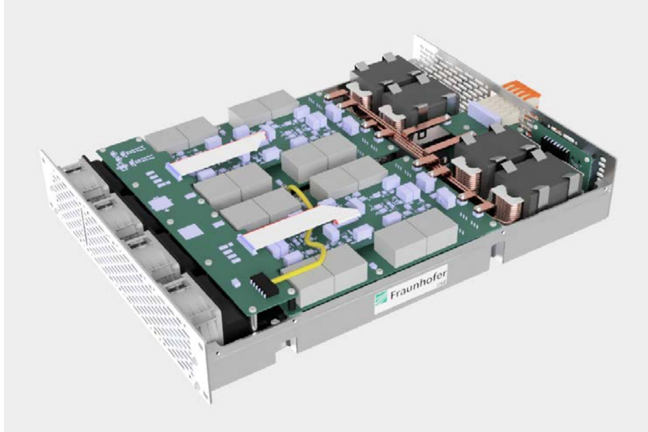
In the charging park application, multiple DC/DC converters are used as charging points for electric vehicles (EVs), supplied by a common DC grid and connected to the AC mains via one large AC frontend. The power of those charging points is usually in the range of 50 – 350 kW each, although high power levels for truck charging (Megawatt Charging System, MCS) are about to be standardized as well. By utilizing a DC grid, there is a reduction in the resource requirements (cables and power electronics) as well as more stable AC grid utilization.

Overall efficiency can be improved, resulting in a reduction of OPEX. One example of such a charging park is the Sortimo Innovation Park in Zusmarshausen, designed and built by eloaded GmbH and Steinbacher Consult Ingenieurgesellschaft mbH, with whom Fraunhofer IISB has been in close contact regarding the 1000 V DC grid interconnecting the charging points.

The DC grids group provides extensive support in the design and planning of DC charging parks. A core topic here is the protection concept. Since there is no standardized analytical approach for DC grids to calculate short-circuit currents, Fraunhofer IISB models the underlying grid including all power electronic components and simulates the short-circuit currents at various points in the network in order to then carry out the design and coordination of the protective elements.



Converter and system simulation for charging applications



Bidirectional SCI (semiconductor-based isolation) DC/DC converter prototype, 50 kW in 19-inch housing with 2 HU

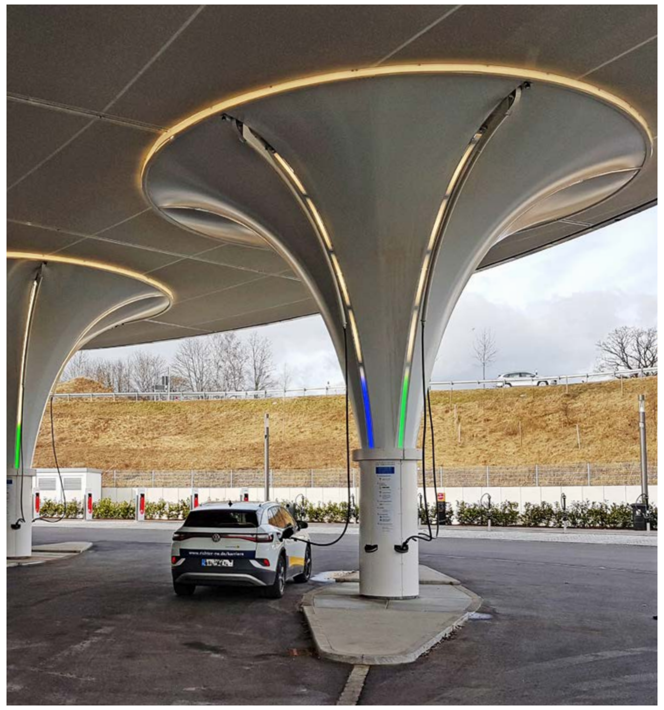
Currently, two research projects are underway in which the DC Grids group is developing DC/DC converters for charging stations with DC supply. One project, DCI4Charge, involves the development of a conventional galvanically isolated converter that is supposed to cover a wide operating range through an innovative control strategy, in order to charge both 400 V and 800 V vehicles. This is usually achieved through a two-stage system, so the IISB solution can save costs and materials. In the second research project, eMobiGrid, the possibility of using a transformerless approach is investigated to reach the same level of safety between two charging points as is currently achieved with traditional galvanic isolation. For this purpose, a new converter topology is being built, where a so-called semiconductor-based isolation is realized. Here too, significant savings in costs, materials, and volume can be achieved.

Charging parks are also interesting in terms of standardization. Fraunhofer IISB has been actively involved for years in establishing norms for both general bidirectional DC charging, particularly emphasizing electrical safety, and DC grids. This extensive experience translates into substantial know-how. For example, there are normative requirements regarding the inductance on the EV side of the charging points. To ensure that the battery protection switch in the EV can successfully interrupt the current during a fault condition, it is essential to limit the effective inductance. Fraunhofer IISB is part of the working group that has outlined these specifications, which have been incorporated into the relevant section of the IEC 61851-23 Ed. 2.

In response to these requirements, Fraunhofer IISB has developed and patented a device that can be used to measure this energy equivalent inductance effectively. This device ensures compliance with the established standards, thereby enhancing the safety and reliability of DC charging systems.

On the side of the Open DC Alliance (ODCA), the association of industry and academia that promotes the specification of DC grids and supports their market entry, EV charging is also seen as an important application for DC grids. In the national research project "DCI4Charge," the Fraunhofer IISB is developing a DC/DC converter to enable bidirectional charging from an industrial DC grid. This last work package of this project is to consolidate the research results into an amendment to the current ODCA system specification to comprehensively describe DC charging points as a component of (industrial) DC grids.

In conclusion, the ongoing advancements in DC grid applications and the commitment to standardization and organizations like the ODCA are vital for the future of electric vehicle charging infrastructure. The DC grids group of Fraunhofer IISB supports those developments with their extensive knowledge on power electronics, grid design, protection systems, fault simulations and standardization.



New DC charging park in Zusmarshausen
© Bernd Wunder / Fraunhofer IISB

Locations and Network

Headquarters of Fraunhofer IISB

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.

The available infrastructure includes among others: A test center for electric cars, a medium-voltage test bench, an application center for DC grid technology, and an 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.

The Fraunhofer IISB operates various crystal growth and wafering laboratories in which crystals and sub-strates can be grown from different semiconductor materials such as SiC, AlN or GaN. In addition to an advanced packaging line for power electronics, the institute also runs an environmental laboratory for testing active and passive components specifically geared towards the application areas of energy transmission, mobility, aerospace and industry.

iisb.fraunhofer.de

Technology Center High Performance Materials THM

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. Supported by the Free State of Saxony, 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. 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.

One major point is the role of defects for the reliability and functionality of upcoming devices and the integration of processes and materials into prototypes and test vehicles.

Fraunhofer THM is a research partner for industry within the framework of industrial contracts and publicly funded projects in the production, application, and recycling of semiconductor and energy materials.

thm.fraunhofer.de

X-ray diffraction analysis of battery test cells at Fraunhofer THM in Freiberg © Daniel Karmann / Fraunhofer IISB

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)

Chair of Electron Devices (LEB)

The Fraunhofer IISB and the Chair of Electron Devices (German abbreviation: LEB) of the Universität 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.

For many years now, the vocational training as a microtechnologist has been offered jointly by the IISB and the Chair of Electron Devices. Also, employees of the IISB assist in courses and internships at the university.

leb.tf.fau.de

Chair of Power Electronics (LEE)

The Chair of Power Electronics (German abbreviation: LEE) of the Universität Erlangen-Nürnberg is headed by Prof. Martin März, also head of the Power Electronic Systems Division.

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.

lee.tf.fau.de

Locations and Network

Technische Universität Bergakademie Freiberg (TUBAF)

Institute of Applied Physics (IAP)

Institute of Applied Physics of the TU Bergakademie Freiberg is headed by Prof. Johannes Heitmann, also head of the Energy Materials and UWBG Semiconductor Technology Division and head of the Technology Center High Performance Materials THM in Freiberg.

The THM has been conducting joint research with the TU Bergakademie Freiberg for more than 15 years, and with the Institute of Applied Physics (IAP) for 8 years, complementing each other's competencies and sharing resources in the field of electronic device fabrication, characterization, and material processing.

Main activities of the IAP are the development and evaluation of new materials and processes, like thin film dielectrics and contact material formation for nitride semiconductor and photovoltaic devices, synthesis and characterization of semiconductor nanostructures, and the defect characterization of semiconductor materials and its impact on and the reliability of microelectronic and photovoltaic devices.

tu-freiberg.de/fakultaet2/angph

University of Bayreuth

Bavarian Center for Battery Technology (BayBatt) / Chair of Electronics for Electrical Energy Storage (LEEE)

The Bavarian Center for Battery Technology (BayBatt) at the University of Bayreuth is a research center that bundles interdisciplinary fundamental research, the development of innovative battery technologies, and technology transfer to the industry. With the BayBatt, an expertise center is being established that provides know-how and research to meet the increasing demand for storage technologies, e.g., to ensure grid stability as the share of renewable energies grows.

The core topics of the BayBatt are the safety and sustainability of batteries and their components, the intelligent use of the storage medium, and economic efficiency. The entire spectrum of battery technology is considered, from the molecular basis to the structuring of electrodes and cell development. Specific focus is on the battery cells and systems, and the use of batteries in connected energy storage systems.

Within BayBatt, Fraunhofer IISB cooperates closely with the Chair of Electronics for Electrical Energy Storage (LEEE), led by Prof. Vincent Lorentz, at the University of Bayreuth. Prof. Vincent Lorentz is also head of the Intelligent Energy Systems Department at Fraunhofer IISB.

The main focus of the chair's research is on solutions for the electronic monitoring and control of electrical energy storage systems such as batteries, supercaps, and fuel cells, which are used in mobile and stationary applications. For example, the foxBMS® battery management system platform emerged from an initiative of Fraunhofer IISB in 2015. It is being further developed in BayBatt and enables research and validation of safer, more robust and reliable system architectures.

electronics.uni-bayreuth.de

»Red Place« at the Faculty of Engineering of the Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) © David Hartfiel

Locations and Network

Academic Teaching

Lectures Held by IISB Researchers

Lecturer	Lecture
Dr. Bernd Eckardt	Electrical Energy Storage Systems
Dr. Andreas Erdmann	Optical Lithography
Prof. Dr. Marc Hainke	Basics of Construction
	Construction & CAD
	Construction & Development
	Engineering Mechanics
	Fluid Mechanics & Thermodynamics
	Materials Engineering
	Medical Product Development
	Medical Technology Materials
Prof. Dr. Johannes	Alternative Solar Cell Concepts
Heitmann	Functional Nanomaterials
	Semiconductor Chemistry
	Nanoelectronic Devices
	Physics for Engineers
	Materials Analysis
Dr. Michael Jank	Flexible Electronics
	Nanoelectronics
	Power Semiconductor Devices
Dr. Maximilian	Selected Topics in
Hofmann	Vehicle Electrification

Lecturer	Lecture
Dr. Jürgen Lorenz	Process and Device Simulation
Prof. Dr. Vincent	Analog Circuit Technology
Lorentz	Battery System Technology
	Digital Circuit Technology
	Digital and Computer Technology
	Electrotechnical Fundamentals of
	Electrochemical Energy Storage Systems
Prof. Dr. Martin März	Power Electronics
	Power Electronics for
	Decentral Energy Systems
	Thermal Management in Power Electronics
Prof. Dr. Schulze	Bipolar Technology
	CMOS Technology
	Quantum Electronics Physics
	Semiconductor Devices
	Spintronic and Quantum Computation
	Technology of Integrated Circuits
	Tunnel and Quantum Well Devices

IISB's scientific staff holds academic lectures and supervises a multitude of final theses.

µe-bauhaus erlangen-nürnberg

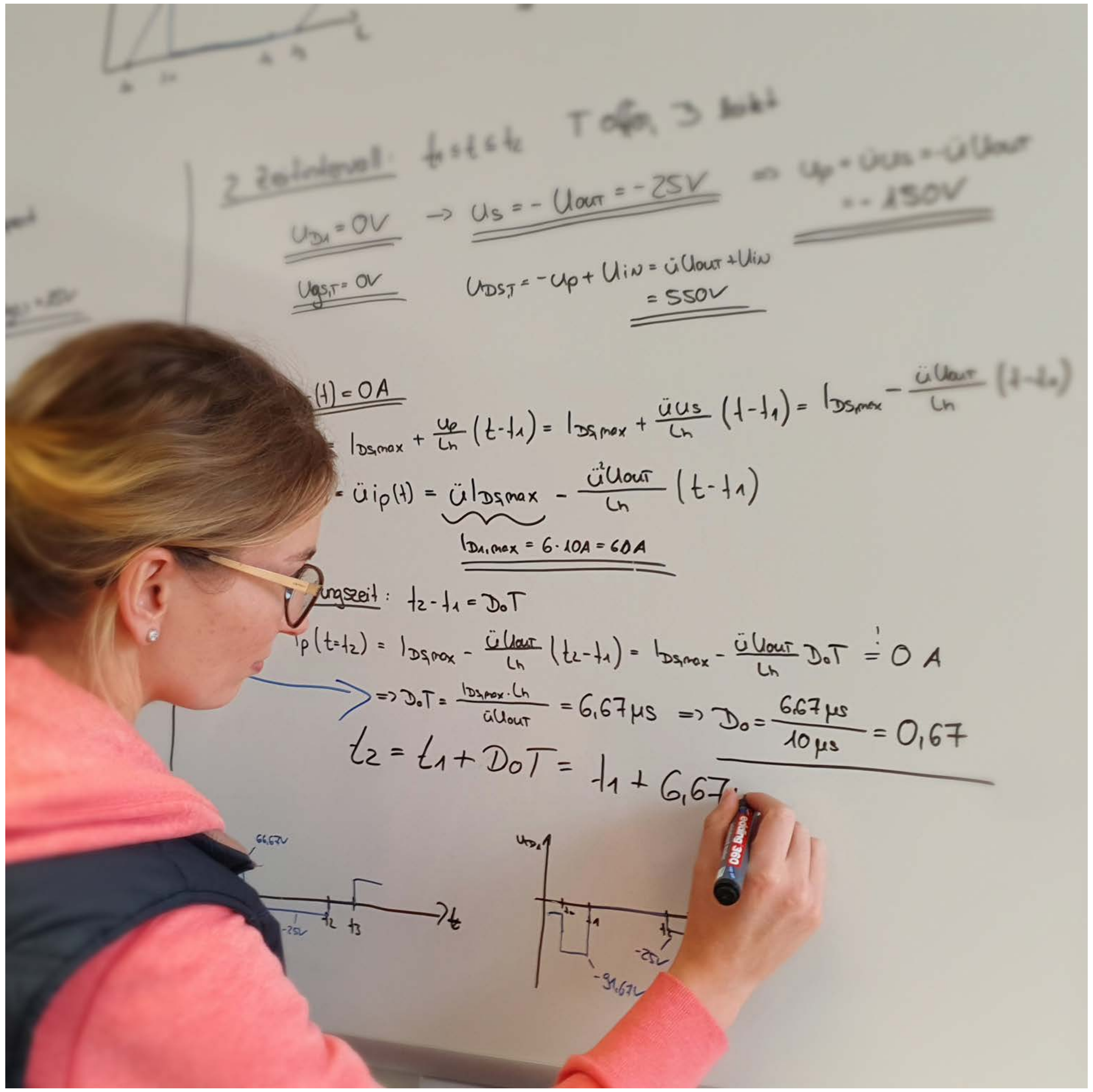
The Technical-Academic Master Forge

The µe-bauhaus erlangen-nürnberg transfers the teaching concept of the famous Bauhaus Weimar-Dessau-Berlin to the idea of a «Bauhaus of Microelectronics« within the Chair of Electron Devices (LEB) and Fraunhofer IISB.

This includes the self-understanding that «teachers« and «learners« work together and jointly plan and realize extensive ideas and designs. The indispensable basis of this creative work is the thorough technical training of students in laboratories and at trial and work stations, which enables them to learn and work independently in teams in a creative manner.

At the µe-bauhaus, the theoretical study of natural sciences and electrical engineering and information technology runs parallel to practical training along the process chain, starting with the design of devices, their development and production up to validation, trial and testing.

iisb.fraunhofer.de/bauhaus



Highly skilled and dedicated professionals are vital not only for as as an institute, but also for the German and European research society and industry. This makes it all the more important to provide students and apprentices with a profound theoretical education without losing sight of practical applicability © Melanie Lavery / LEE

Locations of the Fraunhofer-Gesellschaft in Germany © Fraunhofer

The Fraunhofer-Gesellschaft

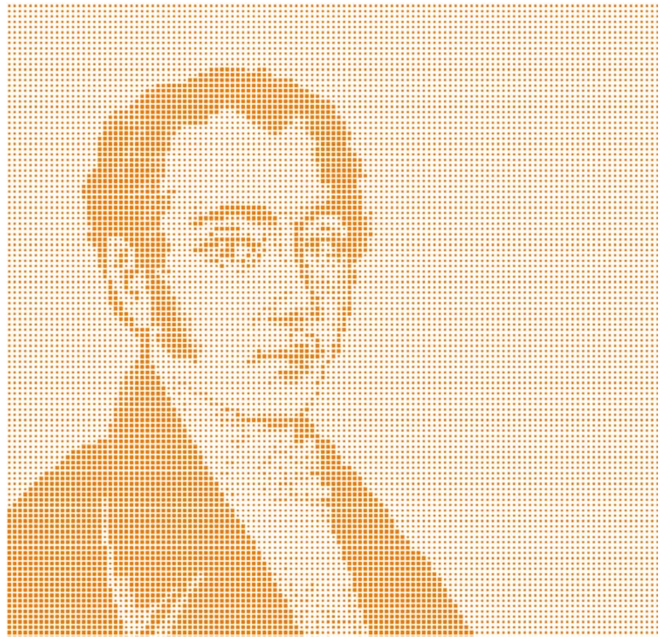
Fraunhofer

The Fraunhofer-Gesellschaft, headquartered in Germany, is one of the world's leading organizations for applied research. Since its founding as a nonprofit organization in 1949, Fraunhofer has held a unique position in the German research and innovation ecosystem. With nearly 32,000 employees, the research organization operates 75 institutes and independent research units across Germany. The Fraunhofer-Gesellschaft plays a major role in innovation by prioritizing research on cutting-edge technologies and the transfer of results to industry to strengthen Germany's industrial base and for the benefit of society as a whole.

Fraunhofer's primary customer base consists of large and medium-sized companies that utilize its expertise to boost their competitiveness with new technologies. For years, Fraunhofer has been one of the most active patent applicants in both Germany and Europe. Its extensive international patent portfolio is the basis for technology transfer through research projects, spin-offs and licensing. Moreover, Fraunhofer addresses societal goals in key technology sectors through interdisciplinary and international partnerships in specific markets. Examples include developments in microelectronics, artificial intelligence (AI), quantum computing, healthcare, the circular economy, new materials, energy systems, critical infrastructure security and defense.

Fraunhofer is an attractive and established partner in publicly funded joint projects with industry partners. The Fraunhofer-Gesellschaft is also instrumental in strengthening Germany's innovation and industrial base and ensuring its viability. Its activities create jobs in Germany, increase public-sector investments, give companies competitive edges and foster public acceptance of advanced technology. International partnerships with leading research partners and companies around the world ensure direct contact with the most influential research communities and economic areas.

Fraunhofer's annual business volume is €3.6 billion, €3.1 billion of which is generated by contract research – Fraunhofer's core business model. Unlike other public research organizations, base funding from the German federal and state governments is merely the foundation for the annual research budget. This serves as the basis for groundbreaking precompetitive research that will become important for the private sector and society in the years ahead.



Joseph von Fraunhofer © Anja Grabinger / Fraunhofer IISB

Fraunhofer's distinctive feature is its large share of industry revenue, guaranteeing close collaboration with the private sector and industry and the consistent focus of Fraunhofer's research on the market. In 2024 alone, industry revenue accounted for €867 million of its total budget. Fraunhofer's research portfolio is augmented by competitively acquired public-sector funding, pursuing the right balance between public-sector and industry revenue.

Highly motivated employees are the most important factor behind Fraunhofer's success. The research organization therefore fosters an environment that encourages independent thinking, creativity and goal-driven work. It supports career development in both research and industry by providing targeted programs for professional and personal development.

The Fraunhofer-Gesellschaft is a recognized nonprofit organization named after Joseph von Fraunhofer (1787–1826), a Munich-based scholar who enjoyed equal success as a scientist, inventor and entrepreneur. His legacy continues to inspire the organization's spirit of innovation to this day.

fraunhofer.de

Locations of the cooperating FMD institutes across Germany © loewn / FMD

The Research Fab Microelectronics Germany (FMD)

The FMD as Enabler of Transformation and Innovation

The Research Fab Microelectronics Germany (FMD for its acronym in German) brings together the expertise and technological infrastructure of its 15 cooperating institutes across Germany, which are part of the Fraunhofer-Gesellschaft and the Leibniz Association.

The FMD provides cutting-edge application-oriented technologies and system solutions for promising microelectronics. Thus, the FMD contributes significantly to the technological resilience of Germany and Europe. The Fraunhofer IISB is one of the institutes cooperating within the FMD.

Chiplet Innovation for Europe: The APECS Pilot Line has been launched under the EU Chips Act

The pilot line for Advanced Packaging and Heterogeneous Integration for Electronic Components and Systems (APECS) launched at the end of 2024 is a crucial part of the EU Chips Act, intended to drive chiplet innovation and strengthen semiconductor research and manufacturing capabilities in Europe. The institutes cooperating within the FMD are closely working with further European partners on the implementation of the APECS pilot line. They are thus significantly contributing to increasing Europe's technological resilience as well as its global competitiveness in the semiconductor industry.

By enabling large industry players, SMEs, and start-ups to gain easier access to cutting-edge technology, the APECS pilot line aims to build a strong foundation for a resilient and robust European semiconductor supply chain. APECS is co-funded by the Chips Joint Undertaking and national funding authorities of Austria, Belgium, Finland, France, Germany, Greece, Portugal, Spain, through the Chips for Europe Initiative. The overall funding for APECS amounts to € 730 million over 4.5 years.

Building Bridges between Research, Industry and Politics

By regularly organizing events as part of major joint projects involving multiple institutes, such as the Green ICT @ FMD ("Competence Center for Sustainable Information and Communication Technology") or the FMD-QNC ("Research Fab Microelectronics Germany - Quantum and Neuromorphic Computing Modules"), the FMD gathers key stakeholders to jointly address the future challenges of electronics research while boosting the development of tomorrow's technology.

Green ICT Connect: The second conference on sustainable information and communication technologies (ICT) was held as early as October 2024. The Green ICT Connect is a central event that promotes the exchange of ideas and networking among key representatives from the worlds of research, industry, and politics. Through panel discussions and expert talks, the conference aims to foster sustainable microelectronics with a focus on innovative approaches and technologies. A further purpose of this event lies in familiarizing small and mid-sized enterprises (SMEs) with the portfolio of the Green ICT @ FMD competence center.

QNC Summit and FMD Innovation Day: The first conference on Quantum and Neuromorphic Computing (QNC) was held in April 2024. QNC was also the focus of FMD Innovation Day 2024. Both events provided a platform for research experts, industry representatives as well as policy-makers to share their insights on hardware developments in the field of QNC. Furthermore, both events served as a forum to jointly define research and technological challenges while also providing an opportunity to identify synergies within the realm of enabling technologies.

Research. Connect. Move Forward!

Women shape the microelectronics of tomorrow: FMD is committed to advancing the role of female scientists in microelectronics by raising awareness about the importance of equal opportunities and fostering collective solutions to professional challenges in this field.

An example of this is the Female Scientist Breakfast, which has already been successfully established as regular slot of both the QNC Summit 2024 and the Green ICT Connect 2024. The Female Scientist Breakfast provides an ideal setting for female undergraduates, young professionals, and (aspiring) women scientists to connect and gain insights from inspiring female role models in academia and industry. This casual gathering features engaging keynote talks, a Q&A session, and opportunities to share experiences with other women in the microelectronics field.

The FMD as One of the Four Partners of the "Chipdesign Germany" Network

Aiming to connect and expand the existing chip design expertise in Germany, the FMD, together with the other three cooperation partners edacentrum, Leibniz University Hannover and University of Kaiserslautern-Landau in Rhineland-Palatinate, have created a platform for a pre-competitive, transparent exchange between all stakeholders involved in chip design. The network acts as a central point of contact in Germany for all matters related to this topic. As such, Chipdesign Germany develops and implements measures for: training and further education of young professionals, technology monitoring, support for start-ups and SMEs in microelectronics, as well as science communication to raise public awareness of chip design. The kick-off event for the network took place in June 2024.

Securing Skilled Workers, Attracting Young Talents, Supporting Start-ups and SMEs

Besides its wide technological portfolio, the various cooperation opportunities it provides and the coordination of large collaborative projects, the FMD also has accelerators dedicated to support start-ups, SMEs and research groups along with programs designed exclusively for students and young professionals.

The Green ICT Award: This student prize, which has already been conferred twice, honors outstanding bachelor's and master's theses on the subject of resource-efficient information and communication technology. The Green ICT Award is part of the activities of the "Green ICT @ FMD" competence center.

The Green ICT Camp: This week-long program for students is designed to inspire, engage and bring together young students in the field of sustainable microelectronics. The first edition of the camp took place in early September 2024. Further camps will continue to be held in 2025.

The (Deep Tech) Accelerators: Launched in 2022 as part of the Green ICT @ FMD and FMD-QNC projects, the Green ICT Space and QNC Space programs, are primarily oriented to support start-ups, SMEs and research groups. Both accelerators have brought together numerous players to work respectively on resource-saving and enabling technologies. The activities undertaken in this context will be pursued until the conclusion of the underlying projects.

FMD Showroom: fmd-insight.de/showroom

Green ICT Space: greenict.de/en/startups

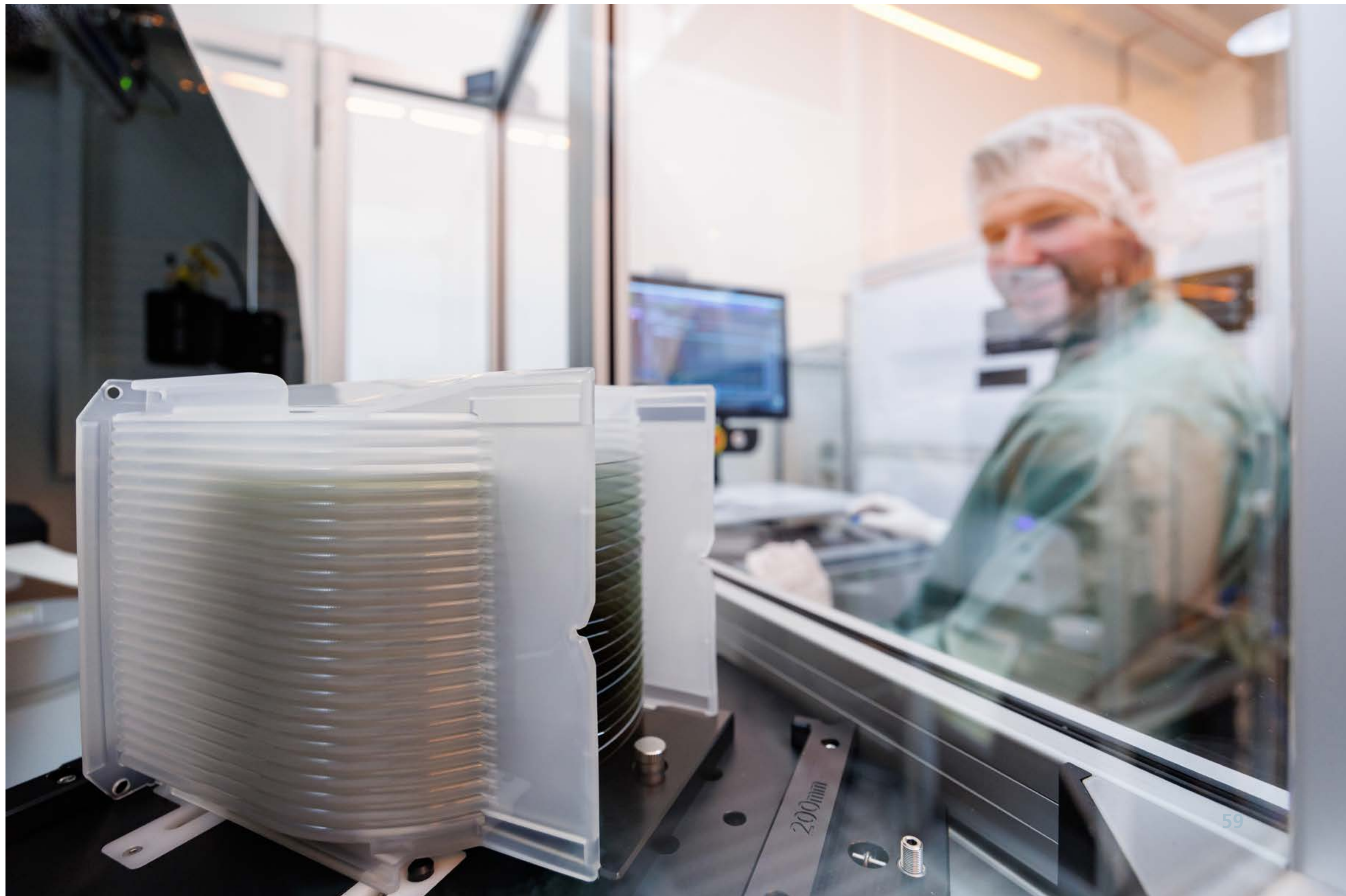
FMD-QNC: module-qnc.de/en

forschungsfabrik-mikroelektronik.de

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 enables 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.



Within the FMD, the IISB specializes in highly efficient wide and ultra-wide bandgap power electronics
© Daniel Karmann / FraunhoferIISB

The Research Fab Microelectronics Germany (FMD)

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, Ga_2O_3 or diamond, are usually crystals with smaller 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.

iisb.fraunhofer.de/sic-services

IISB Science Stars

Young Engineer Award 2024 of the ECPE European Center for Power Electronics goes to Sibasish Laha

Sibasish Laha from the Testing and Reliability Group at IISB was awarded the Young Engineer Award at the CIPS 2024 conference in Nuremberg for his outstanding presented work entitled „Milliseconds Power Cycling (PCmsec) Driving Bipolar Degradation (BD) in Silicon Carbide Power Devices".

In his paper our colleague Sibasish and his co-authors Jürgen Leib, Andreas Schletz, Martin Maerz, Christian Liguda, Firas Faisal and Davood Momeni describe an innovative approach to silicon carbide (SiC) power cycling.

Until now, bipolar degradation (BD) tests have not been sufficiently differentiated in the investigation of failure and fault mechanisms for SiC power devices. SiC power products may experience voltage degradation which stems from the stacking faults (SFs) growth, commonly known as BD. To properly evaluate the BD impact on the electric performance of devices, it is important to distinguish it from other stress-related degradation such as power metal or interconnection. This aspect has not yet been addressed, although the BD mechanism is well understood.

The paper outlines a methodology by modifying the power cycling test (PCsec) to PCmsec in order to systematically investigate the effect of BD while controlling the impact of thermal degradation. This method enables a thorough evaluation of the distinct influences of both degradation contributors.

https://www.ecpe.org/

DGKK Prize from the German Society for Crystal Growth (DGKK) for Dr. Jochen Friedrich

Congratulations to Dr. Jochen Friedrich on receiving the 2024 DGKK Award from the German Society for Crystal Growth (DGKK)! The award honors Dr. Jochen Friedrich, Head of the Materials Department at Fraunhofer IISB, for his outstanding scientific and technological work in the field of crystal growth and epitaxy, as well as his commitment to promoting public awareness of these topics.

Particularly noteworthy are his scientific achievements in application-oriented research and development for the semiconductor industry. Jochen Friedrich pursues a holistic scientific approach: the systematic combination of theory and practice through the targeted analysis of material properties and industrial manufacturing conditions with a view to later product quality. For example, the transfer of the vertical gradient freeze process for the large-scale production of the optical material calcium fluoride (CaF2) attracted international attention. Jochen Friedrich also advanced the numerical modeling of Czochralski growth for the mass production of silicon. The CrysMAS software developed in his department for the simulation of crystal growth processes and equipment is licensed worldwide by Fraunhofer IISB. In his 2019 "top downloaded" open-access paper "Erlangen - An Important Center of Crystal Growth and Epitaxy: Major Scientific Results and Technological Solutions of the Last Four Decades," he himself provides an overview of the far-reaching milestones in Erlangen's crystal research activities.

Jochen Friedrich is not only a constant presence in the scientific world, but is also personally committed to making crystal research accessible to the public, both regionally and throughout Germany. Through regular initiatives such as crystal growing competitions, project weeks at schools, exhibitions, and display boards, he inspires not only pupils and young adults to take an interest in materials research.

The award ceremony took place on March 7, 2024, during the German Crystal Growth Conference in Erlangen. Prof. Andreas Erb, Chairman of the German Society for Crystal Growth, presented the award certificate.

https://dgkk.de/

Sibasish Laha with the Young Engineer Award 2024 of the ECPE European Center for Power Electronics
© Elisabeth Iglhaut / Fraunhofer IISB

At the German Crystal Growth Conference in Erlangen, Prof. Andreas Erb (right), Chairman of the German Society for Crystal Growth (DGKK), Presented the Award Certificate to Dr. Jochen Friedrich (left)
© Elisabeth Iglhaut / Fraunhofer IISB

Fastest Known Method to Reliably Detect Overcurrent in Protective Devices for LVDC System: Johannes Gehring Receives IISB R&D Award 2024

Johannes Gehring, research scientist in the DC Grids Group of the Intelligent Energy Systems Department at Fraunhofer IISB has been honored with the Fraunhofer IISB R&D Award 2024 for his invention of an overcurrent limiting and detection unit (OLDU).

OLDU offers unbeatable advantages as a detection unit in protective devices, especially for DC applications, such as in electric vehicles, charging stations, local DC or on-board grids for ships and aircraft, where very fast switch-off times and short-circuit current limitation are required.

OLDU can be used in switchgear for currents of up to several thousand amperes with ultra-fast detection in the nanosecond range, is implementable as a pure hardware solution and also cost-effective. Furthermore, it is compatible with IEC 60947-10 and has already been filed for a patent (EP23202843).

https://www.iisb.fraunhofer.de/dc-grids

Johannes Gehring with the IISB R&D Award 2024
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Fraunhofer IISB R&D Award 2024 Honors Outstanding Teamwork: Infrastructure Platform for Successful R&D in the Field of SiC Epitaxy

As part of a so-called Joint Lab at Fraunhofer IISB, AIXTRON SE operates equipment, works on process development for SiC epitaxy and runs a demo center for its customers. Joint Labs like this are a great opportunity for companies to collaborate with Fraunhofer IISB in an industry-compatible laboratory environment.

For our epitaxy Joint Lab, the awarded IISB team ensures the continuous fault-free operation of already 5 state-of-the-art G10 SiC reactors, and enables the installation of new systems with minimal downtime. By setting up automated metrology and by optimizing wafer logistics, workflows and data management, the team has also established a modern wafer characterization facility at the IISB with a fast feedback loop for AIXTRON.

We are thrilled for our colleagues Rainer Apelt, Nino Fröbisch and Katharina Roßhirt-Lilla from the SiC Epitaxy Group of the Materials Department together with Christian Heilmann, Rainer Schönweiß and Christopher Torscher from the Infrastructure Group within the Central Services Department. Such outstanding results are the base for the success of the Joint Labs model at Fraunhofer IISB!

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

Christian Heilmann, Rainer Schönweiß, Katharina Roßhirt-Lilla, Nino Fröbisch, and Rainer Apelt (from left to right) received the Fraunhofer IISB R&D Award 2024 for outstanding teamwork
© Thomas Richter / Fraunhofer IISB

IISB Science Stars

Leonard Kuhn wins Energiepreis 2024 of the Energy Campus Nuremberg (EnCN) for Master's Thesis

We congratulate Leonard Kuhn on winning the Energiepreis 2024 from Energie Campus Nürnberg (EnCN)!

Leonard Kuhn, a member of the Aviation Electronics Group at Fraunhofer IISB, received the award on November 18, 2024, for his master's thesis. The thesis is entitled "Control circuit for a pyrotechnic disconnector in a fully electric helicopter powertrain" and was submitted by the Chair of Power Electronics (LEE) at FAU Erlangen-Nürnberg. The holder of the LEE chair is Prof. Martin März, who also serves as Scientific Director for Power Electronic Systems at Fraunhofer IISB.

The thesis focuses on the failure safety of aviation applications in order to meet safety requirements and ensure the reliability and availability of future electric powertrains in electric hybrid aircraft. Specifically, Leonard Kuhn worked on the development and implementation of an active fuse in the DC link of the powertrain for aviation applications. This increased the reliability and availability of the entire DC link and laid the foundation for the feasibility of electric flight. This innovative concept makes a significant contribution not only to aviation but also to the energy transition.

Christian Zens, Chancellor of Friedrich-Alexander University Erlangen-Nuremberg, presented the award certificate in his role as Chairman of the EnCN e.V. A total of ten students received an EnCN Energy Award 2024 for their outstanding contributions to energy research and the German energy transition. The award-winning work covers topics such as new energy technologies, rational energy use and efficiency improvements, and the development of practical solutions.

https://www.encn.de/

Dr. Susanne Hoffmann, acting Head of the Economic Development Department of the City of Nuremberg, and Christian Zens, Chancellor of Friedrich-Alexander University Erlangen-Nuremberg, awarded Leonard Kuhn from Fraunhofer IISB with the prize certificate
© Energie Campus Nürnberg / EnCN

LZE Prize 2024 from Leistungszentrum Elektroniksysteme e.V. for Dr. Peter Evanschitzky

We sincerely congratulate Dr. Peter Evanschitzky from our Modeling and Artificial Intelligence Department on winning the LZE Prize 2024! The electrical engineer received the award for his significant improvements to the mask solver for the Dr.LiTHO simulation software. The software developed at Fraunhofer IISB is used by leading semiconductor manufacturers as well as producers of lithographic and optical systems. With the upgrade that Dr.LiTHO users will benefit from, Dr.LiTHO is significantly superior to other software solutions in terms of computing time, memory requirements and flexibility.

Peter Evanschitzky succeeded in implementing a rigorous solution to Maxwell's equations without resorting to simplified models and assumptions. With the rigorous-physical mask solver, Dr. Litho users are ideally equipped for future demands, especially considering the constantly increasing complexity and request for ever more detailed and elaborate calculations.

The LZE Prize by the Leistungszentrum Elektroniksysteme (LZE) is awarded for above-average achievements in the transfer of knowhow from research into application. Together with industry partners and further research institutes, Fraunhofer-Gesellschaft, Fraunhofer IIS, Fraunhofer IISB, and FAU Erlangen-Nürnberg (FAU) have established the LZE as an interface between science and industry.

https://lze-innovation.de/

Institute director of the Fraunhofer IISB, Prof. Jörg Schulze (left) with the winner of this year's LZE prize, Dr. Peter Evanschitzky
© Elisabeth Iglhaut / Fraunhofer IISB

Best Paper Award at SPIE Conference on Computational Optics 2024 for Valeriia Sedova

At the SPIE Optical Systems Design 2024 in Strasbourg, PhD Student Valeriia Sedova was awarded third place for the Best Paper during the SPIE Conference on Computational Optics on April 10 - 11.

At the SPIE Conference on Computational Optics, Valeriia Sedova presented the paper "Advances in modeling and optimization for two-photon lithography". The decisive evaluation criteria for the papers were clarity of presentation, scientific merit, and potential innovative impact. The Best Paper Awards included a cash reward and an award certificate and were sponsored by ASML, Nikon and ZEISS.

Two-photon lithography provides unique opportunities for the fabrication of 3D optical metasurfaces. The classical design of metasurfaces neglects fabrication effects and assumes an ideal building block with sharp edges and corners. Optical and chemical effects during lithographic fabrication lead to rounded features and proximity effects, revealing the complex aspects of the manufacturing process.

The manufacturable design of functional metasurfaces requires predictive modeling of the optical and photochemical effects in two-photon lithography. Modeling of two-photon lithography is performed using different approaches for the mathematical description of photoresist effects, including simple threshold models, a compact model that emulates the important phenomena during the processing of the photoresist, and a full model that includes details on the polymerization of the photoresist material. This research not only refines methodologies but also provides valuable guidance for future research.

Valeriia Sedova holds a Bachelor's degree in Optics and Lasers and pursued her Master's degree in the Elite program, the Master Programme in Advanced Optical Technologies at FAU (Friedrich-Alexander-Universität Erlangen-Nürnberg), specializing in computational optics. With a focus on computation and modeling of various optical lithography techniques, including EUV, grayscale, and two-photon lithography, Valeriia has been working as a researcher in the Lithography and Optics Simulation Group of the Modeling and Artificial Intelligence Department at the Fraunhofer Institute for Integrated Systems and Device Technology IISB for the past four years.

Valeriia Sedova with the third place Best Paper Award at SPIE Conference on Computational Optics 2024
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